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Effects of White-tailed Deer Herbivory on Forest Plant Communities

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EFFECTS OF WHITE-TAILED DEER HERBIVORY ON FOREST PLANT COMMUNITIES

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ABSTRACT

The impact of white-tailed deer (*Odocoileus virginianus*) herbivory on forest ecosystems has received more attention as deer populations continue to increase in many areas. We investigated the effects of deer herbivory on plant communities in three different geographic regions to increase the general knowledge of herbivory impacts and also to investigate specific regional effects where research has been lacking.

Twelve exclosures were constructed in clearcut hardwood stands on the Clemson Experimental Forest, SC. Sapling, seedling, and understory species richness (S), Shannon's Diversity Index (H'), and Evenness (J') were compared between exclosures and paired control plots after the first and second growing seasons post harvest. Also, percentage coverage for vines, forbs, grass, and woody vegetation were compared. There were no significant differences (α=0.05) in vegetation between the exclosures and control plots. In addition, vegetation was compared in mature upland hardwood stands between two levels of deer density: relatively high density and relatively moderate density. Plots were located in mature upland hardwood stands. Seedling S, and sapling S and H' were significantly greater in the area of moderate deer density (p=0.0461, p=0.0343 and p=0.0186, repectively). Woody percentage coverage was higher in 2005 than 2006 (p=0.0097) without regard to deer density, and vine percentage coverage was higher in 2006 than 2005 (p=0.0040) without regard to deer density. None of the vegetation groups' percentage coverage was significantly influenced by deer density. The exclosures will need to be monitored for at least ten years in order to get more sufficient data to make inferences on the effects of deer herbivory. Also, disturbance such as fire

may be needed along with long-term monitoring in the mature stands before inferences can be made on herbivory impacts to vegetation.

The second study site was located in the central Appalachians of West Virginia. Since 2001, the property has been managed using three harvest intensity rotations: 20, 40, and 80 year. An equal number of vegetation plots under each type of management were measured in 2001 and 2005 to study if the intensity of timber harvest influenced herbivory impacts. Also, nine deer exclosures with paired controls were randomly established in each harvest regime in 2001 and measured two years and five years after construction. The results did not support that timber harvest intensity affected the influence of herbivory on seedling, sapling, and understory S, H' or J' or vegetation groups' cover percentage. The exclosure data did not support that deer herbivory affected the plant community. Interestingly, the relative deer density decreased on the property since the initiation of the study, and the results may support slight recovery of the forest plant communities since 2001. Deer density and vegetation communities will need to be monitored long-term before stronger conclusions can be made about the impacts of herbivory.

Three 20-year- old deer exclosures were compared to a similar non-fenced plot at the Preserve at Callaway Gardens, GA. No statistical analyses were performed but there were some clear observational differences in vegetation between inside the exclosures and the surrounding stands. Strawberry bush (*Euonymus americanus*), a highly preferred browse species, was taller and denser inside the exclosures. Also, *Smilax spp*. and *Desmodium spp.* plants were clearly larger and denser inside the exclosures. These species may be useful as indicators in monitoring changes in vegetation due to deer herbivory.

DEDICATION

I would like to dedicate this work to my family; to my parents, Dale and Connie Thrift, to my brother, Robby Thrift, and to my grandfather, Harmon Thrift.

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CHAPTER 1

OVERVIEW OF THE EFFECTS OF WHITE-TAILED DEER ON FOREST PLANT COMMUNITIES

Since the start of ecology as a discipline, researchers and professionals have recognized the strong influence of large herbivores on ecosystem processes such as nutrient cycling, pathways of energy flow, plant succession, and disturbance regimes (Hobbs 1996, Schoenecker et al. 2004, Wiesberg and Bugmann 2003). Plant-herbivore interactions can have a central role in these processes because of the relationship between the palatability, growth, and decomposition of plants and the browsing preference and intensity of the herbivore (Augustine and McNaughton 1988). Over the last several decades, increasing attention has been given to the role that white-tailed deer, *Odocoileus virginianus*, have in shaping ecosystem communities and processes (Rooney and Waller 2003, Augustine and DeCalesta 2003, Russell et al. 2001, Alverson et al. 1988). The onset of this heightened study can be attributed to the observed overbrowsing of plants due to the increased densities of white-tailed deer over much of its range (Garrott et al. 1993). The impacts to forests related to overbrowsing are economically, socially and ecologically important issues because of the increased anthropogenic demand on eastern North America's forests for fiber, harvest sustainability, multiple-use recreation, and awareness of biological diversity. Deer herbivory is complex in nature and creates many challenges to managers and scientists. Patterns of interactions between plant communities and herbivores can vary across time, space, and magnitude, from the individual plant to the ecosystem level (Weisberg and Bugman 2003, Augustine and

DeCalesta 2003). In addition, deer management is a contentious subject that stirs emotional conflict between groups who want to reduce overbrowsing to preserve plants, groups that consider hunting cruel, hunters who want an abundance of deer, and others who are against human intervention with natural processes (Diamond 1992). Therefore, a better understanding of the role of deer herbivory is key in future management of the species to ensure the integrity of eastern North America's forested ecosystems and make wise, well informed decisions regarding an animal with strong influence on forest ecosystems.

White-tailed deer are the most abundant wild ungulate on the North American continent, ranging throughout most of the eastern United States and Canada east of the Rocky Mountains, and also extending into regions west of the Rocky Mountains. Disagreement exists about whether the current abundance of deer exceeds pre-settlement European abundance. Many claims of deleterious impacts from deer are based on the argument that deer are more abundant now than ever. Alverson et al. (1988) suggested that deer densities are 2 to 4 times greater now in northern hemlock-hardwood forest than in pre-settlement times. Other authors suggest similar trends in deer densities (Webster et al 2005, Rooney and Waller 2003). However, others contend that current deer densities are similar to pre-settlement densities (McCabe and McCabe 1997). Despite this disagreement, reliable evidence is available that support deer numbers reached a low point in the early 1900's. Commercial hunting, unregulated seasons, and land use changes decreased the total number to between 350,000 and 500,000 with deer being extirpated from all but the most remote areas of their range (McDonald and Miller 2004, McCabe and McCabe 1984). Deer abundance began to rebound in the 1930's and 1940's with the establishment of hunting regulations, legislation that protected wildlife and funded state wildlife agencies, and land reclamation. By the late 1960's deer numbers had rebounded in most of their historical range (Newsom 1969). Presently, deer herds have existed in many areas at high densities for several decades and continue to increase in certain areas. The successful recovery has been largely due to the regulation of hunting, elimination of most non-human predators, well intentioned restocking programs, and the mosaic of edge habitats provided by modern agriculture and forestry.

White-tailed deer share a long evolutionary relationship with plant communities; dating back to the earliest evidence of *O. virginianus* in North America 4 million years ago (Halls 1984). During this long evolutionary history, plant tolerance to browsing, important nutritional requirements, and habitat carrying capacity relationships were all established. However, both sides of this plant-herbivore dynamic relationship have been impacted by humans through large scale land-use changes from forestry, development, and altered disturbance regimes, and from population management of deer herds directly from hunting and indirectly from predator extirpation (McCullough 1979). Comparing plant-herbivore interactions of today versus pre-settlement conditions is not practical because of the lack of data on deer numbers. Another reason is that the change in land-use and land cover has drastically altered the plant communities at the landscape level to a degree where comparing herbivory in a historical landscape to a modern landscape would be impractical. However, maintaining ecosystem integrity of existing forests should be high priority and learning the role of deer herbivory in shaping ecosystem processes is imperative.

Investigations of deer population trends coincided with the regional recovery of herds. Observations and experiments documenting deer herbivory followed shortly, with the first literature being published in the 1940's and 1950's from the Great Lake States and the Northeast (DeBoer 1947, Switzenberg 1955, and Webb et all 1956). Stoeckeler et al. (1957) observed severe differences in sapling height and abundance of a hardwood-hemlock stand in Wisconsin excluded from browsing versus stands exposed to browsing. There were 11,234 saplings in the excluded stand versus 164 saplings in the control stand after eight years. Deer decreased the average height and diameter of 2 out of 7 species and changed the herbaceous species composition in the Adirondack forest of New York (Webb et al 1956).

Along with the above examples, publications on deer herbivory have accumulated over the last 60 years and perspectives vary depending on the location and goals of the research. Ecosystem management has been adopted by wildlife biologists and a review of the literature supports the premise that deer are agents of ecological change. Most research has been concentrated in the Great Lakes States (Alverson and Waller 1997, Augustine and Frelich 1998, Anderson and Loucks 1979, Wiegmann and Waller 2006) and the Northeast (Horsley et al. 2003, Tilghman 1989, Marquis and Brenneman 1981, Marquis and Grisez 1978, Marquis 1981), primarily Pennsylvania. Data exist in other regions that also support deer having a negative impact to plant communities (Jones et al 1997, Rossell Jr. et al. 2005, Russell and Fowler 2004). Variation in length of study, successional stage, study objective, climate, deer density, and habitat carrying capacity from the studies make drawing conclusions from pooled research difficult across the geographic range of deer.

Therefore, it is important to consider the implications of each study and use caution when applying the results of the studies to areas outside their scope. Furthermore, identifying the areas where information on the subject matter is lacking and pursuing new methods in researching deer herbivory impacts should be used to guide future research.

Information on the effects that deer have on tree growth is relatively abundant, stemming from the concern over loss of timber production but also concern for changes in successional patterns and species composition. Certain tree species can range from being highly favorable forage species and highly susceptible to browsing, to species being less favorable and highly tolerant to browsing or any combination of the above. Extensive damage to forests exists in certain locations where deer densities occur at higher than normal levels. A classic example is the hemlock, *Tsuga canadensis*, forest in Wisconsin; deer negatively impact the regeneration of hemlock by overbrowsing the evergreen species. In 12-year old exclosures hemlock seedlings were several times more abundant than outside exclosures while sugar maple, *Acer saccharum*, a browse tolerant species, replaced hemlock in areas of heavy browsing (Anderson and Loucks 1979). Additional studies attribute browsing as reducing the recruitment of hemlock and northern white cedar, *Thuja occidentalis*, with complete regeneration failure occurring at the highest relative deer densities (Rooney and Waller 2003). These findings that deer are an important factor in hemlock regeneration problems are consistent with Alverson et al. (1988), who also state that white cedar and Canadian yew, *Taxus canadensis*, are heavily impacted with the reproduction of the latter almost non existent in the region. Rooney et al. (2002) also investigated factors affecting regeneration of white cedar, an important timber species in the Upper Great lakes, and concluded regeneration of this species is unlikely without significantly reducing deer numbers or protecting seedlings from browsing. Not only are evergreen species affected by deer in the region but northern red oak, *Quercus rubra,* and yellow birch, *Betula alleghaniensis*, are also reduced from deer browsing. Regeneration of northern red oak seedlings >30 cm tall declined linearly with increased local browsing, while complete regeneration failure occurred at highest browsing pressure. Yellow birch seedlings were most abundant in intermediate deer densities and lowest at low and high deer densities (Rooney and Waller 2003). Deer browsing has also significantly impacted the successional development of old-growth red pine, *Pinus resinosa,* forest in North Central Minnesota. After a 32-year exclosure study, deer had greatly reduced the growth rate and species composition of trees outside the exclosure (Ross et al. 1970). In the Great Lakes states evergreen species are particularly vulnerable to deer browsing because of the lack of other food sources during the heavy snowfalls in the winter. Scientists project that ongoing chronic herbivory will shift the stand composition of forests in the Upper Great lakes where, the dominant canopy species, hemlock, overtime will be replaced by browse tolerant maple species, *Acer. spp*. (Alverson et al. 1988).

Deer herbivory impacts to forests are not restricted to the Great Lakes States; decreases in timber production and species composition changes have been a concern for forest managers in the Allegheny forests of Northwestern Pennsylvania for at least three decades (Marquis 1981, Marquis and Brenneman 1981, Marquis and Grisez 1978, Marquis 1975). This area is dominated with mixed hardwood forests consisting of sugar maple, black cherry (*Prunus serotina)*, yellow birch, fire cherry (*Prunus pensylvanica)*, sweet birch (*Betula lenta*), and striped maple (*Acer pensylvanicum*). From exclosure studies, results showed regeneration failures in 25 to 40% of clear cut stands after five to sixteen years of growth. Fire cherry and sugar maple were most affected while the less favorable species beech, *Fagus grandifolia*, and striped maple actually increased in relative abundance. Marquis attributes advanced regeneration as the key to successful tree regeneration after harvest (Marquis 1975). A study using 9 to 22-year old clear cuts in the Allegheny Plateau attributed deer browsing for the inadequate stocking, delay in seedling establishment, and less valuable tree composition (Marquis 1981). Further research in the area documented black cherry to be relatively low preference for browsing. In clear cuts with the highest deer density, 75% of the sample plots were dominated by black cherry whereas only 18% of stands without deer were dominated by black cherry. The author notes controlling deer density will have the greatest affects on tree regeneration. At the lowest deer densities the trees were nearly twice as tall as high deer density areas (Tilghman 1989). Given the high deer densities in much of Pennsylvania and forage preference, deCalesta (1997) projected understories in old and second growth stands could be comprised of ferns, grasses, mosses, and seedlings of beech, striped maple, and black cherry, a drastic composition change than the natural composition. Advanced regeneration in oak dominated forest can also be important for oak replacement after natural mortality or harvest of mature trees. In central Massachusetts, deer populations of 10-17/km^2 prevented understory initiation of oak which prevented regeneration. The author also suggested oaks will become less abundant while white pine (*Pinus strobus*), red maple, and sweet birch will increase in abundance, resulting in significant changes in tree composition (Healy 1997).

To a lesser degree, deer herbivory has been researched in the eastern Piedmont region. In North Carolina researchers observed a 1.9, and 1.6 times increase in mean height, and diameter after exclusion for the second growing season combined with weeding the plots versus weeding alone. At the Manassas National Battlefield Park, Virginia after a four-year exclosure study in mature stands boxelder (*Acer negundo*), hickory (Carya spp.), and red maple had been eliminated while red and white oaks had been drastically reduced. The researchers predicted less browse favorable or more browse tolerant species such as ash (*Fraxinus spp*.), black cherry, and sugarberry (*Celtis occidentalis*) will shift to greater dominance (Rossell et al. 2005).

Negative impacts of deer herbivory are not limited to commercial timber production. Widespread threats to herbaceous plants have also been attributed to overbrowsing by deer. These plants are particularly susceptible because they never out grow the reach of deer and one bite could eliminate an individual's reproduction for a growing season. In addition, herbaceous plants are an important component of the spring and summer diet, providing more energy than woody twigs (Skinner and Telfer 1974, and Crawford 1982). A nation-wide survey conducted in 1992 identified 98 rare and threatened vascular plants that were impacted by deer browsing. Thirty-eight percent of these species were in the Liliaceae or Orchidacae families (Miller et al. 1992). Deer impacts to these species may be magnified by the continued fragmentation of mature forest which reveals more interior for deer accessibility (Alverson et al. 1988). Numerous studies have documented changes in individual plant height, community diversity and richness from deer browsing (Frankland and Nelson 2003, Anderson et al. 2005, Fletcher et at 2001a, Fletcher et al 2001b, Anderson 1994, Webster et al. 2001).

Studies suggest deer prefer the larger reproductive plants, and accumulated deer browsing can shift the demography of plant populations where the majority of plants are smaller and less reproductive. In southeastern Minnesota deer preferably grazed large trillium (*Trillium spp*.) plants, and the populations became skewered towards small plants resulting in a 50% decrease in reproduction during the growing season (Augustine and Frelich 1998). Rooney and Gross (2003) had similar results concluding deer browsing reduced the number of flowering plants in trillium populations. Expanding on this subject, Knight (2003) stated that timing of the browse event was significant in affecting white trillium (*T. grandiflorum*) populations. Plants browsed early in the season were more likely to remain nonreproductive the following year than plants browsed late in the season while reproductive plants browsed the following year were smaller in size producing less ovules (Knight 2003). The author suggests that active long-term management of deer population is necessary for the conservation of understory herbs (Knight 2004). Cades Cove-Great Smokey Mountains National Park (GSMNP) has experienced chronic high deer densities for several decades. Control versus exclosure plots indicated differences in the plant community; however, due to the intense historic browsing the authors imply many species were absent in both control and exclosure plots, and plants in fenced areas did not recover after eight years, recovery only happening with plants that survived chronic herbivory such as violets (*Viola spp.*). For example, *Maianthemum racemosa* only occurred at one site in the Cove but was present on all reference sites. Other species such as *Uvularia perfoliata*, *Medeola virginia*, *Uvularia sessiliflora* were rare on the Cove but common on the reference sites (Webster et al. 2005). Also, forested areas near open fields heavily used by deer experienced a 25%

reduction in species diversity relative to control areas in the GSMNP (Bratton 1979). Economically important plants are also impacted by deer. In American ginseng (*Panax quinqefolius*) populations, 50% of the fruit bearing plants were browsed and 47 to 100 percent of seeds were consumed. Deer pellet examination yielded no viable seeds and therefore deer can be considered predators of ginseng seeds (Furedi and McGraw 2004). Deer are also associated with long-term changes in forest understories. Over the last half century more generalists species have increased whereas rare, sensitive plants are decreasing. Wiegman and Waller (2006) referred to these species as "winners" and losers", respectively. The authors concluded that the winners are more tolerant to herbivory while the losers are sensitive, suggesting deer may be driving the shifts in forest understories (Wiegmann and Waller 2006).

Deer can affect plant communities to such a degree that a threshold can be surpassed causing an alternative stable state, defined as "deer altering the vegetation community so profoundly that a mere reduction or cessation of browsing will not permit a return to the original state" (Stromayer and Warren 1997). This hypothesis has been supported from research on the Allegheny plateau where timber harvesting, heavy browsing, and weed competition appear to have produced an alternative stable state (Stromayer and Warren 1997). Also, there is evidence of this condition occurring in central Massachusetts where elimination of hay scented fern cover is needed to restore the development of *Rubus spp*. which in turn should allow for subsequent hardwood regeneration (Cretaz and Kelty 2002).

The alteration of vegetation communities by deer can indirectly affect other wildlife species in cohabitation. For example, deer have been associated with impacting bird community assemblages. There is direct relationship between species richness and abundance of forest song birds and habitat structural complexity. High deer densities can reduce or eliminate understory and midstory vegetation thereby altering the vertical structure of forests. In a ten year study in Pennsylvania, there was a 27% decline in species richness and 37% decline in abundance of intermediate canopy nesting birds between the highest and lowest deer densities. Eastern woodpewee (*Contopus virens*, indigo bunting (*Passerina cyanea*), least flycatcher (*Empidonax minimus*), yellow billed cuckoo (*Coccyzus americanus*) and cerulean warbler (*Dendroica cerulean*) were not observed at deer densities greater than 7.9 deer/km^2 (deCalesta 1994). McShea and Rappole (1997) also associated low bird numbers to forest with low understory density from high deer numbers.

Studying the interaction effects between forest management practices and deer herbivory may result in a better understanding of the role of herbivory in shaping plant communities. Eastern forests are a complex dynamic ecosystem, influenced by abiotic factors such as canopy gaps and fire, among others. Managers imitate wildfire through prescribed burns as well as canopy gaps through thinning to achieve certain goals. Forest ecology studies on effects of fire and canopy gaps are numerous. However, few studies have looked at the interaction effect between fire, canopy gaps, and herbivory. In natural landscapes all three of these factors can occur, the frequency and intensity varying depending on region. However, herbivory studies usually focus on one factor only. Castleberry et al. (2000) examined the influence of herbivory and canopy opening size of forest regeneration in a southern bottomland hardwood forest. Interestingly, they concluded vegetative differences in exclosures and canopy gaps were not attributed to deer herbivory at densities between 7-10 deer/km^2. Contrastingly, other studies have shown that deer do impact regeneration in canopy gaps. Pedersen and Wallis (2004) investigated effects of herbivory of forest gap dynamics across two levels of deer browsing intensity. The tree density in the high relative-deer-density area was significantly lower than the low-relative-deer-density area, and the authors suggest gap closures are inhibited and deforestation is gradually occurring (Pedersen and Wallis 2004). The different outcomes of these two studies could be attributed to the differences in deer density, historic deer density, region, forest type, or other factors. In the Appalachian mountains of West Virginia, plants communities were significantly affected by the interaction of fire, canopy gaps, and herbivory (Collins 2004). For instance, gaps increased shade tolerant and shade intolerant seedlings; fire and fire combined with canopy gaps greatly increased the proportion of shade intolerant seedlings and saplings. However, when deer were present, shade intolerant species were drastically reduced. In summary, white-tailed deer may substantially alter successional trajectories. Intermediate-sized canopy gaps with fires promoted pioneer species when deer were absent. When deer were present these same disturbances conserved pre disturbance species, accelerating the successional trajectory by reducing the competition from pioneer species (Collins 2004).

From a rather extensive catalog of deer herbivory research, it has been shown that deer can impact forest plant communities by reducing tree regeneration, altering species composition and successional patterns, shifting the community to an alternative state, affecting biodiversity by reducing herbaceous species richness, and indirectly affecting other wildlife by altering the vegetation structure and composition. Though deer densities vary from different studies, most all findings are related to higher deer densities being associated with more severe impacts to plant communities. From an overview of the literature, many factors can influence the outcome of deer herbivory studies and the plant community impacts. Tree impacts can vary with the species, tree size and age, stand size, amount of advanced regeneration, species composition, and stand size. Impacts to specific herbaceous species or families can depend on many factors as well including size of plant, abundance, distribution, timing of browsing, and stand size and composition. Because deer are found across a wide range of habitat types, deer densities and carrying capacity, scientific findings continue to be difficult to apply across the range of deer. Therefore, until more universal methods are developed, results of deer herbivory findings should be considered at the scale and locale for which the study was designed.

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CHAPTER 2

EFFECTS OF WHITE-TAILED DEER HERBIVORY ON UPLAND HARDWOOD FORESTS OF THE SOUTH CAROLINA PIEDMONT

Introduction

The impact of white-tailed deer, *Odocoileus virginianus*, herbivory on ecosystems have received more attention as deer populations continue to increase in many areas. Most related work on forest composition and structure has been conducted in areas outside the southeastern United States such as the great lakes states (Alverson et al.1988, Augustine and Frelich 1998, Anderson and Loucks 1979, Wiegmann and Waller 2006), and the Allegheny Plateau region of Pennsylvania (Horsley et al. 2003, Tilghman 1989, Marquis and Brenneman 1981, Marquis and Grisez 1978, Marquis 1981). Information on deer herbivory in the Southeast is lacking; results from the few studies in this area show preliminary negative impacts associated with deer herbivory (Romagosa and Robison 2003, Rossell Jr. et al. 2005, Jones et al. 1997). Since most studies' results can only be applied locally, there is a need for research in the Piedmont region.

In the framework of ecosystem management, understanding the population and habitat interactions between white-tailed deer and Piedmont plant communities is critical. Protecting biodiversity, establishing desired timber production, and managing for a healthy deer herd are all important components in ecosystem management for Piedmont forests. Of the 200 million forest acres in the South, 37% consists of upland hardwoods with an additional 30% made of oak-pine and lowland hardwoods combined. The South produces approximately 60% percent of the Nation's timber products; forest management in this region is expected to intensify to meet the demands of future increase in hardwood timber production and increases in timber prices for the next forty years (Prestemon and Abt 2002, Siry 2002). The value of the South's forests is not restricted to timber production, but includes all wildlife resources dependant on sound integrated forestry practices. White-tailed deer alone provide a $14 billion annual recreational value, in addition to the intangible values provided by a sustainable deer herd (Conover 1997). With the advent of ecosystem management, we have begun to recognize the importance of protecting function and biodiversity to maintain stability and production (Loreau et al. 2006). Therefore, the dilemma lies in the need to protect native ecosystem integrity for the long-term while providing for the current and future sociopolitical needs of forest resources such as intensive timber management and healthy deer herds. Managing for successful hardwood regeneration, particularly oak species (*Quercus spp*.) in the Southeast is a priority for high value timber hard mast production for wildlife food sources. The unsolved issue of hardwood regeneration of preferred species may lead to an insufficient supply of fiber in the future with a shift to less desirable species such as red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), and yellow-poplar (*Liriodendron tulipifera*) (Lorimer 1993).

Investigating the impacts of herbivory on tree regeneration in hardwood clear cuts is important, because of the common forestry practice of using natural regeneration to grow hardwoods. Also, successful hardwood regeneration is dependant on advanced regeneration in mature stands soon to be cut (Marquis and Grisez 1978). Therefore, it is also important to investigate the impacts of deer herbivory to regeneration in mature hardwood stands.

In addition to the need for more baseline information, learning how deer density relates to impacts on timber production and biodiversity will assist in the development of herd management guidelines to maintain timber production and biodiversity. Impacts to plant communities are usually dependent on deer density, and with the use of relative deer density (RDD) there may be a method to standardize impacts across regions based on the percent density of carrying capacity (deCalesta and Stout 1997). Determination of a herd's position on the stock-recruitment curve may allow inferences for managing harvest of deer populations to produce desirable vegetation conditions on the Clemson Experimental Forest. RDD for maximum sustained yield of deer for harvest, yield for timber, and maintenance of biological diversity will be estimated as discussed by deCalesta and Stout (1997).

The specific objectives of this study and associated hypotheses were:

1. To determine the effects of white-tailed deer herbivory on forest plant communities in harvested and unharvested stands on the Clemson Experimental Forest.

   H0: Tree seedling, sapling, and understory plant richness, diversity, and evenness will be the same for the areas of high deer density and moderate deer density.

   Ha: Tree seedling, sapling, and understory plant richness, diversity, and evenness will be different between the areas of high deer density and moderate deer density.

2. To relate relative deer density to impacts on forest plant communities in harvested and unharvested stands in the Clemson Experimental Forest.

   A. Determine each herd's position on the stock-recruitment curve to establish the RDD for maximum sustained yield of deer for harvest, yield of timber, and maintenance of biodiversity.

Methods

This study was conducted on the 7, 024-ha Clemson Experimental Forest (CEF) within Anderson, Oconee, and Pickens counties of South Carolina. The forest is located in the Piedmont physiographic province in the northwestern part of the state. Slightly to moderate steep hills and slopes, with elevations to 305 m characterize the topography. Soils are mostly typic kanhapludults (Cecil, Madison, Pacolet), and rhodic kanhapludults (Hiwassee) characterized by highly weathered, strongly acidic, firm and clayey materials being derived primarily from weathered parent material of granite, schist, and gneiss. The climate is mild and temperate with normal annual rainfall of 139.7 cm. Average temperatures in July are 26.4°C and 6°C in January with a minimum growing season length averaging 200 days a year (Smith and Hallbeck 1979, and Byrd 1972). Analogous with land use practices in the Piedmont, the CEF was farmed intensively in the early 1900s, resulting in severe soil erosion. In 1938, the federal government reclaimed the land and granted it to Clemson University (Sorrells 1984).

The land cover is predominately forested consisting of oaks (*Quercus spp.*), hickories (*Carya spp*.), yellow-popular (*Liriodendron tulipefera*), a few overstory pines e.g. shortleaf pine(*Pinus echinata*) and also planted loblolly pine (*Pinus taeda*) stands of various ages. The CEF consist of two main sections, the 3300-ha section north of campus and the 3720-ha section south of Campus (referred to hereafter as the Keowee and Fant's Grove forests, respectively). Although separated by only a few miles, the Keowee and Fant's Grove forests offer a unique opportunity to study deer impact to their habitat because of the existing differences in land management and deer herd management. Keowee is a more contiguous forest with little agriculture, managed wildlife foodplots or openings. Most of the area is open to archery deer hunting under traditional deer harvest regulations with the exception of one area closed to deer hunting and one area with shotgun hunting for species other than deer. In contrast, Fant's Grove's land cover is a mosaic of forest interspersed with agriculture fields, livestock pastures, and managed foodplots and wildlife openings. Also, deer hunting on Fant's Grove has been under Quality Deer Management guidelines for the last seven hunting seasons. Buck harvest is restricted to animals with at least 4 points on one antler beam. There are also lottery rifle hunts at the end of the archery season to reduce the overall density and even the sex ratio. Hunting on the CEF is regulated by the South Carolina Department of Natural Resources (SCDNR) as public access Wildlife Management Area (WMA). Spotlight surveys and past SCDNR herd health checks suggest Keowee supports a relatively high deer density and Fant's Grove harbors a relatively moderate deer density. Spotlight surveys conducted in 2006 estimated deer density on Fant's Grove at 43 deer/mi^2 and 76 deer/mi^2 on Keowee. The densities were different mainly because more deer are harvested each season from Fant's Grove, and there is one area on Keowee restricted from hunting, which allow the deer densities to remain larger. Also, physical conditions of deer herds can be related to population densities (Keyser et al 2005) and the herd health checks indicate Fant's Grove's deer density is moderate and Keowee's deer density is high. Adult does, greater than 1.5-years old, collected from Fant's Grove weighed an average of 46 kg and carried an average of 1.1 fetuses. Adult does on Keowee averaged 33.45 kg and carried an average of 0.6 fetuses (Richard Morton, South Carolina Department of Natural Resources).

Six hardwood stands, three on Keowee and three on Fant's Grove, were selected for study of the impacts of deer herbivory on hardwood regeneration and plant community composition. All six stands were harvested in 2004 and ranged in size from 2.1 to 4.6 ha. Method II Landscape Ecosystems Classification identified all stands as being in the range of submesic to subxeric (Jones 1988, V. B. Shelburne Forestry professor, personal communication, 2004)) (Table 2.1). Two sample areas were located at or near mid slope within each of the six stands. Within these twelve areas, two sample plots were located; one within a deer-proof exclosure and one outside the exclosure for a paired design. Deer were excluded by constructed page wire fences (20 m x 20 m) with two, 1.2 m, sections of wire set on top of each other for a total height of 2.4 m. Hardwood regeneration was measured and compared from excluded and non-excluded plots during the summers of 2005 and 2006. Vegetation plots were 10 m by 5m with the long axis oriented perpendicular to the contour. Tree seedlings were measured in a 1 m by 10 m section of the plot. All seedlings were counted, identified to species and grouped into one of three height classes: less than 0.3 m, 0.3 to 0.9 m, and greater than 0.9 m. Saplings greater than 1.4 m were measured in the entire 10m by 5m plots. All saplings were counted, identified to species and grouped into four diameter at breast height (dbh) classes: 2.5 cm, 5 cm, 7.5 cm, and 10 cm. All herbaceous and shrub vegetation was measured in the lower 5 m by 5 m section of the plots. All plants were identified to species and percentage coverage was recorded. In addition, five vegetation classes were measured as percentage coverage: vines, forbs, woody, bare, and fern. Species richness (S), Shannon's Diversity Index (H'), and evenness (J') were calculated for each sample plot as follows: $H' = -\sum[(n_i/N)\ln(n_i/N)]$, where N is the total number of individuals and n_i is the total number of individuals in taxa i. J' was calculated from H' by dividing it by the natural log of the number of species (Magurran 2004). Analysis of evenness was restricted to plots that had at least two species with more than two individuals. Data were analyzed using one-way (y=treatment, y=herbivory level) and two-way (treatment x herbivory level) ANOVAs blocked by site within stand and herbivory level for paired comparisons of inside and outside exclosures. The abundances of seedlings and saplings, or count data, were compared using poisson regression.

In addition, deer herbivory effects were also compared between Keowee and Fant's Grove in mature upland hardwoods. Five randomly selected stands for each herbivory level were chosen from a group of similar stands. Within each stand, five vegetation plots were randomly identified using ArcView for a total of 25 plots each. Vegetation measurements, following the same protocol as above, were taken in two consecutive growing seasons for 2005 and 2006. Plots were oriented lengthwise at 135º. Comparisons of S, H', J' were executed using two-way (herbivory level x year) ANOVA's blocked by stand.

All analyses were performed using SAS 9.1 (SAS 2006). Data were transformed using square root or arsine to achieve normality. For convenience all data are presented in the untransformed values. Our critical value was alpha (α) = 0.05.

Table 2.1. Method II Landscape Ecosystem classification (Jones 1988) for the deer exclosure/ non-exclosure paired plots in harvested hardwood stands on the Clemson Experimental Forest, SC.

Forest	Stand	Plot	LEC Class
Keowee WMA	A	1	Intermediate
(High Deer Density)		2	Intermediate
	B	3	Subxeric
		4	Submesic
	C	5	Intermediate
		6	Subxeric
Fant's Grove WMA	D	7	Intermediate
(Moderate Deer Density)		8	Subxeric
	E	9	Subxeric
		10	Subxeric
	F	11	Intermediate
		12	Intermediate

Results

Harvested Hardwood Stands

In late summer 2005, after the first growing season following harvesting, there were 30 species of seedlings and 47 total species of understory plants identified. Of the 1852 individual seedling stems counted, 78 percent were *Liriodendron tulipifera* and *Rubus spp*. combined (n=895 and 547, respectively). The next most frequent seedling species was *Rhus glabra* with 72 individuals or 3.9 percent and the *Quercus spp* combined made up 3.5 percent (Table A.1). There were only 170 saplings counted after the first year's growing season, *Rhus glabra*, *Oxydendrum arboreum*, and *Liriodendron tulipifera* were the three most abundant species (Table A.2). *Conzya canadensis*, *Eupatorium capilifolium*, *Rubus sp*., and *Vitis rotundifolia* were among the understory species with the highest average coverage (Table A.3).

In late summer 2006, after the second year's growth, there were a total of 35 species of seedlings, 23 species of saplings, and 52 species of understory plants. Eighty percent of the 2206 seedling stems counted were *Liriodendron tulipifera* and *Rubus sp*. combined (n=758 and 1006, respectfully). The next most abundant species was *Rhus glabra* with 68 individuals or 3.1% and the *Quercus spp.* collectively made up 4.9 percent of the total (Table A.1). Forty-seven percent of the 457 saplings identified were *Liriodendron tulipifera*; *Rhus glabra* was the next most abundant sapling comprising of 8.5% of the total (Table A.2). *Eupatorium capilifolium*, *Rubus sp*., and *Vitis rotundifolia* had the highest averages of percentage coverage (Table A.3).

When comparing the differences between the exclosures and unfenced plots for Keowee and Fant's Grove, there were no significant differences in understory plant S, H' or J’ after the first or second growing season. Also, there were no significant differences between the seedling S, H’ or J’ for the first of second growing season. Also, seedling abundance (N) was not significantly different between the fenced and unfenced plots of Keowee or between fenced and unfenced plots of Fant’s Grove after the first or second growing season. There were insufficient numbers of saplings to compare after the first year, but there were no differences after the second year between the exclosures and unfenced plots for any of the indexes compared (Table 2.2). Also, there were no significant differences between fenced and unfenced plots when compared without regard to herbivory level.

When comparing the unfenced plots of Keowee with Fant’s Grove’s and the exclosures of Keowee with Fant’s Grove’s, there were no significant differences in understory plant S, H’ or J’ for either the first or second season. Neither were there any significant differences in S, H’, or J’ for seedlings. Although there were no differences in seedling N after the second season, seedling N was significantly greater in the control plots of Fant’s Grove ($p=0.0004$) and in the exclosure plots of Fant’s Grove ($p<0.0001$) when compared to Keowee after the first season. No indexes were significantly different for saplings when compared between the unfenced plots of Fant’s Grove and Keowee, or between the exclosures of Fant’s Grove and Keowee (Table 2.3)

Table 2.2. Seedling, sapling and understory plant indices for unfenced plots and deer exclosures in areas of high deer density and moderate deer density during the first two growing seasons (2005 and 2006) after the hardwood stands were harvested by clearcutting. There are no significant differences of means at the α=0.05 level.

			Unfenced		Exclosure	
Vegetation	Deer Density	Index	Mean	Std	Mean	Std
2005 Seedling	High	N	66.67	28.05	64.17	22.3
		S	8.67	2.07	8.5	2.89
		H'	1.48	0.3	1.51	0.45
		J'	0.69	0.09	0.71	0.12
	Moderate	N	84.5	29.21	93.33	35.43
		S	7.33	2.25	7.5	3.62
		H'	1.04	0.45	1.04	0.48
		J'	0.52	0.22	0.52	0.19
2006 Seedling	High	N	89	27.27	93	28.96
		S	10	2.61	8.83	1.47
		H'	1.4	0.31	1.31	0.22
		J'	0.61	0.09	0.6	0.08
	Moderate	N	87.5	35.27	98.17	24.06
		S	7.33	2.07	8.17	1.72
		H'	1.1	0.4	1.14	0.3
		J'	0.56	0.19	0.55	0.13
2006 Sapling	High	N	16.17	12.92	18.67	9.85
		S	4.67	2.94	3.33	1.51
		H'	1.23	0.51	1.14	0.26
		J'	0.87	0.1	0.89	0.08
	Moderate	N	24	25.15	17.5	13.58
		S	4	1.9	3	1.26
		H'	0.99	0.31	0.63	0.23
		J'	0.69	0.25	0.64	0.2
2005 Understory	High	S	11.33	1.21	11.5	3.4
		H'	1.27	0.34	1.31	0.4
		J'	0.53	0.13	0.55	0.12
	Moderate	S	11.83	2.5	12.33	2.34
		H'	1.42	0.23	1.42	0.25
		J'	0.58	0.1	0.57	0.08
2006 Understory	High	S	10.83	2.04	11	3.46
		H'	1.45	0.21	1.44	0.41
		J'	0.62	0.1	0.61	0.13
	Moderate	S	11.83	2.04	13.67	3.5
		H'	1.53	0.36	1.68	0.37
		J'	0.63	0.17	0.65	0.12

Table 2.3. Seedling, sapling and understory indices for deer exclosures between an area of high deer density and moderate deer density and for unfenced plots between an area of high deer density and moderate deer density during the first two growing seasons (2005 and 2006) after the mature hardwood stands were harvested by clearcutting on the Clemson Experimental Forest, SC. ¥

			High Deer Density		Moderate Deer Density	
Vegetation	Treatment	Index	Mean	Std	Mean	Std
2005 Seedling	Control	N	66.67**a**	28.05	84.5**b**	29.21
		S	8.67	2.07	7.33	2.25
		H'	1.48	0.3	1.04	0.45
		J'	0.69	0.09	0.52	0.22
	Exclosure	N	64.16**a**	22.3	93.33**b**	35.43
		S	8.5	2.88	7.5	3.62
		H'	1.51	0.447	1.04	0.48
		J'	0.71	0.12	0.52	0.19
2006 Seedling	Control	N	89	27.27	87.5	35.27
		S	10	2.61	7.33	2.07
		H'	1.4	0.31	1.1	0.4
		J'	0.61	0.09	0.56	0.19
	Exclosure	N	93	28.96	98.17	24.06
		S	8.83	1.47	8.17	1.72
		H'	1.31	0.22	1.14	0.3
		J'	0.6	0.08	0.54	0.13
2006 Sapling	Control	N	16.17	12.92	24	25.14
		S	4.67	2.94	4	1.9
		H'	1.23	0.51	0.99	0.31
		J'	0.87	0.1	0.69	0.25
	Exclosure	N	18.67	9.85	17.5	13.58
		S	3.33	1.51	3	1.26
		H'	1.14	0.3	0.63	0.23
		J'	0.89	0.08	0.64	0.2
2005 Understory	Control	S	11.33	1.21	11.83	2.5
		H'	1.28	0.34	1.42	0.23
		J'	0.53	0.13	0.58	0.1
	Exclosure	S	11.5	3.4	12.33	2.34
		H'	1.31	0.4	1.42	0.25
		J'	0.55	0.12	0.57	0.08
2006 Understory	Control	S	10.83	2.04	11.83	2.04
		H'	1.45	0.21	1.53	0.36
		J'	0.62	0.1	0.63	0.17
	Exclosure	S	11	3.46	13.67	3.5
		H'	1.44	0.41	1.68	0.37
		J'	0.61	0.13	0.65	0.12

¥ Means within a row followed by different letters are significantly different at the α=0.05 level.

When comparing the vegetation groups percentage coverage after the first year's growing season, vine coverage was almost significantly higher in the fenced plots than unfenced plots (p=0.0722) (Figure 2.1). However, the difference between vine coverage inside and outside the exclosures was not significantly different than zero when compared between herbivory levels. Woody coverage was significantly higher in exclosures than unfenced areas (p=0.0118), but there was neither a difference between herbivory level nor an interaction between the herbivory level and treatment. There were no significant differences for grass or vine coverage (Figure 2.1). After the second growing season, there were no significant differences for the vegetation class' percentage coverage (Figure 2.1).

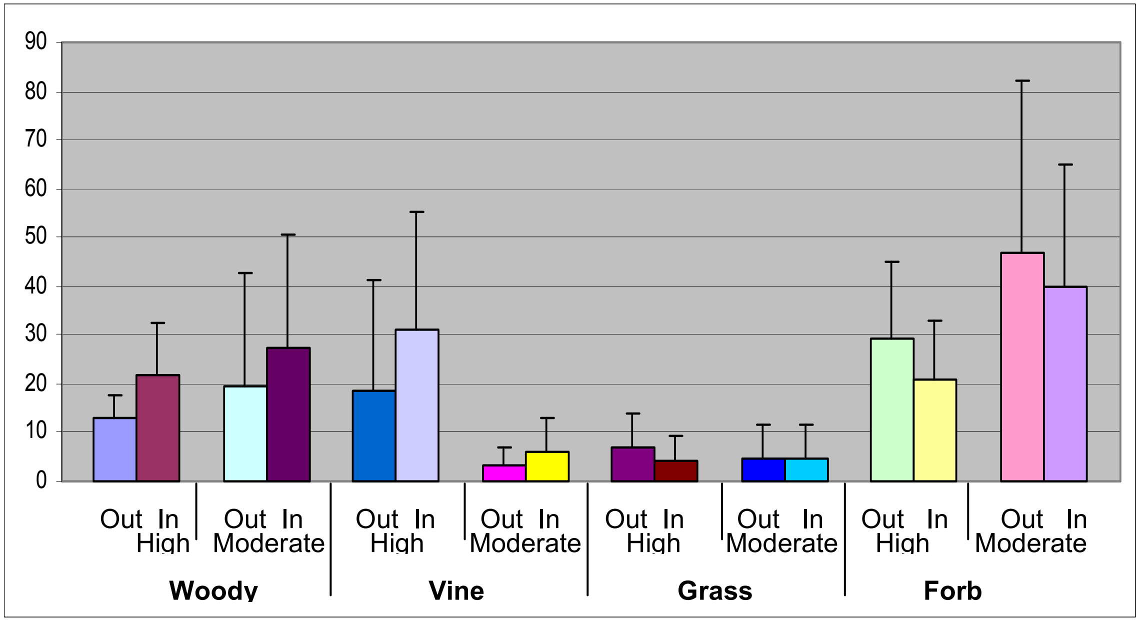

Figure 2.1. Average percentage coverage of four different vegetation groups inside (In) and outside (Out) of deer exclosures within two different relative deer densities: High = High Deer Density and Moderate= Moderate Deer Density. Data were collected in upland hardwood stands on the Clemson Experimental Forest, SC after one growing season post harvest by clearcutting. Adjacent bars with different letters indicate a significant difference at α=0.05 level.

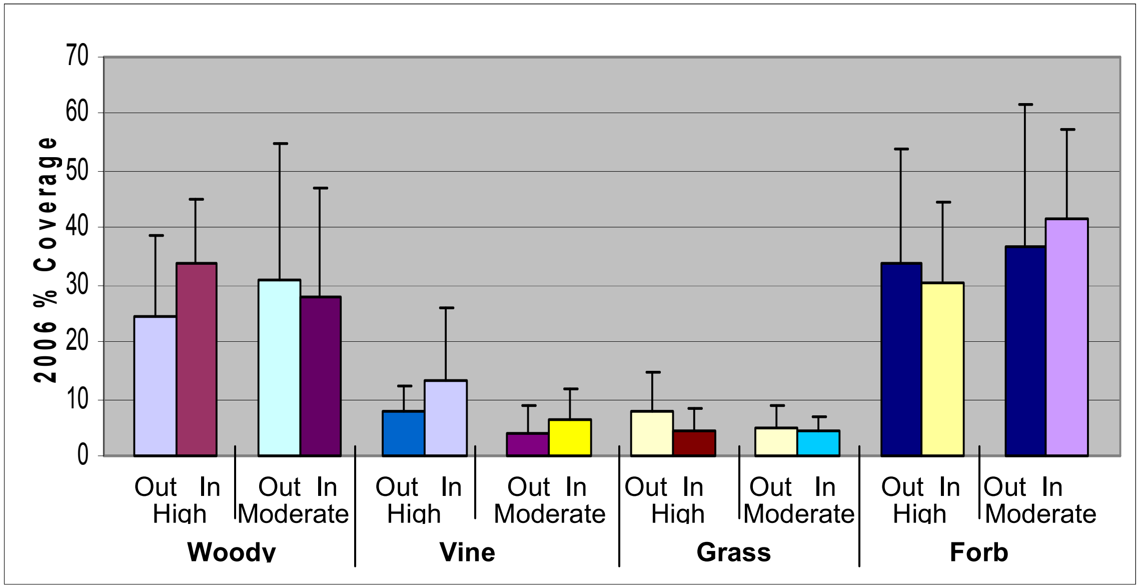

Figure 2.2. Average percentage coverage of four vegetation groups inside (In) and outside (Out) of deer exclosures and within two relative deer densities: High= High deer density, and Moderate= Moderate deer density. Data were collected from hardwood clearcut stands on the Clemson Experimental Forest, SC two years post harvest. Adjacent bars with different letters indicate a significant difference at α=0.05 level.

Mature Hardwood Stands

For the 2005 and 2006 growing season data combined, we identified 38 species of seedlings (Table A.4), 36 species of saplings (Table A.5), and at least 57 species of understory plants (Table A.6). For Keowee, eighty-four percent of the seedlings were less than 0.3 m tall, 15% were between 0.3 and 0.9 m tall, and less than 2% were greater than 0.9 m tall. For Fant's Grove, eighty-one percent of seedlings were less than 0.3 m tall, 18% were between 0.3 and 0.9 m tall, and less than 2% were greater than 0.9 m tall. Total oak seedlings comprised 50% to 58% of the total seedling abundance for Keowee and Fant's Grove. Seedling S was significantly higher for the Fant's Grove than Keowee (p=.0461) (Table 2.4). There were no significant differences of S or N between years or an interaction effect between year and deer density. There were no significant differences for seedling H' or J'. Sapling S, and H' was higher for Fant's Grove than Keowee (p=0.0343 and p=0.0186, respectfully), while sapling J' was not significantly different between deer density or interaction effect with year and deer density. Comparisons of understory plants for the mature stands resulted in higher richness in 2006 than 2005 (p=0.0031), but no significant interaction effect or difference between treatments. There were no significant differences in H' or J' for understory plants in mature stands (Table 2.4).

Grass or forb percentage coverage did not differ between deer densities or years. Although vine percentage coverage was higher in 2006 than 2005 (p=0.0040) (Figure 2.3), there was no difference across deer density or an interaction effect between year and deer density. Woody cover was greater in 2005 than 2006 (p=0.0097) (Figure 2.3), but there was no difference across deer density or no interaction effect between deer density and year. Woody coverage was almost significantly greater in Fant's Grove than Keowee (p=0.06040). There was no significant interaction between deer density and year (p=0.4767), however, for woody coverage.

Table 2.4. Seedling, sapling and understory plant indices for the Clemson Experimental Forest, SC across two levels of herbivory in mature upland harwood stands. Keowee= High deer density and Fan’ts Grove=Moderate deer density. ¥

Vegetation	Index	Keowee		Fant's Grove	
		Mean	Stdev	Mean	Stdev
Seedlings	S	5.32**a**	1.86	6.32**b**	2.03
	H'	1.35	0.4	1.39	0.35
	J'	0.83	0.16	0.78	0.14
Saplings	S	3.18**a**	1.88	4.44**b**	2.33
	H'	1.08**a**	0.41	1.35**b**	0.4
	J'	0.93	0.08	0.91	0.09
Understory	S	5.8	3.6	6.12	2.19
	H'	0.86	0.62	0.91	0.52
	J'	0.51	0.27	0.51	0.28

¥ Means within rows followed by different letters are significantly different at the alpha=0.05 level.

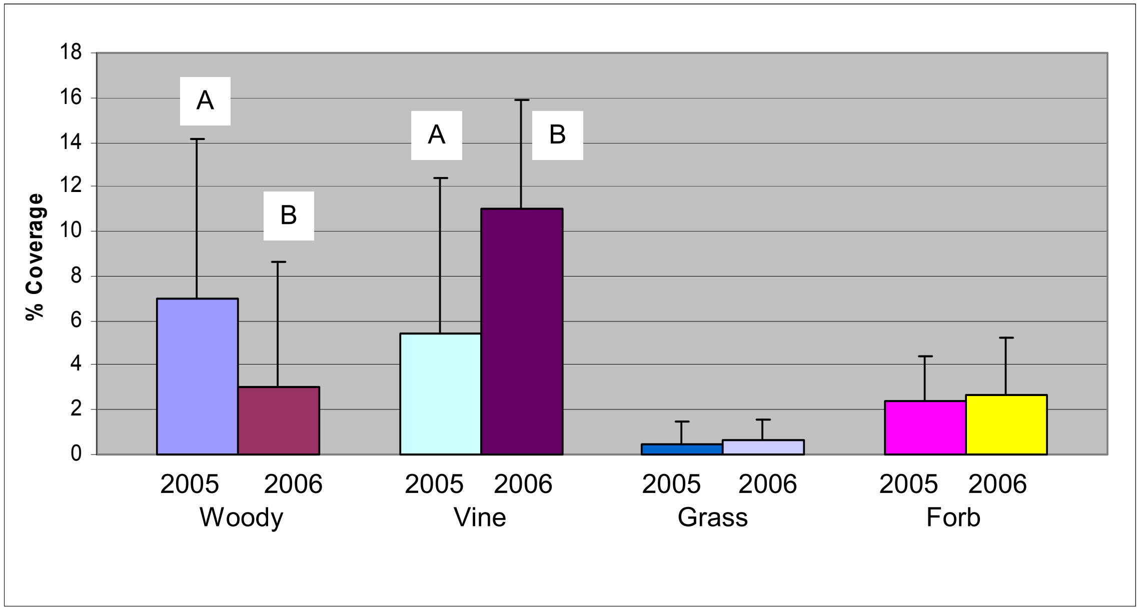

Figure 2.3. Average percentage coverage of four vegetation classes across two Two years (2005 and 2006) in mature upland hardwood stands on the Clemson Experimental Forest. Adjacent bars with different letters indicate a significant difference at the alpha=0.05 level.

Conclusion

The results of this study were not conclusive to support deer herbivory as a major factor influencing upland forest plant communities in the Clemson Experimental Forest. However, there may have been several reasons why this study did not detect such impacts. First for the harvested stands, the data were gathered only from the first and second year post harvest. After comparing the S, H' and J for saplings, seedlings, and understory plants, there were no significant differences between the unfenced plots and exclosures or areas of high deer density and moderate deer density. Although seedling abundance was significantly greater on the unfenced plots for Fant's Grove than Keowee and also greater for exclosures on Fant's Grove than Keowee for the first year post harvest, this difference was more likely due to a variable other than deer herbivory. This statement can be supported because there were no significant differences in seedling abundance after the second year post harvest and because there were no significant differences between controls and exclosures. The deer exclosures in the harvested stands were the initiation of a long-term study and two growing seasons may not have been enough time to detect real differences in regeneration or understory plants between treatments. Related studies usually reported findings at a minimum of 5 years post harvest (Tilghman 1989) or from accumulating years of three to ten years post harvest (Horsley et al 2003). Secondly, there was rapid vegetation growth on the site, including aggressive colonization of yellow-poplar (*Liriodendron tulipifera)* due most likely to numerous seeds and increased light. This proliferation of one tree species, although considered a preferred browse species (Harlow and Hooper 1971, Ford et al 1993, Johnson et al 1995), may have masked some potential impacts from browsing of less frequent, more preferred species such as *Quercus spp.*

There were significant differences among the average percentage coverage of forbs, vines, and woody in the harvested stands. Because there were significantly higher percentages for woody coverage in exclosures than controls, there may be some evidence of herbivory impacts to tree regeneration. However, this evidence is weak because of the lack of differences between the more accurate measurements of species richness, Shannon's Diversity Index, or Evenness, and because there were no significant differences in woody coverage after the second growing season. Similarly, any differences in vine coverage after the first growing season were not apparent after the second growing season. Forb coverage was heavily influenced by blackberry (*Rubus spp)*, the most abundant forb present and considered a preferred deer browse species. Interestingly, forb coverage was not significantly higher in the control plots compared to the exclosures on Fant's Grove or Keowee after the first or second growing season. Past studies stress the importance of blackberry occupying harvested stands for desired succession (Marquis and Grisez 1978). More time will be necessary to analyze the influence of blackberry on the succession of the harvested stands. When examined as a group, the distribution of the percentage coverages of the above vegetation classes have been used by other scientists as indications of herbivory impacts. Previous studies have documented increases in grass coverage and fern coverage as browsing intensifies while forbs, especially *Rubus spp.*, and woody coverage decrease (Tilghman 1989, Marquis and Grisez 1978, and Stromayer and Warren 1997, Ritchie et al 1998, Cretaz and Kelty

2002). This study did not capture any strong patterns of changes in cover percentages in harvested stands.

The results from the mature stands may offer some evidence of deer herbivory affecting plant communities. Past studies have associated reduced seedling and sapling species richness and diversity as an indication of over browsing from white-tailed deer (Bowers 1997, Healy 1997, and Harlow and Downing 1970). For our study, seedling S and H' were significantly lower in Keowee than Fant's Grove as well as sapling S which is consistent with the past studies. However, the size class distribution for seedlings, Keowee and Fant's Grove were very similar. A negative impact from herbivory would more likely show smaller trees in the higher density areas. However, this is not the case because 84% of the seedlings in Keowee were less than a 0.3 m tall and 81% of the seedlings in Fant's Grove were less than 0.3 m tall. In addition this design had a weakness in that it did not have a reference site subject to historical low deer densities. Although woody cover was almost significantly higher on Fant's Grove, there was no strong pattern of shifts in the distribution the vegetation class coverage between the two deer densities.

Since vegetation was compared in harvested and mature hardwood stands, it provided an opportunity to evaluate the before and after harvest conditions of the forest across two herbivory levels. The mature stands in our study were dominated by oak and hickory (*Carya spp.)* with poor regeneration of any species; however, the dominant species colonizing the harvested stands was *Liriodendron tulipifera* regardless of deer density. Past herbivory studies related to composition change have documented the preferred browse overstory species as underrepresented in the regeneration class while less preferred or more tolerant browse species dominating the regeneration class at higher deer densities (Marquis 1981,Alverson et al. 1988, Ross et al. 1970, Anderson and Loucks 1979, Cornett et al. 2000). However, this was not the case of this study's forest; the composition of seedlings in the mature stands consisted of 50% to 58% oak species. Much scientific attention has been devoted to oak regeneration (Loftis and McGee 1993); however, there seems to be a gap between the deer herbivory studies and oak regeneration studies. One method used to regenerate oaks is the shelterwood burn to reduce the competition of shade intolerant species in order to release the oaks (Van Lear et al. 1999, Brose et al. 1999). Surprisingly, the herbivory factor has not been evaluated in these type studies (Van Lear 1999, Barnes and Van Lear 1998, Wang et al. 2005). Deer herbivory studies conducted in ecosystems where fire is an evolutionary factor in plant communities need to take this into consideration. Without this factorial analysis, results in this area should be viewed with caution. Therefore, our results are not sufficient to show strong support for or against deer herbivory as a factor influencing in mature hardwood stands.

Density may be the primary factor affecting spatial and temporal variation in the effects of deer populations. Experimental and comparative descriptive statistics have shown that deer population density is often positively and significantly correlated with the magnitude of their effects on vegetation (Anderson 1994, Augustine and Frelich 1998, Frelich and Lorimer 1985, Rooney et at 2000). When comparing our deer densities with other studies (Russell et al. 2001) showing significant impacts from herbivory, we found our estimates to be among the higher densities represented. Therefore, concluding that our densities were not high enough to impact the vegetation would not be accurate.

Although the relative deer densities of our two areas were different at the time of our study, it is important also to consider the historic deer densities. Both are believed to have experienced higher deer densities prior to regulated hunting, thus chronic herbivory may have reduced the reachable vegetation in the mature stands. In combination with the lack of disturbance and continued relatively high browsing pressure, the stagnation of plant growth in mature stands will likely continue.

Management Implications

Our results did not allow estimations of the relationship between densities and vegetation impacts on the stock recruitment curve as proposed. Although our results did not reveal a clear difference between treatments, this does not mean deer are not impacting the plant communities. Since Keowee and Fant's Grove shared similar regeneration composition in the mature stands, it could mean that both deer densities surpass the threshold of herbivory impacts. Due to abiotic factors suppressing release, such as insufficient light, the severity of herbivory between the densities may be indistinguishable. Before management recommendations can be made about the deer herd on the Clemson Experimental Forest, further investigations should be conducted on the impacts of deer herbivory. The study plots in the clear cuts should be maintained for long-term monitoring, at least 10 years. In addition, more intensive research should examine the vegetation response at multiple levels such as fire, canopy gaps, and herbivory in the mature hardwood stands. Also, more thorough vegetation measurements may capture the effects of herbivory more clearly such as looking at individual seedling survival and growth. Indicator species should be evaluated across different habitat types.

For example the height of strawberry bush, a highly preferred and common species, should be considered for individual plants on upland sites. Most indicator studies utilize a mesiphytic species, but rarely are upland species considered. Finally, there appear to be two options to better measure the effects of herbivory: one is to construct large exclosures in the different type habitats in addition to the harvested stands so they would capture the variability intrinsic to forest stands and monitor the vegetation for the long term; another option is to promote a vegetation release though a disturbance. It is difficult to measure vegetation when it is sparse; promoting a growth response could help distinguish the impacts from deer herbivory.

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CHAPTER 3

WHITE-TAILED DEER HERBIVORY EFFECTS ON FOREST REGENERATION, BIODIVERSITY, AND ECOSYSTEM FUNCTION-BASELINE VEGETATION ASSESSMENT ON THE MEADWESTVACO WILDLIFE AND ECOLOGICAL RESEARCH FOREST, WV

Introduction

Deleterious impacts to forest vegetation from white-tailed deer (*Odocoileus virginianus*) herbivory are common in the Middle Atlantic region of the United States. In the Allegheny Plateau region of Pennsylvania, these impacts have ranged from changes in tree species composition to complete regeneration failure (Marquis 1981, Marquis and Brenneman 1981, Tilghman 1989). Concerns about deer herbivory are also focused on changes in long term plant successional patterns (Nowacki and Abrams 1994), and causing alternative stable state ecosystems (Stromayer and Warren 1997). In addition, loses of plant biodiversity have been attributed to increased deer densities (Fletcher et al. 2001, Miller et al. 1992, Redding 1987). The aforementioned impacts to plant communities have been associated with indirect negative impacts to other wildlife species as well through changes in vegetation structure (deCalesta 1994, McShea and Rappole 1997).

The Appalachian Mountains in east-central West Virginia share similar species compositions and forest types as those present in the Allegheny Plateau. A specific example is the MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF) located in Randolph County, WV. This forest has been characterized as one heavily impacted by high deer browsing pressure. Many understory communities display signs of shrub layers dominated by striped maple (*Acer pensylvanicum*) and dense hay-scented fern (*Dennstaedtia punctilobula*) ground cover (Ford and Rodrigue 2001). Other vegetation characteristics such as apparent browse lines throughout the property on low quality forage such as rosebay rhododendron (*Rhododendron maximum*), hedged morphology and low-ground creeping of green briar (*Smilax spp*.) support high browsing pressure. Further, the results of a deer herd health check performed by the Southeastern Cooperative Wildlife Disease Study also indicate that high deer densities may threaten herd health (Fischer 1996). Therefore, managers recognize the importance of gaining baseline data on the effects of deer herbivory for this research forest.

There is also need to relate deer density to vegetation impacts in order to provide management recommendation for the property's deer herd. Though results from past herbivory studies are difficult to implement in locales outside the scope of the research, deer density was the main factor determining the level of impacts. Relatively high deer densities, regardless of ecosystem are associated with the most severe impacts (Russell et al. 2001). deCalesta (1994) proposed a conceptual framework to integrate deer management with ecosystem management. Through this framework managers may be able to locate the relative deer densities (RDD), or percent of carrying capacity (K), that would provide for maximum sustained yield of harvest, threshold of sustaining biodiversity and timber production. Even though deer densities at each RDD value may differ among landscapes, they hypothesize that the ratios of RDD to K will be consistent. Herbivory studies to date used differences in deer density as the major treatment factor. However, RDD can be also be adjusted through landscape level vegetation changes that could increase or decrease carrying capacity. Managers can change the RDD by providing more browse without changing the deer density.

The goal of this study is to establish baseline conditions for a long-term research project to examine the effects of white-tailed deer herbivory on forest regeneration, biodiversity and ecosystem function with the two following objectives.

1. To determine the immediate and long-term effects of white-tailed deer herbivory on forest plant communities across three levels of RDD on the MWERF.

2. To relate RDD to impacts on forest plant communities on the MWERF.

Methods

The study was conducted on the 3413-hectare MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF) of Randolph County West Virginia. Located in the Allegheny Mountain and Plateau physiographic province in the east-central part of the state, the elevation of the forest ranges from 734 meters to 1180 meters. Topography consists of steep slopes, with broad ridge tops and narrow valleys. Soils are well drained acidic inceptisols and ultisols of the Gilpin-Dekalb-Buchanan series. MWERF's climate is cool and moist with annual precipitation often exceeding 160 cm, and snow commonly occurring throughout the winter months. The forest is classified as a mixed mesophytic forest where high elevations are dominated by northern hardwood-Allegheny hardwoods including American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), black cherry (*Prunus serotina*), Frasier magnolia (*Magnolia fraseri*), red maple (*Acer rubrum*), and sugar maple (*A. saccharum*). At lower elevations, species also consist of yellow-poplar (*Liriodendron tulipifera*), northern red oak (*Quercus rubra*), basswood (*Tilia americana*), cucumber magnolia (*M. acuminata*), sweet birch (*B. lenta*), and white ash (*Fraxinus americana*). Montane red spruce (*Picea rubens*) and eastern hemlock (*Tsuga canadensis*) stands also occur at upper elevations. The understory is comprised of striped maple (*A. pensylvanicum*) and sweet birch (*B. lenta*) along with areas of dense ground cover of hay-scented (*Dennstaedtia punctilobula*) and New York fern (*Thelypteris noveboracensis*) (Cambell 2004).

The MWERF was established in 1994 to evaluate the impacts of industrial forestry on wildlife and ecosystem processes in the central Appalachian Mountains. The forest is comprised mostly of second growth, naturally regenerated hardwoods that were originally cut between 1916 and 1928. Current silviculture involves even-aged techniques of clear cutting and leave-tree harvest. The harvested stands are left to regenerate naturally to foster a desirable species mix.

The MWERF is sectioned into 9 different compartments of similar size. A systematic grid of transects covering the entire property was created with 18 points per compartment randomly selected for vegetation plots. Three harvest intensity regimes were assigned to each of the 9 compartments which include 20-year, 40-year, and 80-year clear cut rotation (referred from here as 20 YT, 40 YT, and 80 YT, respectfully). Vegetation was recorded in 10 m by 5 m rectangular plots with the long end oriented to a 135° compass bearing. Tree saplings greater than 1.4 m tall were recorded for the entire 10m by 5m plots. Each stem was identified to species and grouped into one of four diameters at breast height (dbh) class categories: 2.54 cm, 5 cm, 7.5 cm, and 10 cm. Also, vegetative coverage groups were measured and recorded to percentage coverage for six classes for the larger plot: grass, fern, woody, forbs, vines, and bare ground. All herbaceous plants were identified to species and percentage coverage in a nested 5 m by 5 m plot. Tree seedlings were measured in a nested 1 m by 10 m plot by counting all stems less than 1.4 m, identifying them to species and grouping them into three height classes: < 0.3 m, 0.3 to 0.9 m, and >0.9 m. The plots were measured in summers in 2001 and 2005. Vegetation characteristics were compared between the three harvest intensity treatments for seedlings, saplings, and herbaceous plants, and vegetation class coverage. Differences in species richness (S), Shannon's Diversity Index (H'), and Evenness (J') (Magurran 2004) were compared using two-way (treatment x year) ANOVA's. The percentage coverage of the vegetation classes were analyzed with logistic regression because of the variability in the distribution. Grass and bare ground were not analyzed due to the lack of frequency in the plots. A few plots measured in 2001 could not be measured in 2005 due to damage, or drastic vegetation changes from logging after the plots were established. Therefore, some plots were eliminated from analysis in order to compare the same plots from both sampling years.

In addition, 27 deer exclosures paired with unfenced plots were randomly established on the forest, 3 in each compartment in 2001. Vegetation sampling followed the above methods. The exclosures and paired unfenced plots were measured in 2003, two years after construction (Y2) and 2006, five years after construction (Y5). Abundance (N), S, H' and J' were compared for seedlings, saplings, and understory species. Differences in vegetation class coverage were also compared between fenced and unfenced plots. Data were analyzed by SAS using one way ANOVAs to compare the differences between the fenced and unfenced plots across treatment levels for Y2 and Y5. Also, differences in vegetation between fenced and unfenced plots were compared using a paired student's t-test, without regard to harvest treatment (SAS 2006).

All data were transformed when necessary to achieve normality, for convenience all data are presented untransformed. The significance level was α=0.05.

Results

Y2 Inside versus Outside Exclosures

The three most abundant sapling species were *F. grandifolia*, *B. lenta* and *A. saccharum*, both inside and outside the exclosures (Table B.1). The three most abundant seedling species were *A. saccharum*, *A. rubrum*, and *L. tulipifera* (Table B.2). The three most frequently occurring understory species were *Viola sp*., *Smilax sp.* and *Thelypteris noveboracensis* (Table B.3). There were significantly more saplings outside the fences than inside the fences combined at Y2 (p=0.0094). Specifically, the 80 YT had more saplings outside the fences than inside (p=0.0481), but there were no differences within the other two harvest regimes when comparing inside and outside the exclosures, or no differences between treatment levels (p=0.89). There were no significant differences in S, H', or J' for saplings after Y2 (Table 3.1). Seedling abundance was almost significantly higher inside than outside exclosures for the 20 YT (p=0.0506), but no differences within the 40 YT and 80 YT. Contrastingly, seedling S was almost higher outside than inside fences for the 40 YT (p=0.0752), but there were no significant differences within the 20 or 80 YT. H' was not significantly different for seedlings. Also, within the 20 YT J' was higher outside than inside the exclosures (p=0.0117) (Table 3.2). No other scenarios were significantly different. Understory S or J' were not significantly different, although H' was almost significantly higher inside than outside within the 40 YT (p=0.0801) (Table 3.3).

Y5 Inside versus Outside Exclosures

The three most abundant sapling species were *F. grandifolia*, *A. saccharum*, and *B. lenta* (Table B-I). The three most abundant seedlings were *A. saccharum*, *A. rubrum*, and *L. tulipifera* (Table B.2). *Viola sp*, *Smilax sp*., and *T. noveboracensis* were the most frequently occurring understory species (Table B.3). Sapling abundance, S, or J' were not significantly different after Y5. However, H' was greater outside than inside the exclosures combined (p=0.0143). Specifically, H' was higher outside than inside exclosures within the 40YT (p=0.0384), but there were no differences within the 20YT or 80YT (Table 3.1). Seedling N, S, or J' was not significantly different after Y5. Seedling H' was almost significantly greater inside than outside fences combined (p=0.0752) (Table 3.2). There were no differences in understory plants communities after Y5 (Table 3.3). When comparing the difference between inside and outside between treatments, only Y2 seedling J' was significantly different (p=0.0395). Specifically, the difference between inside and outside (estimate=0.094) for the 80YT was greater than the difference between inside and outside (estimate= -0.229) for the 20YT (p=0.0120). No other differences were significant (Table 3.4).

Table 3.1. Sapling species average indices inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest (MWERF) two years (2003) and five years (2006) after construction: abundance (N), species richness (S), Shannon-Weiner Index of Diversity (H'), and species evenness (J') (Magurran 2004). ¥

			Inside		Outside	
		Index	Mean	Std	Mean	Std
2003 Sapling	20	N	10	8.49	15.86	9.74
		S	3	1.69	3.5	1.51
		H'	1.05	0.21	0.78	0.35
		J'	0.79	0.12	0.67	0.18
	40	N	6.56	4.98	13.44	8.65
		S	2.67	1.41	3	2.29
		H'	0.87	0.38	1.01	0.49
		J'	0.7	0.15	0.78	0.1
	80	N	21.13**a**	27.99	31.38**b**	39.15
		S	4.22	1.39	3.44	3.13
		H'	0.92	0.4	0.9	0.24
		J'	0.73	0.29	0.71	0.24
	Total	N	12.42**a**	17.53	20.13**b**	24.14
		S	3.31	1.59	3.31	2.34
		H'	0.95	0.33	0.9	0.37
		J'	0.74	0.19	0.71	0.18
2006 Sapling	20	N	12	9.11	9.57	10.23
		S	2.43	2.07	2	1.15
		H'	0.58	0.09	0.78	0.2
		J'	0.83	0.12	0.78	0.24
	40	N	9.33	12.88	9.89	4.01
		S	2.67	1.22	3.44	1.81
		H'	1.03**a**	0.3	1.31**b**	0.16
		J'	0.87	0.11	0.89	0.06
	80	N	10.29	5.74	13.57	11.69
		S	2.29	1.11	2.57	1.13
		H'	0.87	0.23	1	0.26
		J'	0.81	0.09	0.85	0.14
	Total	N	10.43	9.66	10.91	8.65
		S	2.48	1.44	2.74	1.51
		H'	0.87**a**	0.29	1.09**b**	0.29
		J'	0.84	0.1	0.85	0.14

¥ averages with different subtended letters are significant at the α=0.05 level

Table 3.2. Seedling species average indices inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction: abundance (N), species richness (S), Shannon-Weiner Index of Diversity (H'), and species evenness (J') (Magurran 2004). ¥

			Inside		Outside	
	Treatment	Index	Mean	Std	Mean	Std
2003 Seedling	20	N	52.5a	48.13	25b	28.13
		S	4.75	1.58	4	1.69
		H'	0.95	0.44	1.07	0.3
		J'	0.622**a**	0.23	0.85**b**	0.12
	40	N	64.78	77.13	64.33	81.38
		S	4.56	1.88	4.89	2.15
		H'	0.99	0.44	1.2	0.55
		J'	0.65	0.24	0.72	0.3
	80	N	17.11	19.34	26.11	16.65
		S	3.44	2.07	4.67	2.12
		H'	0.95	0.46	0.96	0.48
		J'	0.74	0.23	0.64	0.15
	Total	N	44.5	55.77	39	52.76
		S	4.23	1.88	4.54	1.96
		H'	0.97	0.43	1.08	0.45
		J'	0.67	0.23	0.74	0.22
2006 Seedling	20	N	44.86	25.92	33.14	32.13
		S	6.29	1.8	5.15	1.46
		H'	1.33	0.33	1.28	0.33
		J'	0.744	0.18	0.79	0.11
	40	N	52	53.75	45	45.61
		S	6.67	3.12	4.56	2.13
		H'	1.33	0.58	0.89	0.4
		J'	0.73	0.22	0.64	0.21
	80	N	11.58	12.99	21.14	15.99
		S	4.43	4.83	4.71	2.98
		H'	1.48	0.69	1.3	0.6
		J'	0.89	0.15	0.75	0.3
	Total	N	36.86	39.05	33.64	34.1
		S	5.87	3.43	4.78	2.17
		H'	1.37	0.51	1.12	0.46
		J'	0.77	0.19	0.72	0.21

¥ averages with different subtended letters are significant at the $\alpha=0.05$ level

Table 3.3. Understory species indices inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction: species richness (S), Shannon-Weiner Index of Diversity (H'), and species evenness (J') (Magurran 2004). ¥

			Inside		Outside	
	Treatment	Index	Mean	Std	Mean	Std
Understory 2003	20	S	5.38	2.92	4.86	1.55
		H'	0.7	0.64	0.76	0.5
		J'	0.39	0.33	0.45	0.27
	40	S	5.44	2.92	5.55	2.01
		H'	1.09	0.34	0.71	0.36
		J'	0.6	0.2	0.45	0.18
	80	S	6.22	3.27	5.22	1.86
		H'	0.98	0.41	1.01	0.49
		J'	0.46	0.23	0.55	0.3
	Total	S	5.69	2.88	5.23	1.77
		H'	0.93	0.48	0.84	0.45
		J'	0.48	0.26	0.48	0.24
Understory 2006	20	S	6	2.71	5	2.71
		H'	1.13	0.53	0.84	0.55
		J'	0.65	0.2	0.55	0.28
	40	S	6.44	3.78	6	3.71
		H'	1.12	0.45	1.29	0.71
		J'	0.69	0.33	0.72	0.34
	80	S	4.86	3.76	4.86	3.29
		H'	1.49	0.81	1.41	0.26
		J'	0.8	0.31	0.87	0.19
	Total	S	5.83	3.39	5.35	3.2
		H'	1.22	0.57	1.16	0.6
		J'	0.7	0.28	0.7	0.3

¥ means with different subtended letters are significant at the α=0.05 level

Table 3.4. Vegetation indices' differences between inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest compared across three treatments: 20, 40, and 80 year timber harvest rotation.

	Index	F value	P-value
2003 Seedling	N	2.11	0.144
	S	2.13	0.1419
	H'	0.24	0.7862
	J'	3.78	0.0395*
2005 Seedling	N	1.73	0.2034
	S	0.87	0.4326
	H'	0.41	0.6697
	J'	0.59	0.57
2003 Sapling	N	0.21	0.809
	S	0.71	0.504
	H'	0.98	0.399
	J'	1.27	0.3104
2006 Sapling	N	0.78	0.4727
	S	0.91	0.4167
	H'	0.33	0.7282
	J'	0.39	0.684
2003 Understory	S	0.47	0.634
	H'	1.45	0.2568
	J'	1.7	0.2129
2006 Understory	S	0.22	0.8026
	H'	0.9	0.4246
	J'	0.53	0.5976

*mean J' was significantly different at the $\alpha=0.05$ level. The 80 year treatment difference was greater than the 20 year treatment.

Timber Harvest Rotation Treatments

There were no differences between treatments for 2001 or 2005 for any of the indices. However, sapling J' was greater for the 20YT than the 80YT (p=0.0409) and the 40 YT was greater than the 80 YT (p=0.0085) for the two years combined (Table 3.5). Sapling J' was almost significantly higher in 2005 than 2001 (p=0.0579). Also, sapling H' was not affected by treatments, but it was higher in 2005 than 2001 (p=0.0497) (Table 3.6). There were no differences in sapling S, and there were no interaction effects between year and treatment for any sapling indices (Table 3.5 and 3.6). Seedling S was greater in 2005 than 2001 (p<0.0001), and seedling S was almost greater for the 40YT than 20YT or 80 YT (p=0.0518 and P=0.0574, respectfully). There were no significant interaction effects between year and treatment. Seedling H' was also greater in 2005 than 2001 (p<0.0001), and seedling H' was greater for 40YT than the 20YT or 80YT (p=0.0004 and p=0.0003, respectfully). There were no interaction effects between year and treatment for seedling H'. Seedling J' was greater in 2001 than 2005 (p<0.0001), but there were no treatment effects or interaction effects (Table 3.5 and 3.6). Understory plant richness was greater in 2005 than 2001 (p<0.0001), but there were no treatment or interaction effects. Also, there were no significant differences in understory H' or J' (Table 3.5 and 3.6).

Table 3.5. Vegetation indices on the MeadWestvaco Wildlife and Ecosystem Research Forest compared across three treatment levels: 20, 40, and 80 timber harvest rotation and within two years. ¥

			20		40		80	
	Year	Index	Mean	Std	Mean	Std	Mean	Std
Seedling	2001	S	3.87	1.8	4.58	2.3	3.64	1.75
		H'	0.97	0.37	1.26	0.4	0.92	0.4
		J'	0.66	0.27	0.72	0.26	0.66	0.21
	2005	S	5.44	2	6.36	2.35	5.87	2.58
		H'	1.17	0.4	1.4	0.4	1.22	0.44
		J'	0.69	0.17	0.76	0.15	0.73	0.15
	Total	S	4.66	2.06	5.47	2.48	4.76	2.46
		H'	1.08**b**	0.4	1.33**a**	0.4	1.08**b**	0.48
		J'	0.68	0.22	0.74	0.21	0.7	0.18
Sapling	2001	S	2.76	1.76	3.11	2.05	2.92	1.77
		H'	0.833	0.4	0.95	0.36	0.82	0.4
		J'	0.76	0.21	0.82	0.15	0.71	0.21
	2005	S	2.82	1.76	3.04	1.78	2.88	1.84
		H'	0.98	0.35	0.91	0.38	0.93	0.4
		J'	0.84	0.15	0.8	0.17	0.77	0.15
	Total	S	2.79	1.75	3.08	1.91	2.9	1.8
		H'	0.9	0.38	0.93	0.37	0.87	0.4
		J'	0.76**ab**	0.19	0.81**a**	0.16	0.74**b**	0.18
Understory	2001	S	4.69	2.08	5.11	2.68	4.74	2.4
		H'	0.84	0.32	0.93	0.439	1	0.44
		J'	0.611	0.27	0.65	0.3	0.69	0.26
	2005	S	6.07	3.44	5.83	2.79	6.28	2.91
		H'	1.03	0.63	0.98	0.49	1.09	0.55
		J'	0.69	0.26	0.6	0.33	0.61	0.29
	Total	S	5.38	2.91	5.47	2.74	5.52	2.76
		H'	0.94	0.5	0.96	0.44	1.05	0.48
		J'	0.61	0.3	0.63	0.3	0.67	0.27

¥ means within rows with different subtended letters are significantly different at α=.05 level.

Table 3.6. Vegetation indices on the MeadWestvaco Wildlife and Ecosystem Research Forest compared between two years using repeated plots. 20, 40, and 80 are the different timber harvest rotations in years. ¥

			2001		2005	
	Treatment	Index	Mean	Std error	Mean	Std error
Seedling	20 year	S	3.87	0.32	5.44	0.32
		H'	0.96**a**	0.06	1.17**b**	0.06
		J'	0.66	0.03	0.7	0.03
	40 year	S	4.58	0.32	6.36	0.32
		H'	1.25	0.07	1.39	0.06
		J'	0.72	0.03	0.76	0.03
	80 year	S	3.64	0.32	5.87	0.32
		H'	0.92	0.07	1.22	0.06
		J'	0.66	0.03	0.73	0.03
	Total	S	4.03**a**	0.19	5.89**b**	0.19
		H'	1.04**a**	0.04	1.26**b**	0.04
		J'	0.68	0.02	0.73	0.02
Sapling	20 year	S	2.76	0.27	2.82	0.27
		H'	0.83	0.06	1	0.07
		J'	0.76	0.03	0.84	0.03
	40 year	S	3.11	0.27	3.04	0.27
		H'	0.94	0.06	0.91	0.06
		J'	0.82	0.03	0.8	0.03
	80 year	S	2.92	0.26	2.88	0.26
		H'	0.81	0.06	0.94	0.06
		J'	0.71	0.03	0.78	0.03
	Total	S	2.93	0.16	2.91	0.16
		H'	0.86**a**	0.03	0.94**b**	0.04
		J'	0.76	0.02	0.81	0.02
Understory	20 year	S	4.69	0.41	6.1	0.41
		H'	0.84	0.07	1.03	0.04
		J'	0.51	0.04	0.54	0.04
	40 year	S	5.11	0.4	5.83	0.4
		H'	0.93	0.07	0.98	0.07
		J'	0.52	0.04	0.54	0.04
	80 year	S	4.74	0.4	6.2	0.4
		H'	1.01	0.07	1.08	0.07
		J'	0.61	0.04	0.56	0.04
	Total	S	4.84**a**	0.23	6.03**b**	0.23
		H'	0.92**a**	0.04	1.03**b**	0.04
		J'	0.55	0.02	0.55	0.02

¥ averages with different subtended letters are significantly different at α=.05 level.

Vegetation Cover Classes- Inside and Outside Deer Exclosures

There were no significant differences when comparing the percentage coverage of ferns, forbs, vines, or woody inside the exclosures to outside the exclosures for 2003 (Figure 3.1) or 2006 (Figure 3.2). Also, treatments did not influence the differences between inside and outside the exclosures for each of the four vegetation classes for 2003 or 2006 (Figures 3.3 – 3.10).

Vegetation Cover Classes-Timber Harvest Rotation Treatments

Treatment significantly affected fern coverage ($p= 0.001$), where coverage was greater in the 20 YT than 80 YT ($p= 0.0003$) and greater in the 40 YT than 80 YT ($p= 0.0029$). Also, there was an interaction effect between year and treatment ($p= 0.0027$), where coverage was greater for the 20 YT than 80 YT in 2001 ($p< 0.0001$), greater for the 40 YT than the 80 YT in 2001 ($p< 0.0001$), greater for 40 YT in 2001 than 2006 ($p= 0.0285$), and greater for 80 YT in 2006 than 80 YT in 2001 ($p= 0.0029$) (Table 3.7 and 3.8). There was no treatment effect or interaction effect between treatment and year for forb coverage, but year 2006 had greater coverage than 2001 ($p= 0.035$) (Table 3.7 and 3.8). Grass coverage was affected by treatment ($p= 0.0272$), where the 20 YT was greater than the 80 YT ($p= 0.0084$) and the 40 YT was greater than the 80 YT ($p= 0.0273$) (Table 3.7 and 3.8). Grass coverage did not differ between years, nor was there an interaction effect between treatment and year. Vine percentage coverage was not influenced by year or treatment. Woody coverage was greater in 2006 than 2001 ($p= 0.0305$), but was not affected by treatment.

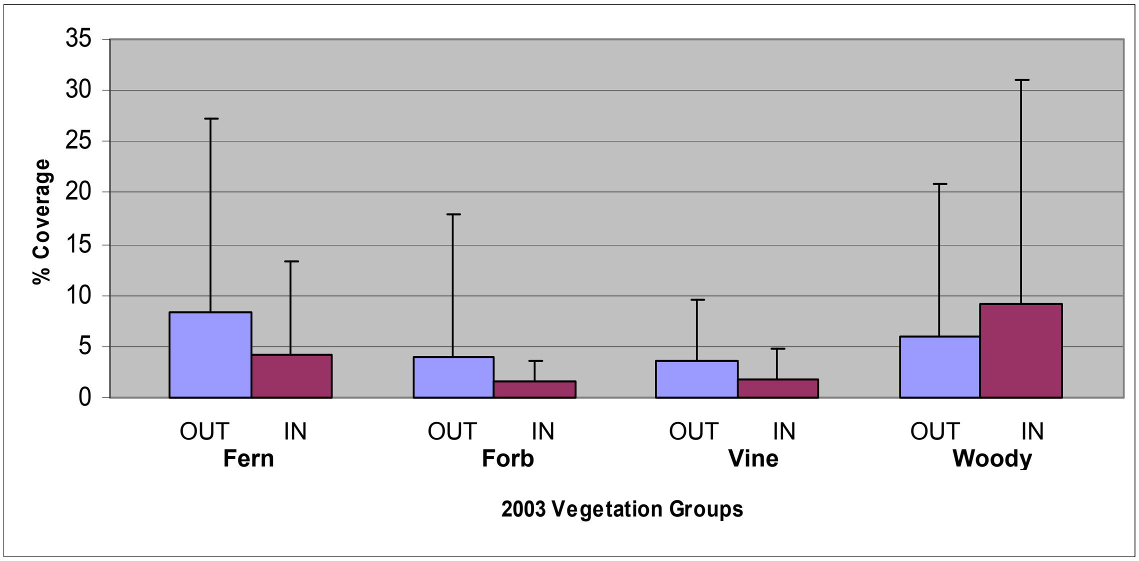

Figure 3.1. Percentage coverage of four vegetation groups inside (IN) and outside (OUT) deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction.

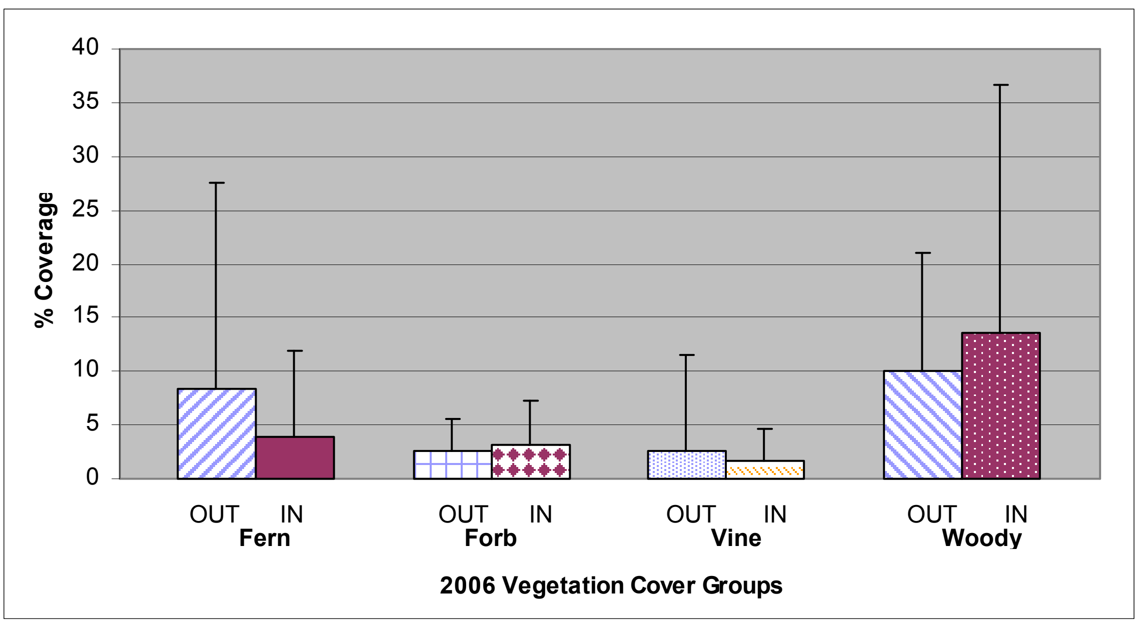

Figure 3.2. Percentage coverage of four vegetation groups inside (IN) and outside (OUT) deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest five years after construction.

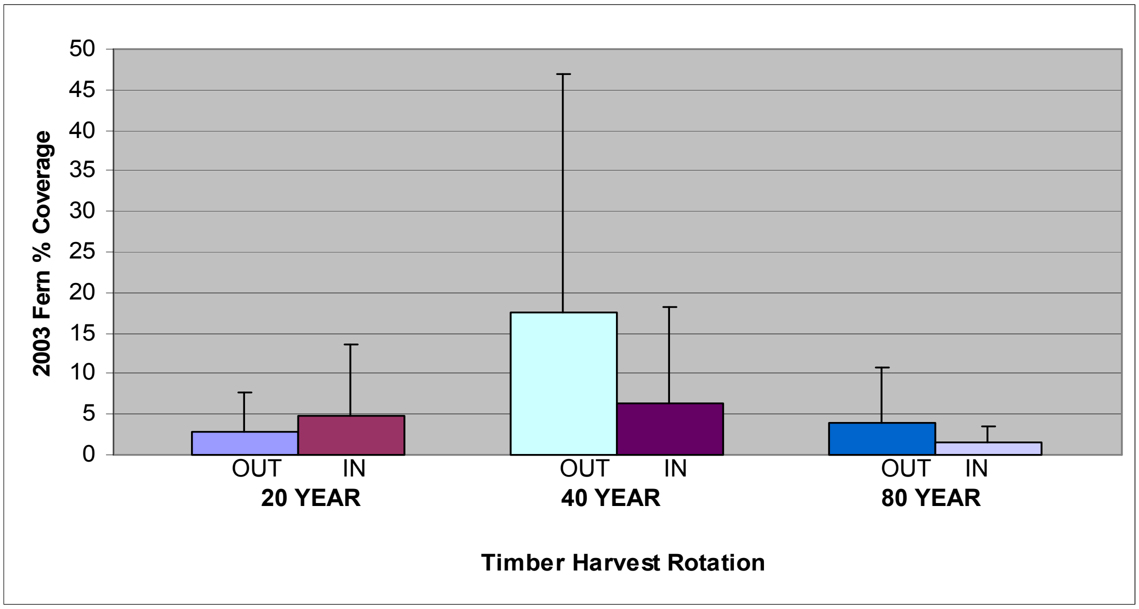

Figure 3.3. Percentage coverage of ferns inside (IN) compared to outside (OUT) deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

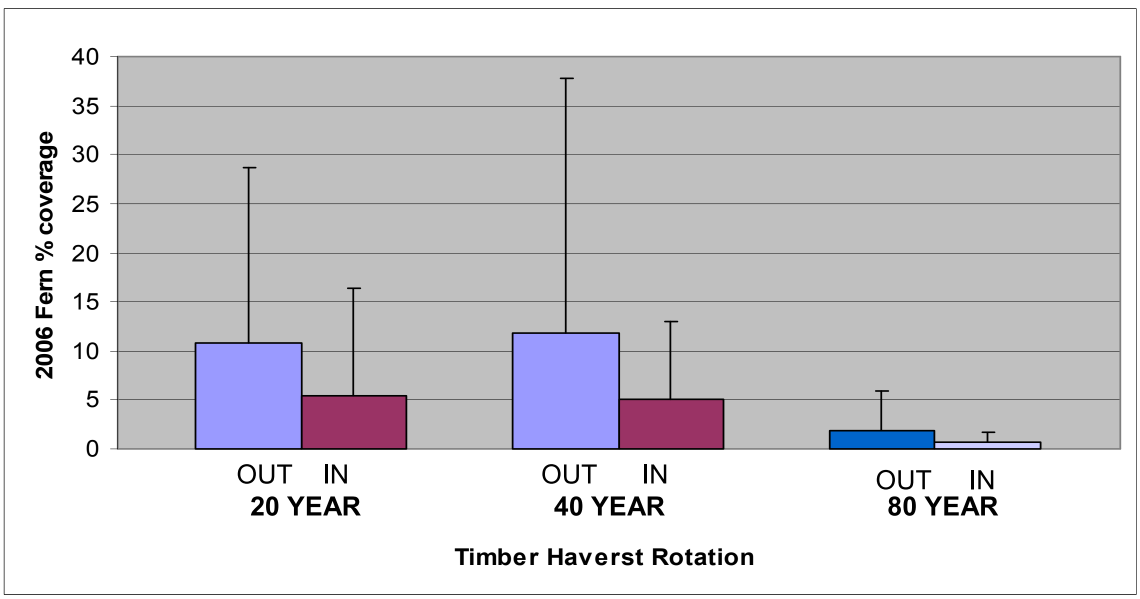

Figure 3.4. Percentage coverage of ferns inside (IN) compared to outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest five years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

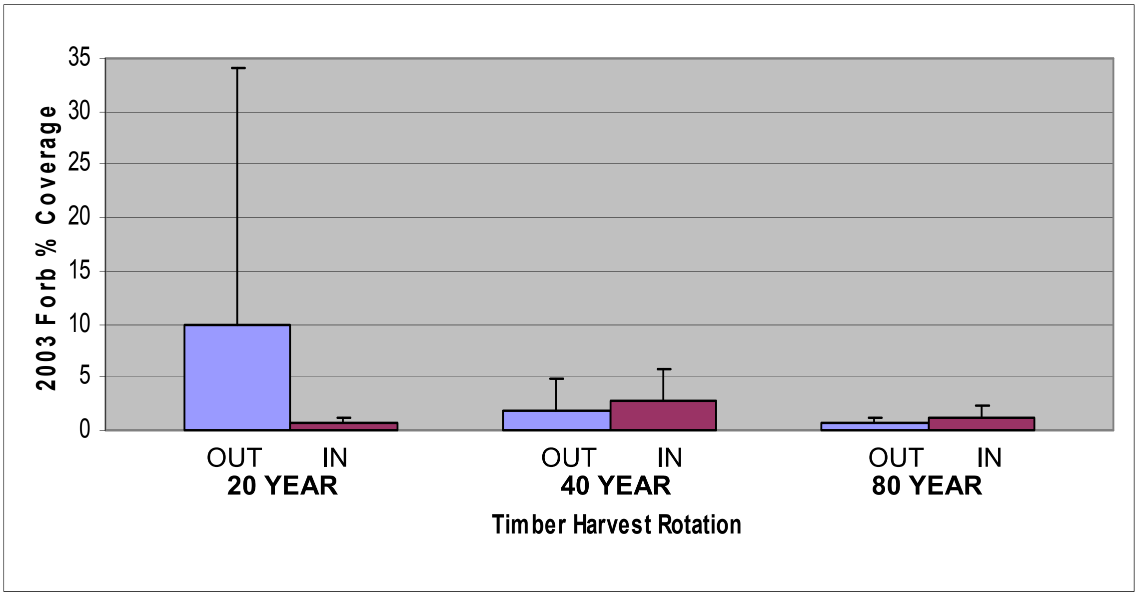

Figure 3.5. Percentage coverage of forbs inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

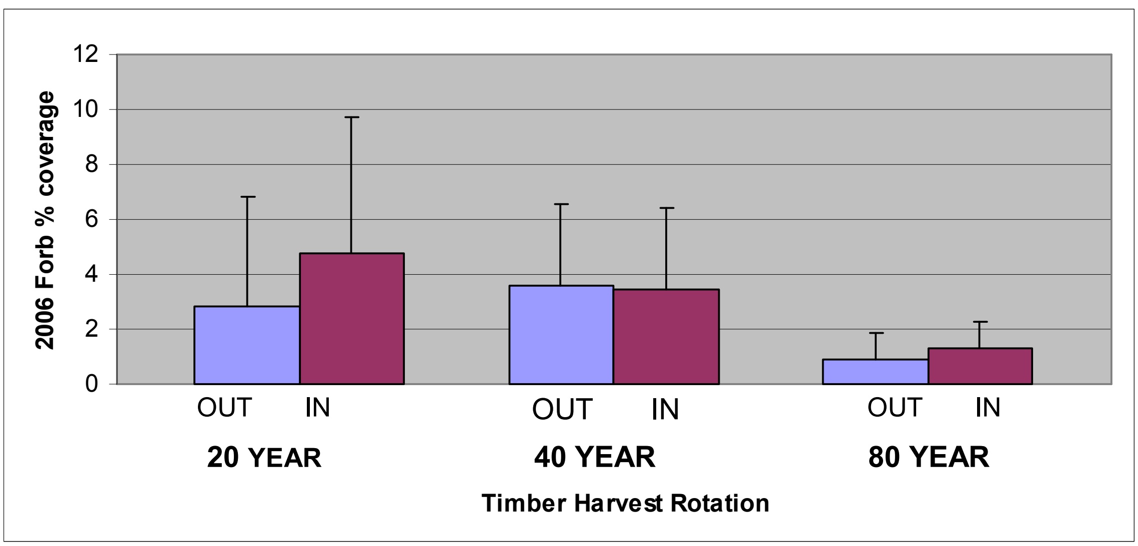

Figure 3.6. Percentage coverage of forbs inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest five years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

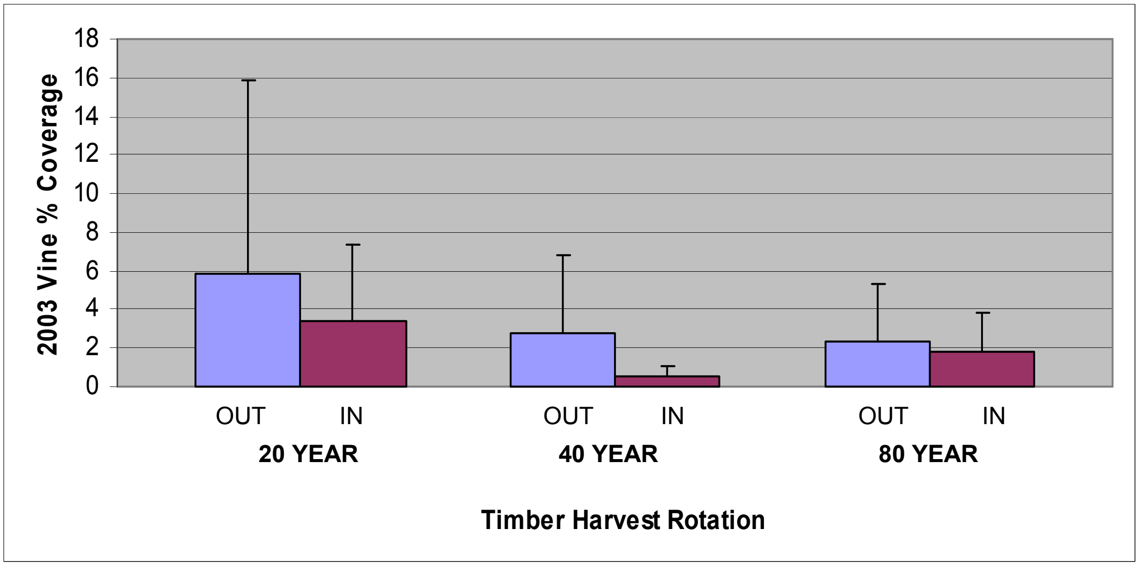

Figure 3.7. Percentage coverage of vines inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction within three timber harvest rotation treatments: 20, 40, and 80 year

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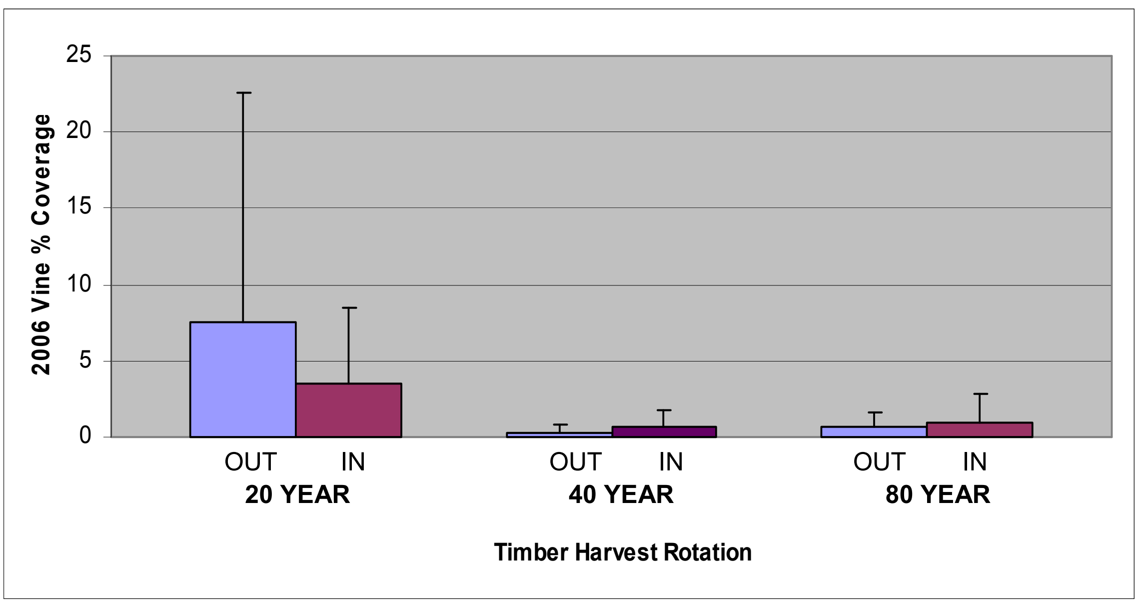

Figure 3.8. Percentage coverage of forbs inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest five years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

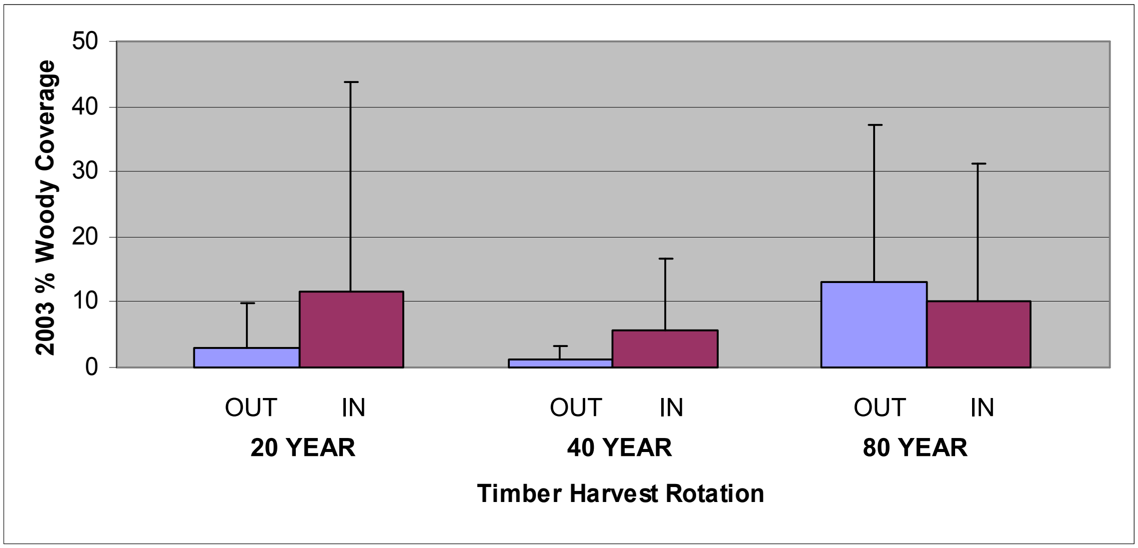

Figure 3.9. Percentage coverage of forbs inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

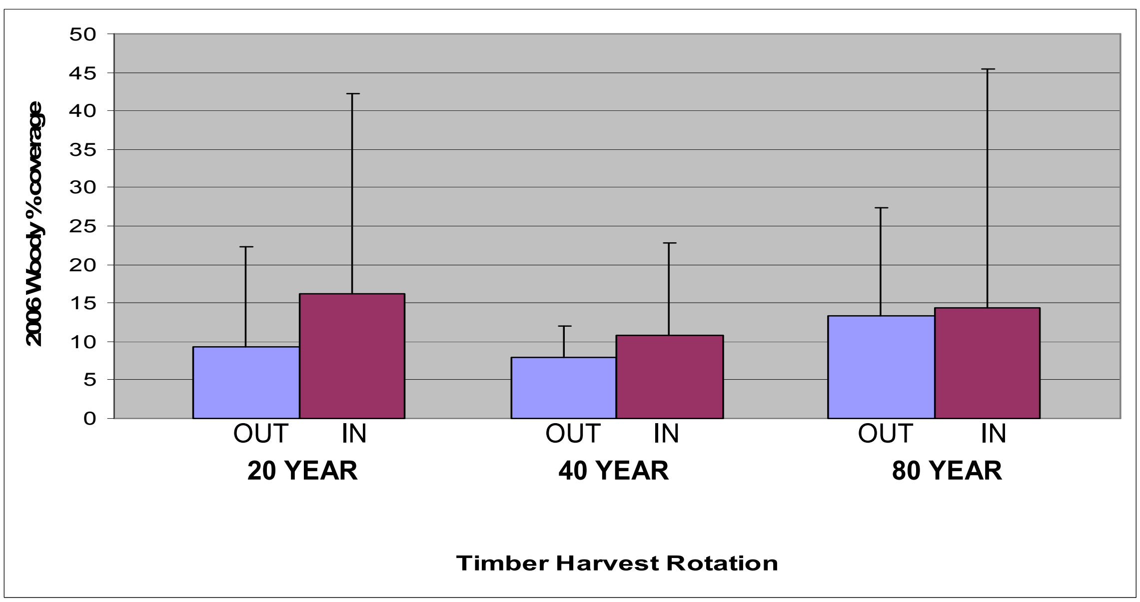

Figure 3.10. Percentage coverage of forbs inside (IN) and outside (OUT) deer exclosures MeadWestvaco Wildlife and Ecosystem Research Forest two years after construction within three timber harvest rotation treatments: 20, 40, and 80 year.

Table 3.7. Vegetation group average % coverage on the MeadWestvaco Wildlife and Ecosystem Research Forest across three timber harvest rotations: 20 year, 40 year, and 80 year. ¥

		20		40		80	
		Mean	std	mean	std	Mean	std
2001	Fern	12.29**a**	19.13	12.22**a**	24.63	2.45**b**	6.96
	Forb	1.1	3.62	3.91	12.24	2.34	11.27
	Grass	2.33	6.62	0.91	2.65	0.064	0.44
	Vine	4.78	13.48	3.5	11.87	3.72	10.08
	Woody	1.13	3.97	2.83	12.41	2.6	12.41
2005	Fern	10	17.46	7	12.98	7.27	13.13
	Forb	5.52	14.65	4.57	7.38	3.95	5.64
	Grass	1.69	6.7	0.82	3.27	0.32	1.08
	Vine	3.98	12.55	3.06	8.96	4.35	8.2
	Woody	5.25	12.89	7.31	14.74	4.07	4.41
Total	Fern	11.15**a**	18.25	9.61**a**	19.75	4.83**b**	10.7
	Forb	3.3	10.85	4.24	10.06	3.14	8.93
	Grass	0.86**a**	2.96	0.86**a**	2.96	0.19**b**	0.83
	Vine	4.38	12.96	3.28	10.46	4.04	9.15
	Woody	3.19	9.71	5.07	13.74	3.33	9.33

¥ averages with different subtended letters in row are significantly different at α=0.05 level.

Table 3.8. Vegetation group average % coverage on the MeadWestvaco Wildlife and Ecosystem Research Forest between two years and three timber harvest intensity rotations: 20, 40, and 80 years. ¥

Treatment	Vegetation Group	2001 mean	2001 std	2005 mean	2005 Std
20 year	fern	12.29	19.13	10.04	17.46
	forb	1.07	3.62	5.52	14.65
	grass	2.33	6.62	1.69	6.7
	vine	4.78	13.48	3.98	12.55
	wood	1.13	7.45	5.25	12.9
40 year	fern	12.22**a**	24.63	7**b**	12.98
	forb	3.91	12.24	4.57	7.38
	grass	0.91	2.65	0.82	3.27
	vine	3.5	11.87	3.06	8.96
	wood	2.83	12.41	7.31	14.74
80 year	fern	2.45**a**	6.96	7.27**b**	13.13
	forb	2.34	11.27	3.95	5.64
	grass	0.064	0.44	0.32	1.08
	vine	3.72	10.08	4.35	8.2
	wood	2.6	12.41	4.07	4.41
Total	fern	8.91	18.84	8.07	14.6
	forb	2.45**a**	9.87	4.67**b**	9.92
	grass	1.09	4.16	0.94	4.33
	vine	3.99	11.79	3.8	10
	wood	2.2**a**	10.39	5.55**b**	11.57

¥ averages subtended by different letters are significantly different at $\alpha=0.05$ level.

Conclusions

There is lack of strong evidence from our results to support that deer herbivory negatively impacted the forest plant communities on the MWERF. First, we would expect the characteristics of the 20 YT plant communities to resemble that of a forest under lower browse pressure, the characteristic of the 40 YT to resemble that of a forest under moderate browse pressure, while expecting the 80 YT to resemble a forest under higher browse pressure. Our results did not demonstrate any clear patterns of herbivory impacts across treatments. For example, the only significant results were for seedling H', and sapling J' for the two sampling years combined. However, for seedlings, the total relative abundance for each browse sensitive species, or for non-preferred species that historically dominate in areas under high browse pressure, did not show a pattern of decrease or increase across treatments. Also, J' for sapling evenness is less reliable because the sample size decreased due to the number of plots with zero, one or two species, which made it impossible to calculate J'. The percentage coverage also showed no usual pattern changes associated with past herbivory studies. In fact, fern coverage and grass coverage were the lowest in the 80 YT, the area expected to have the highest coverage of these two non-preferred browse groups. The three clear-cut harvest intensities of 20, 40, and 80 year rotations are long term management goals of the forest which were intended to alter the RDD by changing the carry capacity. Five years into the implementation of the plan is not enough time for the practices to influence the vegetation to a magnitude that would be necessary to alter the carrying capacity. Rather, 20 years into the study would be the earliest appropriate time to evaluate the effects of herbivory given the long-term nature of the treatments because of the study's timeline.

Also previous studies monitoring changes to mature forests usually span over several decades (Hough 1965, Tremblay et al. 2005, Cornett et al. 2000, Jones et al. 1997, Van Deelen et al. 1996, Webster et al. 2005, Wiegmann and Waller 2006). The MWERF property shared a similar historic deer density pattern, thus five years into the treatment may not have been sufficient time for the vegetation to recover from the browsing pressure.

Because this long-term research plan was intended to first collect baseline data, comparing differences in vegetation between 2001 and 2005 may be more helpful than making comparisons across treatments. In fact, there were more significant differences in vegetation between the two years than between the treatments. Specifically, the seedling, sapling, and understory indices that were significantly different were all higher for 2005 than 2001, which may suggest a slight recovery from the initial claim that the forest characteristics resembled an area under high browsing pressure. However, the total relative abundance of the most common browse preferred and non-preferred seedling species do not show a strong pattern of change. *A. saccharum*, a preferred speices, decreased in 2005, while *Smilax sp*. increased along with *F. grandifolia* and *P. serotina*. *A. pensylvanicum* and *A. rubrum*, two species Collins (2004) found to increase in the presence of high browse pressure, did not change between years. The increase in understory S and H' is more likely due to more precise plant identification than any environmental factor. From 2001 to 2005 fern coverage significantly decreased in the 40 YT, increased in the 80 YT, but did not change when grouping the treatments together. Forb coverage and woody coverage both increased in year 2005, but the averages were low while the deviations were high. Even with evidence that the vegetation on the

MWERF may have shown signs of slight recovery, data accumulated over a longer time span will be needed to support any strong conclusion of recovery from herbivory.

The deer exclosures are more concrete treatment factors; therefore, evaluating the differences in plant communities inside and outside these should be a better direct indicator of deer herbivory. The vegetation inside the exclosures would be expected to resemble the vegetation descriptions from similar exclosure studies. For example, a more diverse seedling and sapling composition would be expected in the exclosures (Tilghman 1989, Bowers 1997,), while less preferred species such as *F. grandifolia*, *B. lenta*, and *A. pensylvanicum* would be dominant outside exclosures replacing *A. saccharum*, and *A. rubrum* (Marquis 1975). Also, the height of the regenerating woody plants would be expected to be greater inside the exclosures than outside the exclosures (Alverson and Waller 1997, Healy 1997). Our results were not consistent with these herbivory studies. In fact, the sapling indices of significance compared between inside and outside the fences were actually all higher outside than inside for 2003. The two indices in 2003 that were significantly different for seedlings were not significantly different in 2006, where no indices were significantly different. Also, there were no differences in understory vegetation between inside and outside the exclosures. In addition, no differences existed for fern, forb, vine, or woody percentage coverage between inside and outside the exclosures for 2003 or 2006. Again, this is not consistent with other exclosures studies that document increased fern coverage and decreased forb coverage outside exclosures compared to inside exclosures (Tilghman 1989 and Marquis and Grisez 1978). Therefore, our results from the exclosure portion of this study also do not contribute strong evidence that deer are having negative impacts to the vegetation on the MWERF.

Although our results did not provide sufficient evidence to support our research hypothesis that deer herbivory is negatively impacting the MWERF, we should use caution before concluding that deer are not having detrimental impacts to this forest. First it is clear that the harvest intensity treatments are not an effective approach, and the design would need to include a more definitive difference in carrying capacity. However, the exclosure portion of the study should have a defined difference by completely excluding deer with a sample size of 26 and 23 for 2003 and 2006, respectively. Interestingly, the exclosures were randomly placed in all different age stands and habitat types. The placement ranged from fresh clear cuts to five year old clear cuts, to mature stands, and ranged from low elevation upland sites, to beech groves, and to high elevation hemlock stands. This random placement made the variability of importance values of specific species extremely large across sites even with a paired design. In addition, previous herbivory work on the MWERF concluded that disturbances (fires or canopy gaps) amplified the effects of herbivory, while exclosures alone were less successful in capturing herbivory impacts (Collins 2004). This study did detect significant differences in vegetation with only deer excluded, but the plots were located in closer related sites than our exclosures. However, the variability in frequency and abundance of specific species of interest was higher than the plots exposed to disturbance. The results of Tilghman's (1989) study supported similar findings. The differences between inside and outside the exclosures in mature stands were small, even at the highest deer densities, but the differences in thinned and clear cut treatments detected large significant differences between inside and outside exclosures. Placing exclosures in mature stands subjected to herbivory may not get the disturbance necessary for a sufficient vegetation response in order to measure deer impacts after only five years. Finally, this study had an overall weakness of not including a reference site that has experienced low historic deer browsing pressure. The entire property has been subjected to high browsing pressure for several years; therefore it may take a long time for the vegetation to recover sufficiently to detect difference in vegetation due to herbivory.

Management Implications

Our results did not provide clear evidence that deer herbivory was negatively impacting the MWERF. Therefore, making management recommendations for the deer herd based on our conclusions is difficult. Important to note is the suspected decrease in deer density since the initiation of the study. In 2001, managers believed the deer density to be approximately 50 deer/ km^2 (Pat Keyser, PhD, MeadWestvaco, per. comm.) Given the general carrying capacity (k) of a forested landscape in the middle Appalachians, this density is considered relatively high. Deer surveys were conducted again in the fall of 2005 by spotlight counts to be analyzed by distance sampling (Cassey and Mcardle 1999) and game camera grids with bait stations. The number of deer groups observed was too low to allow an accurate estimate of density for the entire property using the distance sampling method. The camera survey was also ineffective. The bait stations attracted blackbear *Ursus americanus*, which discouraged deer from using the areas. Out of approximately 1500 pictures taken of animals, 1200 were bear pictures. From these observations and the increased numbers of coyotes on the property, managers share a consensus the deer population has substantially declined since the onset of the study. This may explain the slight recovery of the vegetation supported by our results of comparisons between 2001 and 2005. In summary, the deer herd level on the MWERF should continue to be estimated on an annual or bi-annual schedule while exclosures and vegetation plots should be sampled every three to five years. Long-term monitoring of the deer herd and vegetation should provide a data set sufficient to relate deer density to vegetation impacts.

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CHAPTER 4

QUALITATIVE ASSESSMENT OF 20 YEAR-OLD DEER EXCLOSURES AT CALLOWAY GARDENS, GA

Introduction

Attempts to monitor the long-term effects of deer herbivory may offer better ecological insight of the impacts to plant communities than studies of lesser duration. The most common tool that managers utilize for herbivory studies has been exclosures. Unfortunately, many of the first studies involving exclosures, which would offer the longest duration of monitoring, did not meet the requirements for rigorous statistical analysis. The main reasons were due to the lack of replication at the onset, a small sample size due to damage occurring to the fences over the years, or biased placement in the forest resulting from convenient fence construction. Although data from these situations were insufficient for strict scientific conclusions, valuable descriptive information has been obtained by managers. For instance, a species' browse preference or recovery of growth have been determined; more importantly, potential indicator species have been discerned and plants threatened from over browsing have been identified.

The Preserve at Calloway Gardens, GA has been maintaining three deer exclosures since the mid 1980's. Information from these exclosures may assist the managers in their goals to operate the Preserve as a model of responsible land and wildlife stewardship. Also, this evaluation may contribute to the general, collective knowledge of deer herbivory since the forest is located in a region where related studies are lacking.

Methods

Callaway Gardens is located in a unique geographic region in southwest Georgia. At this location, the rolling hills of the piedmont meet the coastal plain with the addition of Pine Mountain, the southern most mountain in the state. The intersection of these three ecosystems contributes to the high natural biodiversity of the area. Three, 12m x 12m deer exclosures remain intact from the mid 1980's. Each fence was located in a separate habitat: a longleaf pine stand, a thinned mature loblolly pine stand, and a mature upland hardwood stand. Prescribed fires were conducting on a regular basis and the stands with the exclosures were routinely burned; the two pine stands were burned more frequent than the hardwood stand. We measured the vegetation by two different size plots in July 2006. First, we centered a 10m x 5m plot inside the exclosure and also established a equal sized plots outside the exclosures. This was to mimic the plots used for our other two herbivory studies (see Chapters 2 and 3). All seedlings were identified to species and grouped into three height classes: less than 0.3 m, 0.3 to 0.9m, and greater than 0.9m. Saplings were also identified to species and grouped into four dbh classes: 2.5 cm, 5 cm, 7.5 cm, and 10 cm. Understory plants were also identified to species and percentage coverage was estimated for each species. Secondly, we measured the vegetation in the entire exclosures and in equivalent sized plots outside the fences. Here, seedling and saplings were measured as above, but only presence of species was recorded for the understory plants. No statistical analyzes were performed on the data.

Results and Discussion

Observations of the three 20-year-old exclosures showed particular signs of deer herbivory impacts on the forest plant community at Callaway Gardens. First, the hardwood stand had dense patches of tall strawberry bush (*Euonymus americanus*), a highly preferred browse species, inside the exclosure. A survey outside the exclosure, not only the designated plot but also throughout the stand, did not observe this species with the same characteristics. Instead the plants were single stems scattered sparsely and usually bitten off just above the ground, showing severe signs of browsing. The tree species Florida maple (*Acer floridanum)* occurred within the exclosure in both the seedling and sapling stage with signs of appropriate regeneration. However, a survey outside the exclosure did not find the same regeneration vigor. Mostly small seedlings were observed less than 0.3 m tall. Since the two pine stands were similar in vegetation composition we grouped these two together for observational conclusions. The browse preferred species of green briar (*Smilax glauca*, *S. bona-nox*, and *S. smalli*) was present inside and outside the exclosure. However, the plants were larger and denser inside the exclosure with vines covering the ground and growing up into the midstory. The plants outside the exclosures were small sprouts sparsely distributed on the ground layer. Similar to the genus *Smilax*, species in the *Desmodium* genus are also considered highly preferred browse species. *D. laevigatum*, *D. marilandicum*, and *D. nuttallii* were larger and lusher inside the two exclosures then outside. Besides the above species, no clear observational conclusions were made when comparing the sapling, seedling, and understroy species inside and outside of the exclosures (Table 4.1, 4.2, and 4.3).

In recent years the managers have taken a proactive approach at reducing the deer herd on the property to approximately 20 deer/mi^2, almost half of the density before the reduction. Managers now believe highly selected browse species, practically non-existent outside the exclosures, are beginning to recover, particularly the *Desmodium spp.* All the above mentioned species may be helpful as indicator species in monitoring their plant communities in relation to the deer density. This knowledge will contribute to the overall management goals of the property to serve as a model of land and wildlife stewardship.

Table 4.1. Total abundance of tree saplings inside (Exclosure) and outside (Control) three 20-year-old deer exclosures on the Preserve at Callaway Gardens, GA.

Species	Browse* Preferred	Control	Exclosure	Grand Total
Acer floridanum	Y	-	8	8
Acer rubrum	Y	-	6	6
Cornus florida	Y	3	2	5
Liquidambar styraciflua	N	14	33	47
Liriodendron tulipifera	Y	5	-	5
Nyssa sylvatica	Y	1	1	2
Ostrya virginiana	N	-	3	3
Pinus palustris	N	10	-	10
Pinus taeda	N	7	7	14
Prunus serotina	N	2	-	2
Quercus alba	Y	-	1	1
Quercus falcata	Y	3	3	6
Quercus nigra	Y	-	6	6
Quercus stellata	Y	1	-	1
Ulmus alata	N	3	-	3
Grand Total		49	70	119

* ‘Y’ indicates species is preferred deer browse, ‘N’ indicates species is not preferred deer browse as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

Table 4.2. Total abundance of seedling tree species inside (exclosure) and outside (control) three 20-year-old deer exclosures on the Preserve at Callaway Gardens, GA.

Species	Preferred* Browse	Control	Exclosure	Grand Total
Acer floridanum	Y	28	46	74
Acer rubrum	Y	128	257	385
Carya glabra	N	22	10	32
Carya tomentosa	N	2	8	10
Cornus florida	Y	3	3	6
Crataegeus	Y	-	1	1
Diospyros virginiana	N	14	19	33
Fagus grandifolia	N	2	-	2
Ilex opacum	N	-	1	1
Liquidambar styraciflua	N	149	130	279
Liriodendron tulipifera	Y	7	2	9
Myrica cerifera	N	37	-	37
Nyssa sylvatica	Y	17	28	45
Ostraya virginiana	N	350	117	467
Oxydendrum arboreum	Y	-	2	2
Pinus taeda	N	-	1	1
Prunus serotina	N	28	52	80
Quercus alba	Y	4	10	14
Quercus falcata	Y	84	77	161
Quercus nigra	Y	80	46	126
Quercus phellos	Y	25	13	38
Quercus stellata	Y	17	40	57
Rhus copallina	N	292	17	309
Rhus glabra	N	2	2	4
Sassafras albidum	Y	9	53	62
Ulmus alata	N	-	2	2
Vaccinium elliotii	Y	-	1	1
Vaccinium stamineum	Y	1	-	1
Grand Total		1301	938	2239

'Y' indicates species is preferred deer browse, 'N' indicates species is not preferred deer browse as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

Table 4.3. Understory species presence (y) and absence (-) inside (exclosure) and outside (control) three 20-year-old deer exclosures on the Preserve at Callaway Gardens, GA.

Species	Preferred* Browse	Control	Exclosure
Andropogon virginica	N	Y	Y
Aster spp		Y	-
Schizachyrium scoparium	N	Y	Y
Callicarpa americana	N	-	Y
Chamaerista nictitans	Y	Y	Y
Chimaphila maculata	N	Y	Y
Chryopsis mariana	N	-	Y
Cirsium spp	N	-	Y
Clitoria mariana	Y	Y	Y
Desmodium laevigatum	Y	-	Y
Desmodium marilandicum	Y	Y	Y
Desmodium nuttallii	Y	-	Y
Dicanthelium spp.	N	Y	Y
Euonymus americanus	Y	Y	Y
Eupatorium capillifolium	N	Y	-
Eupatorium hyssopifolium	N	-	Y
Euphorbia pubentissima	N	Y	-
Galactia volubilis	N	Y	-
Galium pilosum	N	Y	-
Gelsemium sempervirens	Y	Y	Y
Hypericum hypericoides	N	Y	-
Lespedeza cuneata	N	Y	Y
Lespedeza hirta	Y	Y	-
Lespedeza virginica	Y	-	Y
Lonicera japonica	Y	-	Y
Mitchella repens	N	Y	-
Parthenocissus quinquefolia	N	Y	Y
Prenanthes altissima	N	-	Y
Rubus spp.	Y	Y	Y
Saccharum alopecuoides	N	Y	-
Sedge	N	Y	Y
Smilax bona-nox	Y	-	Y
Smilax glauca	Y	Y	Y
Smilax smallii	Y	-	Y
Solidago odora	N	-	Y
Solidago spp	N	Y	-
Toxicodendron radicans	N	-	Y
Vaccinium formosum	Y	-	Y
Vaccinium staminum	Y	Y	Y
Vitis rotundifolia	Y	Y	Y

*'Y' indicates preferred deer browse, 'N' indicates not preferred deer browse as cited by (Miller and Miller 1999. Forest Plants of the SE and Their Wildlife Uses The University of GA Press 454 pgs)

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APPENDICES

Appendix A
Clemson Experimental Forest Vegetation Data

This appendix contains data collected during the deer herbivory study on the Clemson Experimental Forest, SC

Table A.1. Seedling species abundance after the first (2005) and second (2006) growing seasons post clearcut harvest on mature upland hardwood stands on the Clemson Experimental Forest.

	2005			2006		
species	Unfenced	Exclosure	Total	Control	Exclosure	Total
*Acer rubrum**	4	17	21	5	16	21
Aralia spinosa	12	5	17	2	5	7
Betula nigra	-	-	-	6	4	10
Broussonetia papyrifera	-	-	-	1	1	2
Carya glabra	9	9	18	13	15	28
Carya tomentosa	2	8	10	1	2	3
Cercis canadensis	8	5	13	2	7	9
*Cornus florida**	14	6	20	6	8	14
Fagus grandifolia	1	-	1	5	-	5
Fraxinus americanus	2	-	2	1	-	1
Ilex opaca	-	1	1	-	1	1
Juniperus virginiana	-	-	-	1	-	1
Kalmia latifolia	6	-	6	4	-	4
*Ligustrum sinense**	-	1	1	-	-	-
*Liriodendron tulipifera**	414	481	895	369	389	758
Lyquidambar styraciflua	3	13	16	8	4	12
*Nyssa sylvatica**	7	13	20	15	17	32
*Oxydendrum arboretum**	15	16	31	1	-	1
Pinus taeda	5	11	16	9	8	17
Pinus virginicus	-	-	-	2	-	2
Prunus serotina	4	18	22	9	21	30
*Quercus alba**	25	21	46	40	34	74
*Quercus coccinea**	1	-	1	-	-	-
*Quercus falcata**	1	1	2	6	12	18
*Quercus marilandica**	2	3	5	-	-	-
*Quercus nigra**	-	-	-	-	1	1
*Quercus phellos**	-	-	-	1	-	1
*Quercus prinus**	-	-	-	2	-	2
*Quercus rubra**	2	7	9	5	7	12
*Quesrcus stellata**	-	1	1	1	1	2
Rhus copallina	1	-	1	8	3	11
Rhus glabra	53	19	72	35	33	68
*Rubus sp. **	281	266	547	471	535	1006
Baccharis spp.	-	-	-	-	1	1
Sassafras albidum	16	2	18	2	1	3
*Smilax sp. **	11	16	27	12	15	27
Ulmus alata	8	4	12	1	1	2
*Vaccinium arboreum**	-	1	1	1	5	6
*Vaccinium staminum**	-	-	-	14	-	14
Grand Total	907	945	1852	1059	1147	2206

*Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. An. Conf. SE Game and Fish Com 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses The University of Georgia Press 454 pgs)

Table A.2. Seedling species abundance after the first (2005) and second (2006) growing seasons post clearcut harvest on upland hardwood stands on the Clemson Experimental Forest.

	2005			2006		
species	Control	Exclosure	Total	Control	Exclosure	Total
*Acer rubrum**	2	12	14	3	14	17
*Acer saccharum**	-	-	-	1	-	1
Aralia spinosa	-	1	1	1	1	2
Betula nigra	-	-	-	1	-	1
Broussonetia papyrifera	-	-	-	1	1	2
Carya glabra	3	-	3	6	2	8
Carya illinoensis	-	2	2	-	-	-
*Cornus florida**	-	3	3	3	2	5
Fagus grandifolia	-	-	-	1	-	1
Fraxinus americana	-	-	-	4	2	6
*Liriodendron tulipifera**	10	11	21	118	96	214
Lyquidamber styraciflua	-	19	19	2	28	30
*Nyssa sylvatica**	3	12	15	10	17	27
*Oxydendron aboreum**	14	7	21	29	5	34
Pinus taeda	-	1	1	4	4	8
Platanus occidentalis	-	-	-	-	1	1
Prunus serotina	2	11	13	11	11	22
*Quercus alba**	4	4	8	9	8	17
*Quercus coccinea**	7	2	9	7	4	11
*Quercus falcata **	-	2	2	-	-	-
*Quercus rubra**	7	-	7	5	1	6
*Quercus stellata**	-	-	-	3	-	3
Rhus glabra	9	21	30	20	19	39
Sassafras albidum	-	-	-	2	-	2
Ulmus alata	-	1	1	-	-	-
Grand Total	61	109	170	241	216	457

* Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

Table A.3. Understory species frequency in upland hardwoods inside and outside deer exclosures. The data were collected the first (2005) and second (2006) growing season after clearcutting on the Clemson Experimental Forest.

	2005		2006	
Species	Control	Exclosure	Control	Exclosure
Ageratina aromatica	-	-	1	2
*Ambrosia artemisiifolia**	3	4	1	3
Andropogon virginicus	9	4	8	9
Aster dumosus	1	-	2	1
Aster pilosus	1	-	1	1
*Aureolaria virginica**	-		-	1
*Chamaecrista fasciculate**	2	2	1	1
Calystegia catesbeiana	-	-	-	1
Chrysogonum virginianicum	-	-	2	1
Cirsium horridulum	1	-	-	-
Conyza canadensis	10	10	-	-
*Clitoria mariana**	-	-	2	1
Coreopsis major	1	-	1	-
Daucus carota	-	1	-	-
Decumaria barbara	-	-	1	-
Dennstaedtia punctiloba	-	-	-	1
Dicanthelium sp.	12	12	12	11
Elephantopus tomentosus	-	1	-	1
Erechtites hieracifolia	3	2	-	-
*Euonymous americanus**		-	-	1
Eupatorium capilifolium	11	10	12	12
Eupatorium serotnum	-	1	1	-
Euphorbia pubertissima	-	-	3	1
*Fragaria virginica**	-	-	1	-
Galium pilosum	1	-	-	-
*Gelsemium sempervirens**	-	-	-	2
Gnaphalium obtusifolium	5	5	7	7
Heterotheca latifolia	-	2	-	-
Hexastylis arifolia	-	-	-	4
Helianthus strumosus	-	-	1	4
Hypericum hypericoides	5	4	6	8
Iris spp.	-	-	1	-
*Kummerowia striata**	1	-	-	-
Laportea canadensis	-	-	-	1
Lattuca spp.	-	-	-	1
Lespedeza bicolor	1	1	-	
Lespedeza cuneata	3	2	2	1
*Lespedeza intermedia**	1	-	-	-
*Lespedeza pilosa**	-	-	4	6
*Ligusturm sinense**	1	-	-	-
Lobelia puberula	-	3	1	2
*Lonicera japonica**	-	2	-	1
*Lysimachia quadrifolia**	-	-	1	-

Table A.3. Understory species frequency in upland hardwoods inside and outside deer exclosures. The data were collected the first (2005) and second (2006) growing season after clearcutting on the Clemson Experimental Forest. (Continued)

	2005		2006	
Species	Control	Exclosure	Control	Exclosure
Mimosa microphylla	-	1	-	-
Packera amonyma	-	-	-	1
Parthenocissus quinquefolia	1	3	1	3
Passiflora incarnata	2	3	1	2
*Phytolacca americana**	6	9	6	7
Poacea	1	1	1	-
Potentilla canadensis	2	4	4	4
Polystichum acrostichoides	-	-	1	-
*Polygonatum biflorum**	-	-	1	-
Prenanthes altissima	-	-	1	-
Pycnanthemum pycnanthemoides	2	1	-	-
Pyrrhopapppus carolinianus	-	1	-	-
*Rubus sp.**	10	12	12	12
Sabatia angularis	1	1	-	1
Sedge	6	6	5	2
Silphium asteriscus	4	3	-	-
Smilax sp.	4	6	10	8
Solanum carolinense	1	3	2	4
Solidago arguta	2	3	-	-
Solidago spp.	5	5	6	6
Sorghum halepense	1	-	-	-
*Toxicodedron radicans**	2	-	3	2
*Vaccinium arboretum**	-	1	-	-
*Vaccinium vaccilans**	4	2	2	1
Verbascum thapsus	1	-	-	y
*Vitis rotundifolia**	12	12	9	12

*Indicates browse species preferred by deer as cited by (Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses The University of GeorgiaPress 454 pgs , and John Thrift 2006, pers. observation)

Table A.4. Abundance of seedling species from two levels of deer herbivory in mature upland hardwood stands on the Clemson Experimental Forest. Keowee=High deer density and Fant's Grove=Moderate deer density.

	2005			2006		
Species	Keowee	Fant's Grove	Total	Keowee	Fant's Grove	Total
*Acer leucoderme**	8	-	8	6	-	6
*Acer rubrum**	11	34	45	15	32	47
*Acer saacharum**	-	-	-	4	3	7
Aescula parviflora	-	-	-	1	-	1
Asimina triloba	2	13	15	-	11	11
Carpinus caroliniana	-	2	2	-	5	5
Calycanthus floridus	-	1	1	1	2	3
Carya glabra	24	36	60	28	30	58
Carya tomentosa	30	49	79	32	48	80
Cercis canadensis	3	1	4	3	-	3
Celtis spp.	-	1	1	-	-	-
*Cornus florida**	15	-	15	17	-	17
*Crataegus**	3	2	5	4	7	11
Fagus grandifolia	2	1	3	2	2	4
Fraxinus americana	2	8	10	-	8	8
Ilex opaca	3	4	7	2	6	8
Juniperus virginiana	-	1	1	-	-	-
Kalmia latifolia	1	-	1	1	-	1
Liquidambar styraciflua	-	8	8	-	13	13
*Liriodendron tulipifera**	44	62	106	6	97	103
Morus rubra	-	4	4	-	2	2
*Nyssa sylvatica**	22	26	48	38	14	52
*Oxydendron arboreum**	1	2	3	-	5	5
Pinus echinada	1	1	2	1	1	2
Pinus strobus	1	-	1	1	-	1
Pinus taeda	2	-	2	4	-	4
Prunus serotina	19	36	55	22	54	76
*Quercus alba**	76	271	347	76	247	323
*Quercus falcate**	55	79	134	79	88	167
*Quercus malandrica**	5	3	8	-	3	3
*Quercus phellos**	3	34	37	6	17	23
*Quercus rubra**	67	41	108	64	34	98
Rhus glabra	-	1	1	-	1	1
*Sasafras albidum**	3	5	8	3	3	6
Aescula parviflora	1	5	6	-	7	7
*Vaccinium stamineum**	2	6	8	8	6	14
*Viburnum rufidulum**	6	-	6	1	-	1
Grand Total	412	737	1149	425	746	1171

* Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

Table A.5. Abundance of sapling species from two levels of deer herbivory in mature upland hardwood stands on the Clemson Experimental Forest. Keowee=High deer density and Fant's Grove=Moderate deer density.

	2005			2006		
Species	Keowee	Fant's Grove	Total	Keowee	Fant's Grove	Total
*Acer leucoderme**	10	-	10	4	-	4
*Acer rubrum**	-	14	14	-	9	9
Aralia spinosa	-	2	2	-	2	2
Asimina triloba	-	12	12	-	10	10
Caprinus carolinensis	-	16	16	-	21	21
Calycanthus floridus	-	-	-	-	1	1
Carya glabra	12	16	28	23	28	51
Carya ovata	1	-	1	-	-	-
Carya tomentosa	6	12	18	3	8	11
Cercis canadensis	-	-	-	1	-	1
*Cornus florida**	25	24	49	29	20	49
*Crataegus**	4	1	5	-	1	1
Fagus grandifolia	-	16	16	-	14	14
Fraxinus americana	-	1	1	-	1	1
Ilex opaca	5	-	5	1	-	1
Juniperus virginiana	-	-	-	1	-	1
Liquidambar styraciflua	4	12	16	5	17	22
*Liriodendron tulipifera**	7	3	10	8	2	10
*Nyssa sylvatica**	23	9	32	26	10	36
*Oxydendrum arboretum**		23	35	13	24	37
Pinus echinata	2	-	2	-	-	-
Pinus strobus	2	-	2	1	-	1
Pinus taeda	8	6	14	13	3	16
Prunus serotina	7	10	17	6	11	17
*Quercus alba**	5	17	22	12	21	33
*Quercus falcate**	4	9	13	-	10	10
Quercus marilandica	1	2	3	2	1	3
*Quercus phellos**	-	2	2	-	1	1
*Quercus rubra**	7	2	9	7	8	15
*Quercus stellata**	5	-	5	2	-	2
*Tilia americana**	-	2	2	-	-	-
Ulmus alata	-	-	-	-	4	4
*Vaccinium arboreum**	-	4	4	-	3	3
Vccinium stamineum	-	1	1	4	2	6
*Viburnum prunifolium**	-	-	-	1	-	1
*Viburnum rufidulum**	2	1	3	3	5	8
Grand Total	152	217	369	165	237	402

* Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses The University of Georgia Press 454 pgs)

Table A.6. Understory plant species frequency in mature hardwood stands on the Clemson Experimental Forest across to levels of deer herbivory. Keowee=High deer density and Fant’s Grove=Moderate deer denity

	2005		2006	
Species	Keowee	Fant's Grove	Keowee	Fant's Grove
Arisaema triphyllum	-	-	-	1
Aristolochia macrophylla	-	-	2	-
Aristolochia serpentaria	6	3	5	8
Arundanaria gigantea	2	-	1	-
Asplenium platyneuron	1	-	1	-
Aster patens	2	1	1	-
Athyrium filix-femina	1	-	-	-
*Aureolaria virginica**	-	-	-	1
Botrychium virginianum	1	2	-	1
Chimaphila maculata	14	9	15	9
Chrysogonum virginianicum	1	-	1	1
Cimicifuga racemosa	1	-	1	-
Clitoria mariana	-	-	1	-
Coreopsis major	1	-	2	-
Decumaria barbara	1	2	-	1
*Desmodium laevigatum**	5	5	6	4
Dicanthelium spp.	5	7	6	6
Diodia virginiana	-	2	-	1
Duchesnea indica	-	1	-	-
Erechtites hieracifolia	1	-	1	-
*Euonymus americanus**	4	13	4	13
Eupatorium capillifolium	-	1	-	1
Euphorbia pubentissima	4	-	3	-
Galium aparine	2	3	1	4
Galium hispidulum	-	-	1	-
*Gelsemium sempervirens**	-	1	-	1
*Geranium maculatum**	-	-	-	-
Goodyera pubescens	1	2	-	3
Helianthus strumosus	-	-	-	1
Hexastylis arifolia	8	14	7	13
Hypericum hypericoides	2	1	1	1
*Lespedeza repens**	1	-	1	-
*Lonicera japonica**	-	1	-	3
*Lysimachia quadrifolia**	-	-	-	1
Mitchella repens	-	1	-	1
Packera amonyma	-	-	1	-
Parthenensis quienquefolia	-	3	7	10
*Polyganatum biflorum**	-	-	2	2
Polystichum acrostichoides	1	2	2	3

Table A.6. Understory plant species frequency in mature hardwood stands on the Clemson Experimental Forest across to levels of deer herbivory. Keowee=High deer density and Fant’s Grove=Moderate deer denity. (Continued)

	2005		2006	
Species	Keowee	Fant's Grove	Keowee	Fant's Grove
Prenanthes altissima	-	-	-	2
*Prosartes lanuginosa**	-	-	3	-
*Rubus spp. **	-	2	-	-
*Sanicula canadensis**	1	-	2	-
Sanicula smalli	1	-	1	-
Scutellaria elliptica	-	2	1	3
sedge	11	13	14	13
Smilax spp.*	23	27	19	21
Smilacina racemosa	3	-	1	-
Solanum canadensis	1	-	-	-
Solidago spp.	2	1	1	1
*Toxicodendron radicans**	-	1	1	2
*Trillium spp. **	-	-	3	-
Uniola sessiliflora	-	-	1	1
*Vaccinium vacillans**	12	4	13	7
Viola spp.	2	1	1	1
*Vitis rotundifolia**	19	23	22	24
Grand Total	140	148	156	165

* Indicates browse species preferred by deer as cited by (Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

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Appendix-B
Meadwestvaco Wildlife and Ecosystem Research Forest
Vegetation Data (MWERF), WV

This appendix contains data collected during the first five years of the deer herbivory study conducted on the MWERF, WV

Table B.1. Total sapling species abundance inside (IN) and outside (OUT) deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction.

	2003 N=26			2006 N=23			Grand Total
species	IN	OUT	Total	IN	OUT	Total	
Acer pensylvanicum	34	20	54	-	11	11	65
*Acer rubrum**	21	16	37	15	5	20	57
*Acer saccharum**	52	63	115	33	49	82	197
Betula alleghaniensis	5	5	10	1	1	2	12
Betula lenta	37	135	172	40	16	56	228
Carpinus caroliniana	1	12	13	4	10	14	27
Carya spp.	2	-	2	1	-	1	3
Fagus grandifolia	50	136	186	73	111	184	370
Fraxinus americana	1	1	2	-	-	-	2
*Hamamelis virginiana**	11	3	14	7	3	10	24
*Lindera benzoin**	1	-	1	-	-	-	1
*Liriodendron tulipifera**	33	52	85	-	5	5	90
Magnolia acuminata	-	2	2	2	2	4	6
Magnolia fraseri	1	-	1	5	-	5	6
Nemopanthus mucronata	1	-	1	-	-	-	1
*Nyssa sylvatica**	2	11	13	19	2	21	34
*Oxydendrum arboreum**	-	6	6	4	3	7	13
Prunus pensylvanica	33	42	75	-	-	-	75
Prunus serotina	1	4	5	3	6	9	14
*Quercus alba**	-	-	-	-	2	2	2
*Quercus coccinea**	1	-	1	-	-	-	1
*Quercus rubra**	1	6	7	4	7	11	18
Rhododendron maximum	1	1	2	-	-	-	2
Rhus glabra	3	5	8	1	-	1	9
Robinia pseudoacacia	-	4	4	-	-	-	4
Tilia americana	5	-	5	-	4	4	9
*Tsuga canadensis**	6	6	12	28	14	42	54
Grand Total	303	530	833	240	251	491	1335

* Indicates browse species preferred by deer as cited by ((Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

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Table B.2. Total seedling abundance inside (IN) and outside (OUT) deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction.

	2003 N=26			2006 N=23			Grand Total
Species	IN	OUT	Total	IN	OUT	Total	
Acer pensylvanicum	16	25	41	50	55	105	146
*Acer rubrum**	201	124	325	159	160	319	644
*Acer saccharum**	431	404	835	228	166	394	1229
Betula alleghaniensis	11	55	66	1	11	12	78
Betula lenta	79	49	128	67	40	107	235
Carpinus caroliniana	-	-	-	9	3	12	12
Carya spp.	3	-	3	-	1	1	4
Celtis laevigata	-	-	-	-	2	2	2
Fagus grandifolia	40	66	106	41	57	98	204
Fraxinus americana	2	5	7	3	2	5	12
*Hamamelis virginiana**	15	3	18	32	7	39	57
*Lindera benzoin**	4	6	10	2	4	6	16
*Liriodendron tulipifera**	71	83	154	34	28	62	216
Magnolia acuminata	-	2	2	11	1	12	14
Magnolia fraseri	4	13	17	16	12	28	45
Nemopanthus mucronatus	6	6	12	3	-	3	15
*Nyssa sylvatica**	4	1	5	8	-	8	13
*Oxydendron arboreum**	1	1	2	1	-	1	3
Prunus pensylvanicum	20	9	29	-	-	-	29
Prunus serotina	57	23	80	78	28	106	186
*Quercus alba**	2	3	5	4	-	4	9
*Quercus coccinea**	3	4	7	-	-	-	7
*Quercus prinus**	-	9	9	3	17	20	29
*Quercus rubra**	12	13	25	28	23	51	76
Rhododendron maximum	1	2	3	4	12	16	19
Robinia pseudoacacia	-	-	-	-	3	3	3
*Rubus spp. **	112	1	113	55	21	76	189
Sassafras albidum	2	5	7	4	7	11	18
*Smilax spp. **	55	100	155	99	101	200	355
*Tsuga canadensis**	-	1	1	1	1	2	3
*Vaccinium vaccilans**	1	-	1	-	2	2	3
*Vitis spp. **	4	1	5	-	-	-	5
Grand Total	1157	1014	2171	941	764	1705	3876

* Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Com. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs)

Table B.3. Understory species frequency inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction.

	2003 N=26		2006 N=23	
Species	IN	OUT	IN	OUT
Actaea pachypoda	1	-	-	-
*Amphicarpaea bracteata**	1	1	1	-
Aralia nudicaulis	2	1	1	1
Arisaema triphyllum	-	-	4	3
Asplenium platyneuron	2	-	-	-
Athyrium filix-femina	-	-	-	1
Boehmeria cylindrica	1	1	-	-
Danthonia spp.	1	1	-	-
Dennstaedtia punctilobula	8	10	9	6
Dicanthelium spp.	2	3	2	1
*Dioscorea villosa**	3	3	-	-
Enemion biternatum	-	-	2	-
Eurybia divaricata	-	-	4	1
Galium aparine	-	-	1	-
Galium spp.	3	-	-	-
Gentiana clausa	-	-	8	5
*Geranium maculatum**	3	-	1	-
Gnaphalium spp.	1	-	-	-
Iris spp.	7	5	-	-
Laportea canadensis	-	-	2	2
*Lilium canadense**	-	-	1	2
*Liparis lilifolia**	-	-	1	-
*Lysimachia quadrifolia**	-	1	-	1
*Medeola virginiana**	3	3	1	5
Mitchella repens	4	2	4	4
Monotropa uniflora	1	-	-	-
Osmorhiza claytonia	-	-	3	4
Oxalis montana	2	1	-	-
Parthenocissus quinquefolia	2	3	3	1
Phegopteris hexagonoptera	1	3	-	-
*Phytolacca americana**	1	1	-	1
Poaceae spp.	2	2	-	-
Podophyllum peltatum	-	-	1	1
*Polygonatum biflorum**	-	-	2	1
Polystichum acrostichoides	6	6	9	8
Potentilla norvegica	2	-	2	-
Prenanthes altissima	1	-	-	-
Prenanthes sempervens	-	-	2	1

Table B.3 Understory species frequency inside and outside deer exclosures on the MeadWestvaco Wildlife and Ecosystem Research Forest two years (2003) and five years (2006) after construction. (Continued)

	2003 N=26		2006 N=23	
Species	IN	OUT	IN	OUT
*Prosartes lanuginose**	8	2	6	2
*Rubus spp.**	9	11	7	6
*Sanicula smallii**	-	-	-	1
Sedge	-	-	3	2
*Smilax spp.**	18	18	16	14
Solidago curtsii	7	5	4	4
Thelypteris noveboracensis	11	14	8	14
Thelypteris phegopteris	5	8	-	-
Tiarella cordifolia	-	1	1	1
*Tipularia discolor**	-	-	1	1
*Trillium spp.**	7	7	5	5
Urtica dioica	1	-	-	-
*Uvularia spp.**	1	-	-	-
*Vaccinium spp.**	2	2	3	3
*Viburnum acerifolium**	2	3	-	-
Viola spp.	16	18	12	16
*Vitis aestivalis**	-	-	-	1
*Vitis spp.**	1	-	-	-

*Indicates browse species preferred by deer as cited by (Harlow and Hooper 1971. Proc. Annu. Conf. SE Game and Fish Comm. 25:18-46, Miller and Miller 1999. Forest Plants of the Southeast and Their Wildlife Uses. The University of Georgia Press 454 pgs.)