Movements and ecology of a high-density deer herd

on a Georgia state park

by

Charles Henry Killmaster

(Under the Direction of Karl V. Miller and Robert J. Warren)

Abstract

I evaluated vegetation and white-tailed deer (*Odocoileus virginianus*) condition on Red Top Mountain State Park, Georgia one year before and after a herd reduction. After removing 172 deer from the park in 2004, the number of plant species observed increased 31.3%. In 2005, 65 deer were removed and compared to 2004; reproductive rates and body weights of adult females and fawns increased significantly. Thus, 1 year after an 80% reduction in deer density, the initial signs of plant community recovery and deer herd improvement were evident. I also radio-tracked 34 deer on the park to determine movements and responses to human activity. Mean summer home range sizes were small (36.5 [$\pm$ 4.5] and 22.5 [$\pm$1.7] ha for males and females, respectively). A sub-sample of 8 females that was monitored during 24-hour periods revealed that deer on this park were less active and were located farther from roads and other areas of human activity during daylight hours when traffic volume peaked.

Key words: browsing, carrying capacity, herd reduction, overabundance, understory plants, white-tailed deer, diel, deer movements, *Odocoileus virginianus*, state park, vehicular traffic

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Chapter 1

Introduction and literature review

Deer population trends and effects of overabundance

Before European settlement of North America, white-tailed deer (*Odocoileus virginianus*) populations were controlled by large predators and hunting by Native Americans (McCabe and McCabe 1984). During the exploitation era of the 1700's and 1800's, unrestricted commercial and subsistence hunting caused deer populations to plummet. By the mid to late 1900's, stricter hunting regulations, restocking efforts, development of wildlife refuges, and the ability of deer to adapt to anthropogenic habitat disturbances allowed populations to recover. Today, in rural areas of their range, regulated hunting combined with natural predation can maintain deer numbers within acceptable biological, ecological, and social limits. However, deer management in suburban and urban areas and in parks is quite different. In these areas, deer/vehicle collisions often have replaced regulated hunting and predation as the primary source of deer mortality. When extreme overabundance occurs, disease and starvation leads to the death of individual deer, but only after the ability of the habitat to support deer is drastically reduced (Warren 1991). With continued reproduction and low mortality rates, chronic overabundance will push deer populations beyond acceptable biological, ecological, and/or social carrying capacity (Warren 1991, 1997).

Chronically overabundant deer populations often occur on many suburban properties and state and national parks (Warren 1991). Islands of deer habitat within an otherwise developed landscape allow deer populations to be sustained (Christie et al. 1987, Kilpatrick and Spohr 2000). Although the lack or limitation of deer population control in parks is similar to suburban areas, habitat quality and physiological condition of deer may differ greatly. Deer habitat in suburban areas is typically characterized by fertilized lawns, gardens, and cultivated plants (Swihart et al. 1995, Warren 1997). The nutritional value of this vegetation may be high and even exceed that of a natural ecosystem. In contrast, parks often attempt to promote ecosystems dominated by native plant species. Although deer densities and negative interactions, such as damage to plants and deer/vehicle collisions, may be quite similar in both areas, they may have distinct differences in ecological carrying capacity (Conover 1997). Deer damage to cultivated plants usually results in disgruntled homeowners, whereas heavy browsing of natural vegetation might cause a decline in plant species diversity and abundance (Russell et al. 2001). With excessive browsing, preferred plants within reach of deer become replaced by those of lower preference and/or nutritional value. Tree regeneration can also be hindered leading to alterations in tree species composition and forest structure (Tilghman 1989, Stromayer and Warren 1997). Over-browsing also has negative effects on intermediate canopy nesting songbirds and small mammal populations with narrow habitat requirements (deCalesta 1994, Horsley et al. 2003).

As deer populations approach or exceed biological carrying capacity, subcutaneous fat levels decrease followed by decreased amounts of visceral and bone marrow fat (Riney 1955). Body weights are negatively affected, and suppressed immune systems predispose individuals to increased parasite loads (Davidson et al. 1982). Eventually, a female’s reproductive performance suffers but only after a moderate to severe decline in physiological condition (Verme 1965). Because plants in suburban habitats are especially nutritious, individual deer might not express adverse physiological changes in response to overabundance because social thresholds are exceeded before biological carrying capacity is reached (Warren 1991).

Negative interactions between deer and humans in suburban areas are usually related to damage to landscape plants and deer-vehicle collisions. Deer-vehicle collisions can cause property damage and injury to deer as well as humans (Conover 1997). Damage to vegetative communities and declines in non-game animal species contradict the goals of many parks and park visitors (Warren 1991, Hammitt et al. 1993). Wildlife managers, park managers, local officials, and the general public may seek methods of population control when deer become a social or ecological nuisance (Porter et al. 1994).

Hunting is an effective tool for controlling deer overabundance. However, the constraints of urban and suburban development may limit or eliminate the use of firearms. Although archery equipment and low range firearms, such as shotguns and muzzleloaders, have been used effectively in many areas, their use in other areas may not be feasible or socially acceptable (Warren 2001). Sharpshooting by professionals has been an effective option for many areas where regulated hunting cannot be used. Sharpshooters are professionally trained and more likely to be granted waivers where discharge of firearms is prohibited. Human safety concerns may also be reduced when shooting is conducted by professionals.

Social acceptance of lethal deer removal is variable and dependent on location (Stradtmann et al. 1995). Urban/suburban area residents usually prefer non-lethal methods to reduce deer density, but may accept lethal control after having negative experiences (Warren 2001). Public sentiment towards deer management on parks and wildlife refuges may be different from that of urban and suburban areas. Park visitors may not perceive damage to ecosystems as readily as damage to personal landscaping. Justification for lethal removal based on ecological and biological parameters may be more difficult to deliver to the general public.

Deer movements and behavior

Deer movements, activity patterns, and habitat use are molded by external pressures such as weather, season, predation, and climate (Beier and McCullough 1990). Foraging, social interactions, travel, and rest are normal activities that contribute to survival and reproduction. Balancing energy uptake and expenditure while minimizing predation risk is essential for survival and successful reproduction. The amount of time allocated for each activity is dependent on the stress that a given external pressure imposes. If habitat quality is limiting, deer spend more time foraging and resting to digest nutritionally deficient vegetation.

Activity patterns of deer in rural areas have been studied extensively (Marchinton and Hirth 1984). However, only limited research in developed landscapes has been conducted (Swihart et al. 1995). The movements and activity patterns of rural deer differ from those of their urban counterparts (Beier and McCullough 1990, Swihart et al. 1995). Rural deer are primarily crepuscular (Kammermeyer and Marchinton 1977). However, as wooded habitat is fragmented into patches by development, deer seek refuge in these areas during periods of high human activity (Vogel 1989, Storm et al. 1995). When human activity decreases, deer utilize areas closer to houses, resulting in primarily nocturnal behavior (Kilpatrick and Spohr 2000). Density of housing also influences deer use of habitat fragments (Vogel 1989). In areas of high housing density, deer are dependent on surrounding undeveloped areas, such as parks or wildlife reserves for inactive periods, refuge, and fawning sites (Swihart et al. 1995). These islands of undeveloped land allow suburban deer populations to be sustained (Christie et al. 1987, Kilpatrick and Spohr 2000). Furthermore, populations may become isolated in parks by development or other physical barriers.

Annual home ranges of deer in suburban and park habitats tend to be small compared to rural populations (Christie et al. 1987, Kilpatrick and Spohr 2000, Grund et al. 2002). However, as is the case with rural populations, habitat quality and relative deer density will affect home range size (deCalesta and Stout 1997, Henderson 2000, Kilpatrick and Spohr 2000, Etter et al. 2002). High quality forage and high deer density, typical of most suburban populations, result in decreased home range size. Additionally, the geometric complexity of the home ranges in suburban areas is higher due to fragmentation of foraging grounds and refugia (Etter et al. 2002). In residential areas deer may shift home ranges seasonally as food resources become depleted (Grund et al. 2002). Alternative food sources such as bird feeders and intentional feeding by residents, along with higher quality habitat can lead deer to establish core ranges centered around residential areas (Swihart et al. 1995). Conversely, deer in parks and wildlife refuges that do not support cultivated plants may have more abnormal activity patterns.

Human activity in developed areas affects the behavior and population structure of deer. Fallow deer (*Dama dama*) have a decreased flight response to humans in areas where the volume of human activity is high (Recarte et al. 1998). Similarly, white-tailed deer acclimated to high levels of human activity and supplemental feeding can have decreased flight distances and changes in diurnal activity patterns (Christie et al. 1987, Hammitt et al. 1993). Henke (1997) reported that deer behavior can easily be conditioned with supplemental feeding.

Thesis objective and format

There were 2 primary objectives for this study: to characterize the ecological interactions between deer and the plant community on Red Top Mountain State Park (RTMSP) and evaluate short-term response to an 80% reduction in deer density, and to evaluate the influences of human activity within the park on deer behavior and movement. Specific objectives for each of these topics are as follows:

Deer and plant ecology

1. I assessed the influence of deer on the short-term recovery of understory plants.
2. I evaluated the biological response of deer to an 80% reduction in deer density.

Deer behavior and movements

1. I determined the effect of human activity on deer home range size and location on RTMSP.
2. I evaluated the temporal relationship between deer distance from roads and traffic volume.
3. I determined deer rate of travel in relation to traffic volume.

This thesis was written in manuscript format. Chapters 2 and 3 are separate manuscripts that will be submitted for publication. Chapter 2, titled “Deer and understory plant responses to a large-scale herd reduction on a Georgia State Park,” describes the deer and plant ecology study. Chapter 3, titled “Spatial and temporal responses of deer to traffic on a Georgia State Park," describes the movement ecology study. Chapter 4 includes the summary of my results from both studies and provides recommendations for park and wildlife refuge deer managers.

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Chapter 2

Deer and understory plant responses to a large-scale herd reduction on a Georgia state park[1]

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Abstract

Abundance and diversity of vegetation often suffer from overabundant deer populations and may not recover without significant reductions in population density. White-tailed deer (*Odocoileus virginianus*) populations on Red Top Mountain State Park in Georgia have been overabundant for more than 15 years. We evaluated vegetative communities and assessed deer health one year before and after a large scale deer population reduction and compared these results to an adjacent wildlife management area (Allatoona WMA), where the deer herd has been managed for 47 years. Vegetation surveys were conducted in October 2003 and 2004, before and after the removal of 172 deer from the park in February 2004, which decreased estimated herd density from 36 to 9 deer/km^2. After 1 year of reduced deer density, the number of plant species observed increased 31.3%. In February 2005, we removed an additional 65 deer and used these data to compare indices of nutritional status before and 1-year post reduction. Adult female and fawn body weights were greater ($P<0.0001$) in 2005 than 2004, reflecting the improved nutrition. Reproductive rates also were greater ($P<0.0001$) in 2005 than 2004. Thus, 1 year after an 80% reduction in the deer herd initial signs of plant community recovery and an improvement in deer condition were evident. The dramatic improvements in reproductive output signal the need for continued population management to allow further vegetative recovery.

Index terms: browsing, carrying capacity, herd reduction, overabundance, understory plants, white-tailed deer

Introduction

Passive management of white-tailed deer on many state and national parks has led to exceedingly high deer population densities (Warren 1991). Parks often are surrounded by residential and/or commercial development, creating islands of deer refugia (Christie et al. 1987, Kilpatrick and Spohr 2000). Because deer can negatively affect plant communities, sympatric wildlife populations, and humans, the concept of deer carrying capacity on parks and suburban areas must include ecological and social criteria (Warren 1991, 1997).

Unmanaged deer populations in parks can reach densities equal to those in suburban habitats and share similar symptoms when exceeding social carrying capacity (e.g., increased deer-vehicle collisions and increased damage to cultivated plants; Conover 1995, Etter et al. 2002). However, biological and ecological carrying capacities of these habitats might be quite dissimilar. In suburban areas, deer habitat is characterized by fertilized lawns and ornamental plantings (Warren 1997). The nutritional value of this human-maintained plant community often exceeds that of natural habitats. In contrast, park habitats tend to have vegetation that is more representative of local forest ecosystems and over-browsing of preferred forage plants leads to a greater change in plant species composition and abundance than might occur in suburban habitats (Russell et al. 2001). Selective foraging by deer eliminates many preferred forage species which leaves only species of lower forage quality, leading to reduced biological carrying capacity within the park.

Over-browsing also causes changes in forest structure and composition (Tilghman 1989, Stromayer and Warren 1997), thereby impacting many avian and small mammal populations (deCalesta 1994, Horsley et al. 2003). Declining biological and ecological carrying capacity contradicts the goals of many parks and park visitors (Warren 1991, Hammitt et al. 1993). However, little information exists regarding the biological response of deer populations or the ecological response of plant communities after a major deer herd reduction on a park. Recently, McGraw and Furedi (2005) demonstrated a significant increase in the population growth and viability of a rare plant, American ginseng (*Panax quinquefolius*), after a 50% decrease in deer browsing rates.

We evaluated deer population density and health on a Georgia state park after >15 years of passive management and tested the effects of an 80% herd reduction on deer health, as a measure of biological change. We also surveyed vegetation to determine understory plant species richness and abundance on the park before and after the reduction as a measure of ecological change. We compared our findings with data from an adjacent, state-managed property where the deer population had been managed by hunting for 47 years. The reduction that took place on this park was the first time any Georgia state park was managed by sharpshooting. Public meetings and press releases were used to gather the opinions of state residents in the objectives of the project. Controversial management activities on parks can become a serious issue for park managers (Porter et al. 1994). Therefore, biological and ecological justification for lethal deer removal is crucial.

Methods

Study Area

This study was conducted on Red Top Mountain State Park (RTMSP) and Allatoona Wildlife Management Area (AWMA) located in Bartow County of north-central Georgia. These areas are separated by an arm of Lake Allatoona (~0.4 km wide).

RTMSP is a 578-ha peninsula surrounded on three sides by Lake Allatoona and is managed by the Georgia Parks and Historic Sites Division. The park is primarily forested with mixed pine-hardwood, upland hardwood, and pine-dominated forests. Other habitat components include maintained lawns, grassy roadsides, and mowed wildlife openings (i.e., wildlife viewing areas). The topography is transitional from the Piedmont Plateau to the Ridge and Valley Region with moderately sloping foothills. The only forest management activities on RTMSP are prescribed burning in some pine-dominated areas and sanitation cuts for trees killed by pine beetles. With more than 1.2 million visitors annually, RTMSP is the most heavily visited park in the state due to its proximity to Atlanta (56 km). RTMSP includes 4 km of roads, 19 km of hiking trails, a lodge and restaurant, campground, marina, group shelters, and picnic areas.

AWMA is a 3,764-ha tract of public land managed by the Georgia Department of Natural Resources, Wildlife Resources Division. The landscape and topography is similar to RTMSP and a large portion of AWMA borders Lake Allatoona. AWMA is relatively undeveloped compared to RTMSP, but has several paved and unpaved roads, as well as hiking trails. AWMA is primarily forested with upland hardwood, mixed pine-hardwood, and planted pine stands. There are also a few managed wildlife food plots

(1% of area) and campgrounds. The deer population has been managed by regulated public hunting since 1958.

Vegetation Surveys

We established vegetation sampling transects on RTMSP and AWMA to compare differences between areas with managed and unmanaged deer herds. We used randomly located survey plots to characterize understory species composition and diversity. In October of 2003 and 2004, we established 500-m long line transects at five locations on RTMSP and five locations on AWMA, based on randomly selected compass bearings. Along each transect, we sampled 10, 1-m^2 plots. The number of understory plant species and an observation of percent cover for each species were quantified in each plot. We used the same starting points and compass bearings for 2003 and 2004. However, survey plots were not permanently marked.

Deer Population Estimation

Our deer research was conducted in compliance with requirements of the University of Georgia's Institutional Animal Care and Use Committee (IACUC # A2003-10132-0; UGA Animal Welfare Assurance # A3437-01). We conducted infrared-triggered camera surveys in early February 2004 to estimate deer numbers in RTMSP before herd reduction. A second camera survey was conducted in March 2004, post reduction, to determine the resulting density and efficacy of the sharpshooting effort. Another survey was conducted during February 2005 to estimate population increase from recruitment and immigration prior to a second herd reduction and to determine a target number of deer to be removed. Population estimates were calculated by a modified mark-recapture technique, where the number of unmarked deer recorded on cameras was compared to the number of known, marked deer in the study area (Rice and Harder 1977, Jacobson et al. 1997). Thirty-eight deer were radio-collared as part of another study (Killmaster 2005), and these served as a marked portion of the population for estimating density. Camera locations on the park were pre-baited for a period of 2 weeks using whole, shelled corn. The locations were evenly dispersed throughout the park with one camera per 40.5 ha (15 cameras on the 578 ha) and each camera centrally located within the plot. The 35-mm cameras (DeerCam™ DC-200, NonTypical, Park Falls, WI) were equipped with an infrared trigger to detect movement, a time delay set at 10-minute intervals, and date/time stamping capabilities. During the survey, cameras were monitored daily and bait was replenished as needed. The survey continued for a period of 10 days to obtain a sufficient sample size (Jacobson et al. 1997). Deer density on AWMA was 11 deer/km^2 based on population reconstruction analysis (Kammermeyer 2002).

Deer Herd Reductions

We used sharpshooters from United States Department of Agriculture's Wildlife Services to reduce the deer population on RTMSP from 36 deer/km^2 to 10 deer/km^2 during February-March 2004. During the initial reduction (2004), only deer that were not radio-collared (Killmaster 2005) were removed and there was no selection for sex or age of deer removed. During February 2005, a second reduction was conducted to remove the radio-collared deer and additional uncollared deer.

During 2004 and 2005, 172 and 65 deer were removed, respectively. Each deer was weighed before evisceration using a spring scale and age was estimated by tooth wear and replacement (Severinghaus 1949). To determine reproductive rates, recruitment rates, and peak breeding season, the reproductive tracts of all females were examined for number of corpora lutea in the ovaries as well as sex, age, and number of fetuses (Hamilton et al. 1985, Harder and Kirkpatrick 1994). Following data collection, deer were processed and donated to local food shelters. Biological data were categorized by sex and age class to compare differences between years. Understory plant species per transect, live weight by sex and age class, corpora lutea per female, fetuses per female, and fetuses per pregnant female were compared using 2-sample t-tests (SAS Institute, Inc. 2001).

Results

Vegetation surveys

During the pre-reduction surveys, 59 understory species were recorded on AWMA, whereas only 32 were observed on RTMSP (Fig. 1). During the year following the herd reduction, 51 were observed on AWMA and 42 on RTMSP. The most common species occurred much more frequently on sample plots on AWMA than on RTMSP. For example, on AWMA there were 13 species that were recorded on 5 or more sample plots, whereas only 5 species occurred as frequently on RTMSP (Fig. 1). The most common species on AWMA were *Vaccinium arboreum*, *Smilax* spp., an unknown grass, and *Dichanthelium commutatum*. The most common species on RTMSP were *Dichanthelium commutatum*, *Viburnum* spp., *Aristida purpurascens*, and *Smilax glauca*. The number of species per transect was significantly greater (P=0.0062) on AWMA than RTMSP in 2003 (23.8 and 11.2, respectively), but not in 2004 (20 and 13.8, respectively). Changes in species richness between years were not compared statistically because survey plots were not permanently marked. The increase in plant species richness between 2003 and 2004 on RTMSP (Fig. 1) may reflect the lowered browsing pressure associated with the significant herd reduction implemented on RTMSP. A detailed list of all plant species observed on RTMSP and AWMA can be found in Killmaster (2005).

Deer population estimation and condition

Camera surveys on RTMSP yielded densities of 36 deer/km^2 before the reduction (February, 2004), 10 deer/km^2 immediately following the reduction (March, 2004), and 15 deer/km^2 before the second herd reduction (February, 2005).

Body weights of adult females, male fawns, and female fawns were significantly greater ($P<0.001$) in 2005 than 2004 (Table 1). Body weights between years increased 30.8% for adult females, 74.5% for male fawns, and 65.9% for female fawns. Adult male body weights were 9.1% greater in 2005 vs. 2004, but this difference was not statistically significant. This increase in body weights in 2005 was likely the result of the initial removal of 172 deer in 2004. Because the growth rates for fawns born in spring 2004 would most likely reflect the improved nutritional status, it is not surprising that the greatest differences in body weights between 2005 and 2004 were evident in male and female fawns. Data from yearling males and females were not analyzed due to low sample sizes ($n=1$) in 2005.

Reproductive performance increased immediately after the herd reduction. The number of corpora lutea per adult female increased from 0.83 in 2004 to 1.81 in 2005 ($P<0.0001$) (Table 2). The number of fetuses per adult female and fetuses per pregnant adult female also was greater ($P<0.0001$) in 2005 vs. 2004 (82.3% more and 43.6% more, respectively, Table 2).

Discussion

The dramatic increases in body size and reproductive performance reflected the improved nutritional status that likely resulted from the herd reduction and greater forage availability. However, differences in understory vegetation resulting from other external factors, such as weather were not quantified in this study. Variations in reproductive performance of deer are known to reflect nutritional status (Cheatum and Severinghaus 1950). Although sample sizes were small, none of the 34 female fawns collected in 2004 were pregnant, compared to 3 of 8 in 2005. Conception by female fawns is indicative of excellent nutritional status in a deer herd (Haugen 1975, Abler et al. 1976). In addition, tail fat scores (Riney 1955) of 30 deer captured in 2004 averaged 2.23 (±0.11). When these same animals were removed during the second reduction, tail fat scores had increased ($P=0.0003$, Wilcoxon signed rank test) to 2.9 (±0.15).

Overabundant deer populations can impact understory plant species richness and abundance, as well as result in poor herd health. Specific plants of conservation concern may require at least 50% reduction in deer browsing pressure to maintain population viability (McGraw and Furedi 2005). Furthermore, ecosystems subjected to years of heavy browsing pressure may take decades to fully recover, assuming the deer density is controlled in successive years (Warren 1991, Stromayer and Warren 1997). Deer population control must be maintained, sometimes annually, to prevent future damage or to allow vegetative communities to recover. Because of high reproductive rates, deer populations can rebound from culling operations and return to overabundance within a few years (McCullough 1984). The response in reproductive rates we documented, doubling in some aspects, attest to the reproductive resiliency of deer populations.

Wildlife management can become a serious issue for park officials in areas that are designated for human recreation and maintenance of natural ecosystems (Porter et al. 1994). There are several options for deer population control, ranging from public hunting to fertility control (Warren 2001). We chose sharpshooting for this study based on human safety, logistics, efficacy, immediacy of results, and efficiency. Despite some public opposition to the removal or method of removal of deer from the park, we approached this issue with sufficient biological and ecological evidence to support this management activity. Browse exclosures are an excellent tool for determining impacts of deer browsing as well as public education. We found that extensive preparation and involvement of the public in management decisions can influence the efficiency of controversial management actions.

Conclusions

We found that the immediate reduction in deer density initiated a dramatic response in the physiological condition of deer and early stages of recovery of the vegetative community. Effective public relations played an essential role throughout the duration of this study. We recommend that parks and natural areas that have abundant or overabundant deer herds establish a vegetation sampling program to document temporal changes. To control deer populations on a long-term basis, we recommend that public hunting be used where feasible and socially acceptable. However, in the case of extremely high density herds or areas that have public safety issues associated with hunting, sharpshooting may be the most viable option.

Acknowledgements

Assistance with collection of samples was provided by personnel from Georgia Parks and Historic Sites Division, Georgia Wildlife Resources Division, and volunteers from the University of Georgia. We especially thank C. Gregory and J. Hamilton for their support in the planning, administration, and field work for this project. We would also like to thank D. Hall and D. Hoffman of USDA-Wildlife Services for conducting the herd reductions. This project was funded by the Georgia Department of Natural Resources, State Parks and Historic Sites Division and McIntire-Stennis Project No. GEO-105.

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Figure 1. Understory plant species richness and frequency of occurrence on Red Top Mountain State Park (a) and Allatoona Wildlife Management Area (b), Georgia before (2003) and after (2004) a large-scale deer population reduction.

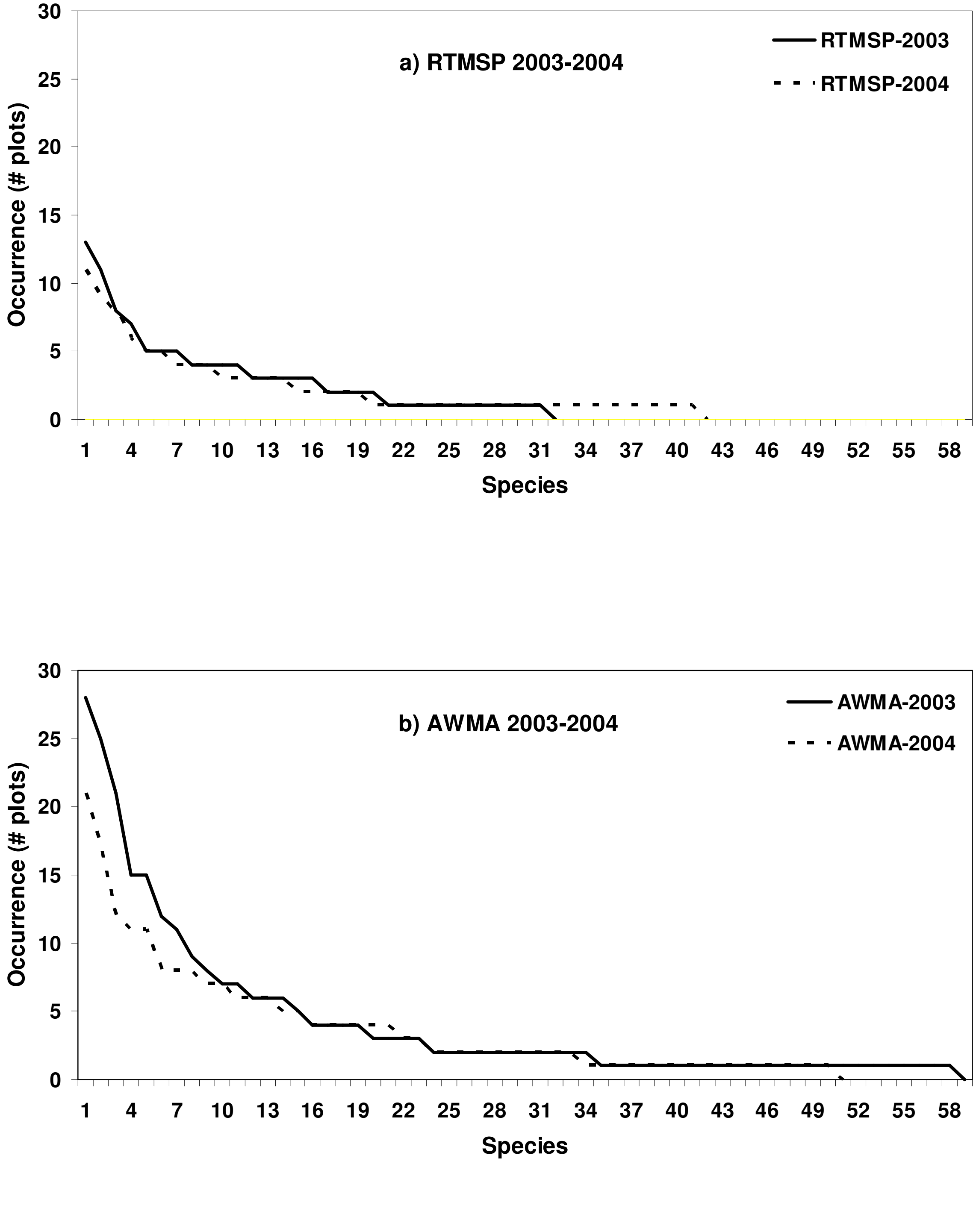

Table 1. Mean whole body weights of white-tailed deer on Red Top Mountain State Park, Georgia, from 2004 (initial reduction) to 2005 (post initial reduction), following an 80% herd reduction.

			Body Weight (kg)		
Age	Sex	Year	Sample size	Mean	Standard Error
Adult (2.5+)	Male	2004	4	38.4 A[a]	12.5
		2005	10	41.9 A	2.2
	Female	2004	82	29.9 A	1.2
		2005	41	39.1 B	1.6
Fawn	Male	2004	27	14.9 A	1.2
		2005	4	26.3 B	3.7
	Female	2004	38	13.8 A	1.0
		2005	8	22.9 B	2.2

[a]Means within age and sex classes for 2004 versus 2005 that have different letters are significantly different ($\underline{P}<0.0001$) ($t \geq -5.63$).

Table 2. Mean measures of reproductive success of white-tailed deer on Red Top Mountain State Park, Georgia from 2004 to 2005, resulting from lowered population density.

Reproductive variable	2004			2005		
	Sample size	Mean	Standard error	Sample size	Mean	Standard error
Corpora lutea per adult female	82	0.83 A[a]	0.07	41	1.81 B	0.11
Fetuses per adult female	82	0.79 A	0.06	41	1.44 B	0.11
Fetuses per pregnant adult female	60	1.08 A	0.04	36	1.58 B	0.08

[a]Means from 2004 to 2005 that have different letters are statistically different ($P<0.0001$).

Chapter 3

Spatial and temporal responses of deer to traffic on a Georgia state park[1]

[1]Killmaster, C.H., R.J. Warren, D.A. Osborn, and K.V. Miller. To be submitted to the *Wildlife Society Bulletin* for publication.

Abstract

Understanding white-tailed deer (*Odocoileus virginianus*) movement patterns and behavior in urban and suburban areas is required to minimize deer-human conflicts. We radio-tracked 34 deer (6 males and 28 females) to determine summer home ranges and responses to human activity in a heavily visited suburban park during summer 2004. As is characteristic of suburban deer populations, mean home range sizes were small (36.5 [± 4.5] and 22.5 [±1.7] ha for males and females, respectively). A sub-sample of 8 does was monitored once per hour for 5-7, 24-hour periods to assess the impact of traffic volume on deer behavior. Nighttime and early morning locations were closer to roads than random locations, suggesting an attraction to road areas when traffic was minimal. Mean distance from roads of the 95% MCP and 50% MCP home ranges did not differ, suggesting that deer did not choose core locations closer or further from roads. Mean rate of travel for the 8 intensively monitored deer was greater (P=0.0002, 3df, f=6.96) in the afternoon period than in the night and early morning periods. Thus, deer on this park were more active and were located farther from roads and other areas of human activity during daylight hours. Park officials should enforce speed limits focusing on times when the volume of vehicular traffic is highest.

Key words: diel, deer movements, *Odocoileus virginianus*, state park, vehicular traffic

Introduction

White-tailed deer movements, activity patterns, and habitat use are affected by factors such as weather, season, predation, and climate (Beier and McCullough 1990). Deer must budget time spent on normal activities (e.g., foraging, social interactions, movement, rest) to balance energy uptake and expenditure, while minimizing risk of mortality. Whereas hunting and predation are the primary causes of deer mortality in rural areas, deer-vehicle collisions are the most common cause of mortality in suburbia (Nelson and Mech 1986, Etter et al. 2002). Predators may not acclimate well to high-density residential areas and hunting programs may be difficult to establish (Warren 1997). Because many deer populations in suburban and park areas are protected from hunting, they exhibit lower annual mortality rates, thereby compounding problems associated with deer overabundance, including deer-human conflicts (Conover 1995, Etter et al. 2002). As interactions between deer and humans increase, deer modify their behavior (i.e. seeking cover or supplemental feeding) to mitigate negative interactions and to benefit from positive interactions, such as supplemental feeding (Henke 1997, Recarte et al. 1998).

Although movements and activity patterns of deer have been studied extensively (Marchinton and Hirth 1984), behavior of deer in suburbia and parks has only recently become the focus of study (Swihart et al. 1995). When considering the increased potential for deer-human interactions in suburban and park habitats, it is reasonable that movement and activity patterns of these deer should differ from those of their more rural counterparts (Beier and McCullough 1990, Swihart et al. 1995). Activity of rural deer is primarily crepuscular (Kammermeyer and Marchinton 1977). However, in parks and suburban areas, deer modify their activity by seeking refuge in areas with vertical cover during periods of high human activity (Vogel 1989, Storm et al. 1995). When human activity decreases, deer utilize other habitats within higher risk areas, which often leads to mostly nocturnal behavior (Kilpatrick and Spohr 2000). There is a temporal relationship between the density of human dwellings and use of these areas by deer (Vogel 1989).

Annual home ranges of deer in suburbia tend to be small compared to those of rural populations (Christie et al. 1987, Kilpatrick and Spohr 2000). However, as is the case with rural populations, habitat quality and relative deer density will affect home range size (Marchinton and Hirth 1984). High-quality forage and high-density deer populations, which are typical of many suburban areas, can result in relatively small home range size and core areas (Swihart et al. 1995). Additionally, seasonal shifts in home ranges of deer occur in residential areas in response to available food resources, such as bird feeders and flower beds (Grund et al. 2002). In areas of high housing density, deer depend on surrounding undeveloped areas, such as parks or wildlife reserves, for refuge and fawning sites (Swihart et al.1995).

In this study we describe the interactions between deer and humans on a Georgia state park. Our specific objectives were to determine summer home ranges size and spatial arrangement with respect to roads, along with spatial and temporal responses to vehicular traffic.

Materials and methods

Study area

Red Top Mountain State Park (RTMSP) is a 578-ha land peninsula surrounded on 3 sides by Lake Allatoona in north-central Georgia. RTMSP is primarily forested with mixed pine-hardwood, upland hardwood, and pine-dominated forests. Other habitats on the park include maintained lawns, grassy roadsides, and mowed wildlife openings. The terrain is transitional from the Piedmont to the Ridge and Valley Region of Georgia with moderately sloping foothills and areas with little or no slope. There are no commercial silvicultural operations on RTMSP other than prescribed burning in some pine-dominated areas and sanitation cuts for trees killed by pine beetles. Due to its proximity to Atlanta (56 km), RTMSP is the most heavily visited park in the state with greater than 1.2 million visitors annually. Features of the park include 4 km of roads, 19 km of hiking trails, a lodge and restaurant, campground, marina, group shelters, and picnic areas. Deer density, based on mark-recapture surveys using infrared cameras (Jacobson et al. 1997) were estimated at 36 deer/km^2 in 2004 (Killmaster 2005).

Deer capture and handling

During January 2004, we captured and radio-collared 33 female and 8 male deer. All deer were captured and handled according to requirements set forth by The University of Georgia's Institutional Animal Care and Use Committee (IACUC #A2003-10132-0). All deer were captured using a pneumatic dart projector fitted with an optical scope (Dan-inject, Bǿrkop, Denmark). Darting was conducted from a vehicle at dispersed locations throughout the park to ensure marked deer home ranges were evenly distributed. Darting locations were baited with whole, shelled corn to attract deer for capture.

Deer were darted intramuscularly with a combination of xylazine hydrochloride (2.5 mg/kg estimated body weight) and ketamine hydrochloride (3 mg/kg estimated body weight) to immobilize them while minimizing capture myopathy (Chalmers and Barrett 1982, Mech et al. 1985). Darts contained radio-transmitters to aid recovery of deer (Pneu-Dart, Williamsport, Pennsylvania). Once anesthetized, deer were hooded, given an optical lubricant, a broad-spectrum antibiotic (Oxybiotic™, 0.1 ml/kg body weight) to prevent infection and a de-wormer (Ivomec™, 1 ml/45 kg body weight). We assessed overall body condition and placed each deer into yearling and adult age classes (Severinghaus 1949). We affixed a radio-transmitter collar with an 8-hour mortality sensor on each deer (Advanced Telemetry Systems, Inc., Isanti, MN.). We attached white or yellow, numbered ear tags (National Band and Tag Co., Newport, Kentucky) to the exterior surfaces of collars to allow visual identification of marked deer. Before releasing deer at their capture sites, we administered yohimbine hydrochloride (0.06 mg/kg estimated body weight) intravenously and intramuscularly to reverse the effects of xylazine hydrochloride (Mech et al. 1985).

Telemetry data collection

To monitor movements and activity patterns of radio-collared deer, we established 160 geo-referenced telemetry stations at easily accessible points along roads and trails. Each station was assigned a number, its coordinates (±5 m) were obtained with a GPS (Geoexplorer III, Trimble Navigations Ltd., Sunnyvale, CA), and the exact station location was permanently marked with a metal tag. Telemetry locations of collared deer were obtained by sequential triangulation, with bearings from 3 or more referenced telemetry stations, and no more than 20 minutes between the first and last bearings (Mech 1983). Standard error of telemetry bearings was 0.87 degrees. Bearings were recorded on standardized data sheets, where the time, date, deer number, and telemetry station also were recorded. The angle between the outermost stations on locations was between 60^{o}-120^{o}. We ceased radio telemetry monitoring during periods of severe thunderstorms for reasons of technician safety and possible bias in deer behavior and movement. Telemetry stations and all bearings, including date and time, were entered into program LOCATE II, which converted the compass bearings from the telemetry stations to X-Y coordinates based on the Universal Transverse Mercator (UTM) system (Nams 2000). Once locations were geo-referenced, they were entered into ArcView 3.2 (Environmental Systems Research Institute, Redlands, CA) and overlaid with coverages of roads, aerial photographs, and topographic maps. All other roads not present on the coverages were entered manually.

Deer survival, summer home ranges, and diel movements

We monitored daily survival of all radio-collared deer from January 2004 to February 2005. Frequent monitoring allowed us to locate a deer soon after death, and facilitated a timely investigation into the cause of death (Nettles 1981, Heisey and Fuller 1985). Mortalities from vehicles were either reported by park visitors or diagnosed through necropsy.

We monitored summer (June-September) minimum convex polygon (MCP) home range use of 34 deer (6 males, 28 females) during 2004. We located each deer once every 2 days, alternating our periods of observation from day to night. Home range size was plotted against number of locations for all deer to ensure adequate sample size and remove outliers (Millspaugh and Marzluff 2001). Based on this analysis, we removed data from 1 male deer due to inadequate sample size. For a subsample of 8 females, we located each deer every 48 hours, but also recorded its location every hour during a series of 6-hour periods. We alternated these 6-hour periods so they covered all times of day and night to determine diel movements of deer totaling 4-6 hour periods. We were able to generate 5-7 diel periods for each deer in the subsample.

Traffic monitoring

We placed electronic traffic counters (Diamond Traffic, Oakridge, Oregon) on 3 primary roads within RTMSP to monitor traffic volume and temporal patterns. The roads we selected were located within or near the home ranges of the 8 deer that we monitored for diel movements. One road lead to a day-use area containing a beach, picnic areas, miniature golf course, group shelter, and concession stand. This area was closed nightly to the public by a gate from 2200 until 0800 hours. One road was accessible at all times and lead to an area with 18 cottages, a lodge and restaurant, a marina, and a group shelter. The remaining road led to a large campground with 93 campsites. This road was gated at all times and only campers had access. Traffic counters only counted vehicles on one side of each road; however, all roads were dead ends. Data loggers (Sensource, Youngstown, Ohio) were wired into the traffic counters to record date, time, and number of vehicles that passed each hour. Information from data loggers was downloaded at the end of each diel monitoring period so the traffic counts could correspond to the hourly locations obtained for the subsample of 8 deer. Downloaded data were imported into a spreadsheet (Excel, Microsoft® software) to be summarized and combined with telemetry data.

Data analysis

All deer locations were used to generate individual summer home ranges. Home ranges were calculated using the Animal Movements V2 extension (Hooge and Eichenlaub 1997) with the 95% and 50% MCP methods. The spatial relationship between deer and roads on the park was analyzed using a combination of 95% and 50% MCP home range centroids, or geometric centers, and randomly generated points within those home ranges. The mean distance of random points within each 95% MCP was compared to those of each 50% MCP. Because means from the 50% MCP home range also were contained within the 95% MCP for each deer, we used a paired t-test (SAS Institute, Inc. 2001) to compare the data obtained for both home range calculations.

We examined the behavioral response to traffic volume by comparing the mean distance between deer locations and the nearest road on an hourly basis for the subsample of 8 deer. This was compared with corresponding hourly vehicular traffic volume. We pooled these hourly data into 4, 6-hour periods that began at 0800 hours and covered the 24-hour day. We then calculated mean rate of travel for each 6-hour period by dividing the distances between hourly deer locations by the number of hours the deer was tracked. A repeated measures analysis of variance, blocked by deer (SAS Institute, Inc. 2001), determined significant differences ($P<0.05$) in mean rate of travel among the 6-hour periods.

Results and Discussion

Survival

From January 2004 to February 2005, 33 of the radio-collared deer (80%) survived. We determined the mortality factors of 8 deer. Of these, 4 (50%) were attributed to collisions with vehicles, 3 (37.5%) were of unknown causes, and 1 (12.5%) was shot during a herd reduction (Killmaster 2005). Of the 3 unknown causes of mortality, we believe that 2 deaths were caused by dogs. Dogs chased an uncollared fawn into the water near the same location and time where 2 radio-collared deer were found dead in the water. This occurred during winter and both deer were in poor condition. Additionally, no radio-collared deer died during the summer monitoring period. Prior to this study, RTMSP averaged 40 deer-vehicle collisions annually (James Hamilton, personal communication).

Home ranges and roads

Mean summer home range size (95% MCP) was 36.5 [± 4.5] ha for males and 22.5 [±1.7] ha for females. These small home ranges agree with other research on suburban deer populations (Christie et al. 1987, Kilpatrick and Spohr 2000). However, deer are known to increase home range size in poor habitat conditions (Harestad and Bunnell 1979). Therefore, the small home ranges we observed seem atypical, considering the extremely poor habitat quality on RTMSP. This apparent disparity is most likely the result of high deer density (Marchinton and Hirth 1984), the constraints of an isolated population, and minimal habitat not subjected to human use.

Home range centroid distance from roads for 95% MCP ($\bar{x}$ =53m±9.6) and the 50% MCP ($\bar{x}$ = 55m±7.6) were not significantly different (P=0.899, 62df, t=0.13) indicating that deer did not focus use of area within their home ranges in relation to roads. Similarly, distances from 50 random locations to the nearest road using random locations rather than centroids within 50% MCP ($\bar{x}$ =57m±6.6) vs. 95% MCP ($\bar{x}$ =73m±6.1) home ranges also were not different (P=0.072, 62df, t=-1.83). In addition, there were no significant differences in the distance from deer to nearest roads during any 24-hour period (Fig. 1). However, deer were generally closer to roads during hours of darkness. All 95% MCP home ranges overlapped roads at some point.

Diel movements and behavior

Mean rate of travel for period 2 (2:00 p.m.-8:00 p.m.) was greater (P=0.0002, 2df, f=6.96) than during periods 3 (8:00 p.m.-2:00 a.m.) and 4 (2:00 a.m.-8:00 a.m.) (Fig. 2). These animals also showed an affinity to roads at night when traffic volumes were lower (Fig. 1), although rate of travel was lower during these same hours. This indicates that deer are more active and farther from roads and other areas of human activity during daylight hours. These results are in contrast to previous studies that indicate deer seek cover during periods of high human activity (Vogel 1989, Storm et al. 1995). This behavior is likely the result of a high-density deer population that became acclimated to human activity, thereby decreasing avoidance response to humans.

Management implications

Deer movements on RTMSP were marginally impacted by human activity. Deer on RTMSP were highly acclimated to humans, frequently taking food "handouts" from park visitors. Some habituated deer commonly stood on roadsides throughout the day and approached vehicles that stopped to throw food (James Hamilton, personal communication). This behavior became a serious issue for park officials due to high volumes of slow-moving traffic and associated deer-vehicle collisions. Previous studies of deer behavior in suburban areas and parks have shown that deer seek refuge during periods of high human activity (Vogel 1989, Storm et al. 1995), whereas deer on RTMSP no longer have a human avoidance response and increase activity when typical suburban deer would remain inactive.

Deer acclimated to high levels of human activity and supplemental feeding can have decreased flight distances and change their diurnal activity patterns (Christie et al. 1987, Hammitt et al. 1993). In addition, deer behavior and movements can be altered by food conditioning (Henke 1997, Kilpatrick and Stober 2002). These kinds of interactions between humans and deer in heavily visited parks can diminish avoidance response. In these areas of very high human use, coupled with high deer densities, the acclimation of deer to human activity certainly will increase the likelihood of negative deer-human interactions even beyond what is often observed in suburban habitats.

Acknowledgments. Assistance with collection of samples was provided by personnel from Georgia Parks and Historic Sites Division, Georgia Wildlife Resources Division, and volunteers from the University of Georgia. We especially thank C. Gregory and J. Hamilton for their support in the planning, administration, and field work for this project. We would also like to thank M. Lang and D. Duncan for long hours spent collecting data. This project was funded by the Georgia Department of Natural Resources, State Parks and Historic Sites Division and McIntire-Stennis Project No. GEO-105.

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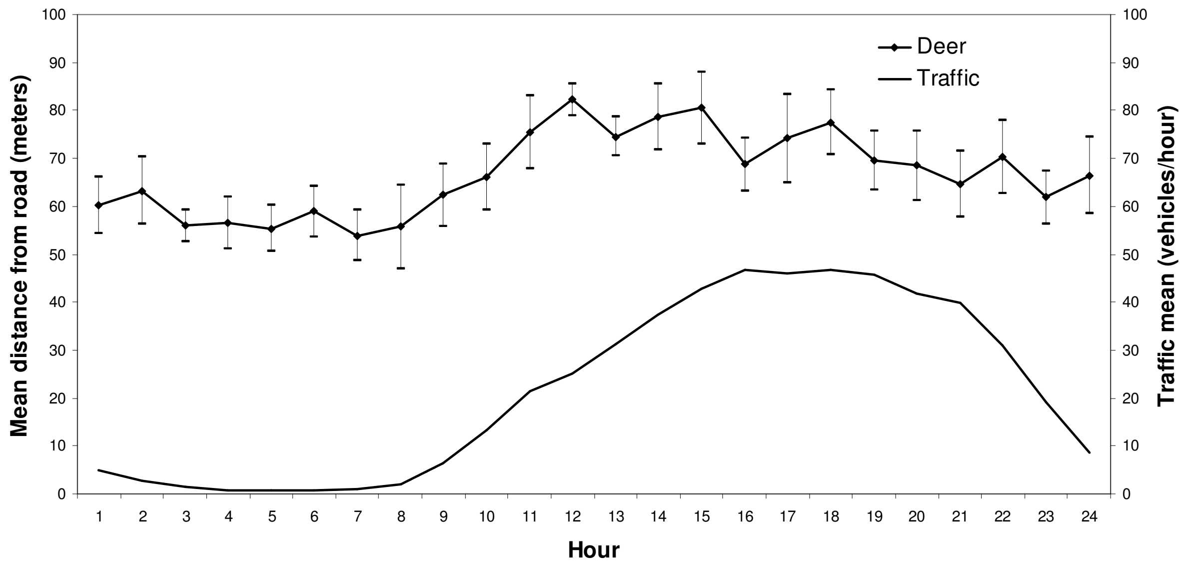

Figure 1. Mean hourly deer distance from roads with standard error and corresponding traffic volume during Summer 2004 on Red Top Mountain State Park, Cartersville, Georgia.

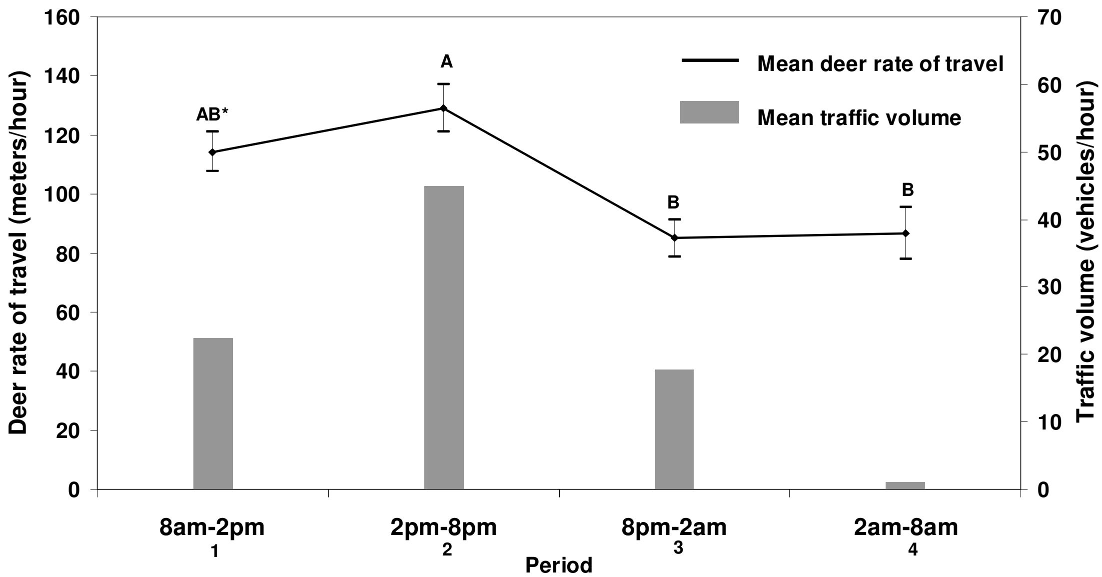

Figure 2. Mean deer rate of travel by time period with associated traffic volume on Red Top Mountain State Park, Cartersville, Georgia. Period rates of travel represent 5 to 9 diel periods for each of 8 adult female white-tailed deer. *Means with the same letter are not significantly different (Tukeys LSD, **α**=0.05).

Chapter 4

Summary and Conclusions

High density populations of white-tailed deer (*Odocoileus virginianus*) in suburban parks can have negative impacts, both socially and ecologically (Warren 1991). Damage to vegetative communities in these areas can lead to negative biological impacts to the deer population (i.e. decreased body weights and reproductive success). Additionally, movement ecology of deer in suburban areas differs from rural deer; primarily related to differences in human activity and food availability (Vogel 1989, Storm et al. 1995, Grund et al. 2002). While hunting maintains deer populations in rural areas, deer-vehicle collisions are the primary source of mortality in developed areas (Conover 1995, Etter et al. 2002). Public opinion of methods for reducing deer-human conflicts may be in direct contrast to those of wildlife managers (Decker and Richmond 1995, Stout et al. 1997). The influence of public opinion in the development of wildlife management plans has become crucial to maintain biologically sound management practices (Doig 1987, Decker et al. 1989). Therefore, knowledge of deer behavior and ecology in developed areas is crucial for the justification of controversial management activities. I conducted a 2 part research project to describe the ecology and movements of deer in a suburban park. I monitored biological responses of deer and vegetation to a large scale herd reduction, and the influence of human activity on deer movements and behavior.

Deer and understory plant responses to a large scale herd reduction

Red Top Mountain State Park (RTMSP) located in north-central Georgia has had an unmanaged deer herd for ≥ 15 years. I conducted a study to document the responses of deer and plants to an 80% reduction in herd density. Prior to the herd reduction, 32 species of understory plants were found on RTMSP during vegetation surveys (October 2003). Surveys conducted on an adjacent state managed property, Allatoona Wildlife Management Area (AWMA), yielded 59 species. AWMA deer have been managed by public hunting for 47 years. Following the reduction, 42 species were recorded on RTMSP and 51 on AWMA (October 2004). Additionally, the frequency of occurrence of the most common plant species was greater on AWMA during both years (i.e. those species were found in more sample plots). The number of species found per sampling transect was statistically higher on AWMA than RTMSP during 2003, but not in 2004.

Camera surveys (Jacobson et al. 1997) on RTSMP estimated the population density to be 36 deer/km^2 before the reduction, 9 deer/km^2 after the reduction, and 15 deer/km^2 prior to a second reduction in 2005. Deer density was 11 deer/km^2 on AWMA based on population reconstruction analysis (Kammermeyer 2002).

Body weights of adult females, male fawns, and female fawns taken in reductions were significantly higher in 2005 than in 2004. Between these years, weights increased by 30.8%, 74.5%, and 65.9%, respectively. Tail fat estimates from deer captured for the second phase of the project were significantly greater in 2005 than 2004. These increases are likely the result of a reallocation of food resources for remaining deer, rather than improvement of habitat quality from reduced deer density.

Reproductive rates of adult females were greater in 2005 than 2004. Corpora lutea per adult females doubled between years. The number of fetuses per adult female and fetuses per pregnant adult female from 2004 to 2005 increased 82.3% and 43.6%, respectively. During 2005, 3 of 7 fawns were pregnant compared to 0 of 34 in 2004.

High density deer herds found in parks can have profound impacts on the local ecosystem as well as the nutritional status of the herd (Warren 1991). I found dramatic responses in nutritional and reproductive status of deer and diversity of vegetation with an 80% reduction in deer density. Although there was some public opposition to sharpshooting to manage the deer herd, I found that sufficient biological and ecological evidence as well as involvement of public opinion led to efficient implementation of the program. Vegetation sampling programs in parks with high density deer herds can also be a valuable tool for park managers.

Spatial and temporal responses of deer to traffic

Movements and behavioral ecology of deer in parks and suburbia has only recently become a focal point of scientific inquiry (Swihart et al. 1995). I conducted a study to document the spatial, temporal, and behavioral responses of a high density deer herd to vehicular traffic on RTMSP. I used radio telemetry to monitor 41 deer on RTMSP for survival, summer home ranges, diel movements, and hourly rate of travel.

Between January 2004 and February 2005, 80% of radio-collared deer survived. The causes of death were deer-vehicle collisions (4), unknown (3), and 1 deer shot in the herd reduction. Of the unknown causes, 2 were suspected to be dog related. Additionally, RTMSP averaged 40 reported deer-vehicle collisions annually, which dropped to less than 10 in 2004 following the first herd reduction (James Hamilton, personal communication).

Mean summer home ranges (95% MCP) for 33 deer (5 male, 28 female) were 36.5 [± 4.5] ha for males and 22.5 [±1.7] ha for females. These home ranges were small, which is characteristic of suburban and urban populations (Christie et al. 1987, Kilpatrick and Spohr 2000). However, unlike suburban areas the habitat quality on RTMSP was poor and deer should have had larger home ranges (Harestad and Bunnel 1979). I compared the mean distance to roads from deer locations within the 95% MCP home range to locations within the 50% MCP to determine if deer spent more time near roads. Furthermore, deer distance from roads was compared to random locations within the 95% MCP home ranges to determine if deer more locations closer to roads than if locations were randomly distributed. There were no differences, suggesting that deer showed no favoritism for areas closer to or further from roads. Due to extensive road systems on RTMSP, there is minimal habitat that is not directly adjacent to roads.

Diel movements and behavior were determined through intensive monitoring of a subsample of 8 females. These deer were located once per hour, totaling 5-7 diel periods for the duration of the study. Distance from these locations to the nearest road was compared with traffic volume on the park. There was an insignificant trend showing deer were closer to roads during nocturnal hours, when traffic volume was lowest. Period rate of travel was greater in period 2 (2:00p.m.-8:00p.m.) than in periods 3 and 4 (8:00p.m.-2:00a.m. and 2:00a.m.-8:00a.m., respectively). Period 2 also had the greatest volume of traffic, suggesting that deer were more active during periods of high human activity. This contrasts with previous research of suburban deer behavior stating that deer remain inactive and in seclusion when human activity peaks (Vogel 1989, Storm et al. 1995). Apparently deer on RTMSP have become habituated to humans, as a result of supplemental feeding by park visitors that has occurred for $\geq$ 10 years (James Hamilton, personal communication).

Populations of deer that are highly acclimated to humans and supplemental feeding can change their diurnal activity patterns (Christie et al. 1987, Hammitt et al. 1993). These changes in combination with high levels of human activity can lead to greater incidence of negative deer-human interactions. Additionally, deer in areas of lower habitat quality, such as parks, may respond to supplemental feeding more readily, thereby compounding negative interactions (i.e. deer-vehicle collisions). Park managers should be aware that supplemental feeding, high density populations, and decreased flight response of deer can potentially increase the incidence of negative deer-human interactions.

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Appendix 1

Vegetation regrowth after release from deer browsing on a Georgia state park

White-tailed deer (*Odocoileus virginianus*) can have negative impacts on native vegetation (Hough 1965, Russell et al. 2001). Many studies have shown that browse exclosures can easily document the effects of deer density on native vegetation (Russell et al. 2001).

Methods

During February 2003, we established 0.04-ha deer exclosures (20m by 20m) at three locations in areas where overstory pines had been removed because of beetle kills on Red Top Mountain State Park (RTMSP), Georgia (Fig. 1). The exclosures were 3-m high woven-wire fencing and were constructed by Georgia Parks and Historic Sites personnel. Plant species composition within each enclosure was quantified in October 2004 to document plant responses to a lack of deer browsing for two growing seasons (Table 1). Additionally, vegetation surveys were conducted outside exclosures on RTMSP and on an adjacent state managed property, Allatoona Wildlife Management Area (AWMA). We used aerial photos and topographic maps to stratify RTMSP and AWMA based on forest type. We used randomly located survey plots to characterize understory species composition and diversity. Our surveys were conducted in October of 2003 and 2004. We established 500-m long line transects at five locations on RTMSP and five locations on AWMA, based on randomly selected compass bearings (Fig. 2). Along each transect, we sampled 10, 1-m^2 plots. The number of understory plant species and percent cover for each species were quantified in each plot (Table 2). We used the same starting points and compass bearings for 2003 and 2004.

Results and Discussion

After 2 growing seasons browse exclosures on RTMSP were visibly more abundant with vegetation than surrounding areas. Although surrounding areas were not sampled, the species diversity appeared to be greater within the exclosures. Information and photographs of these browse exclosures were valuable resources for presenting deer damage to the public. Because the exclosures were located in unforested habitat, the species richness could not be compared to the line-transect surveys, which were conducted in forested habitat. During 2003, the number of species per transect was significantly greater ($P=0.0062$) on AWMA than on RTMSP.

Table 1. Species of plants found in browse exclosures on Red Top Mountain State Park, Cartersville, Georgia.

	Exclosure 1	Exclosure 2	Exclosure 3
Acer rubrum	x	x	
Amaranthus sp.	x		
Andropogon sp.	x	x	x
Aristida purpurasens	x	x	x
Asplenium platyneuron			x
Aster dumosus			x
Carya tomentosa		x	x
Celtis tenuifolia	x		x
Centrosema virginianum			x
Chamaecrista nictitans			x
Chasmanthium sp.	x		
Cirsium sp.	x		
Clitoria mariana	x		
Cornus florida	x	x	x
Crataegus sp.			x
Dichanthelium commutatum	x	x	x
Diospyros virginiana	x	x	
Duchesnea indica	x		
Elephantopus sp.	x		x
Erichtites hieracifolia		x	x
Eupatorium capilifolium	x	x	
Eupatorium compostifolium	x		
Eupatorium serotinum	x	x	
Gnapthalium obtusifolium	x		
Helianthus annuus	x		x
Hypericum hypericoides	x	x	x
Lespedeza cuneata	x	x	x
Lespedeza procumbens	x	x	x
Lespedeza virginica		x	
Liquidambar styraciflua	x	x	
Liriodendron tulipifera	x	x	
Lonicera japonica	x		
Microstegium vimineum	x	x	
Muhlenbergia schreberi		x	x
Nyssa sylvatica	x		
Oxydendrum arboreum		x	
Passiflora incarnata	x		
Phytolacca americana	x		
Pinus sp.	x	x	x
Pityopsis graminifolia	x	x	x
Prunus serotina	x	x	
Pteridium aqualinum		x	
Quercus falcata		x	x
Quercus nigra			x
Rhus copallinum	x	x	
Rhus glabra	x		
Rubus sp.	x	x	

Saccharum alopecuroides	x		
Sassafras albidum		x	
Smilax bona-nox	x	x	x
Smilax glauca	x	x	x
Smilax rotundifolia	x	x	
Solanum carolinense	x		
Solidago nemoralis	x	x	
Solidago odora	x		
Toxicodendron radicans	x		
Vaccinium arboreum		x	x
Vitis rotundifolia	x	x	

Figure 1. Diagram of a browse exclosure on Red Top Mountain State Park, Cartersville, Georgia.

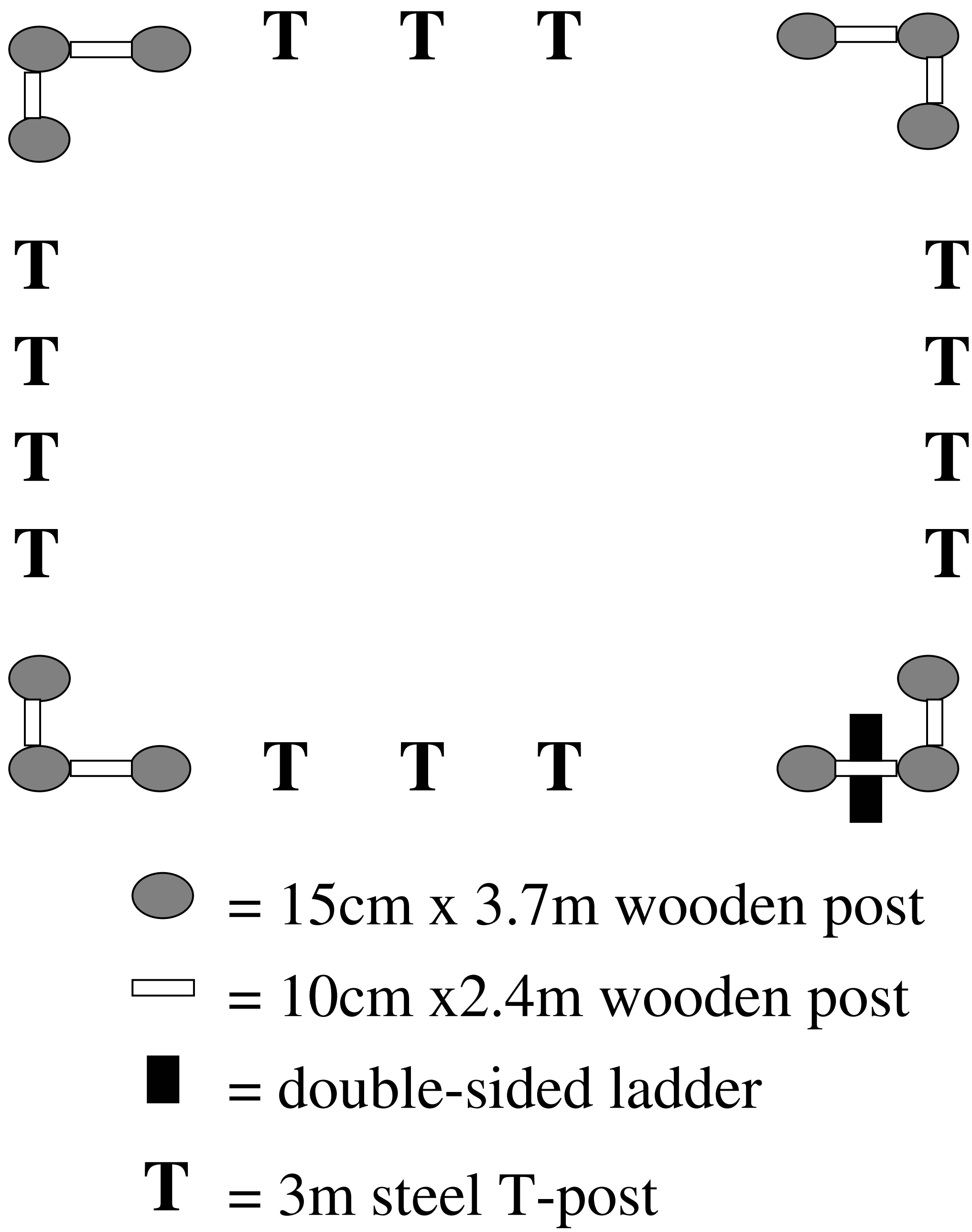

Figure 2. Map of vegetation transects on Red Top Mountain State Park and Allatoona Wildlife Management Area, Cartersville, Georgia.

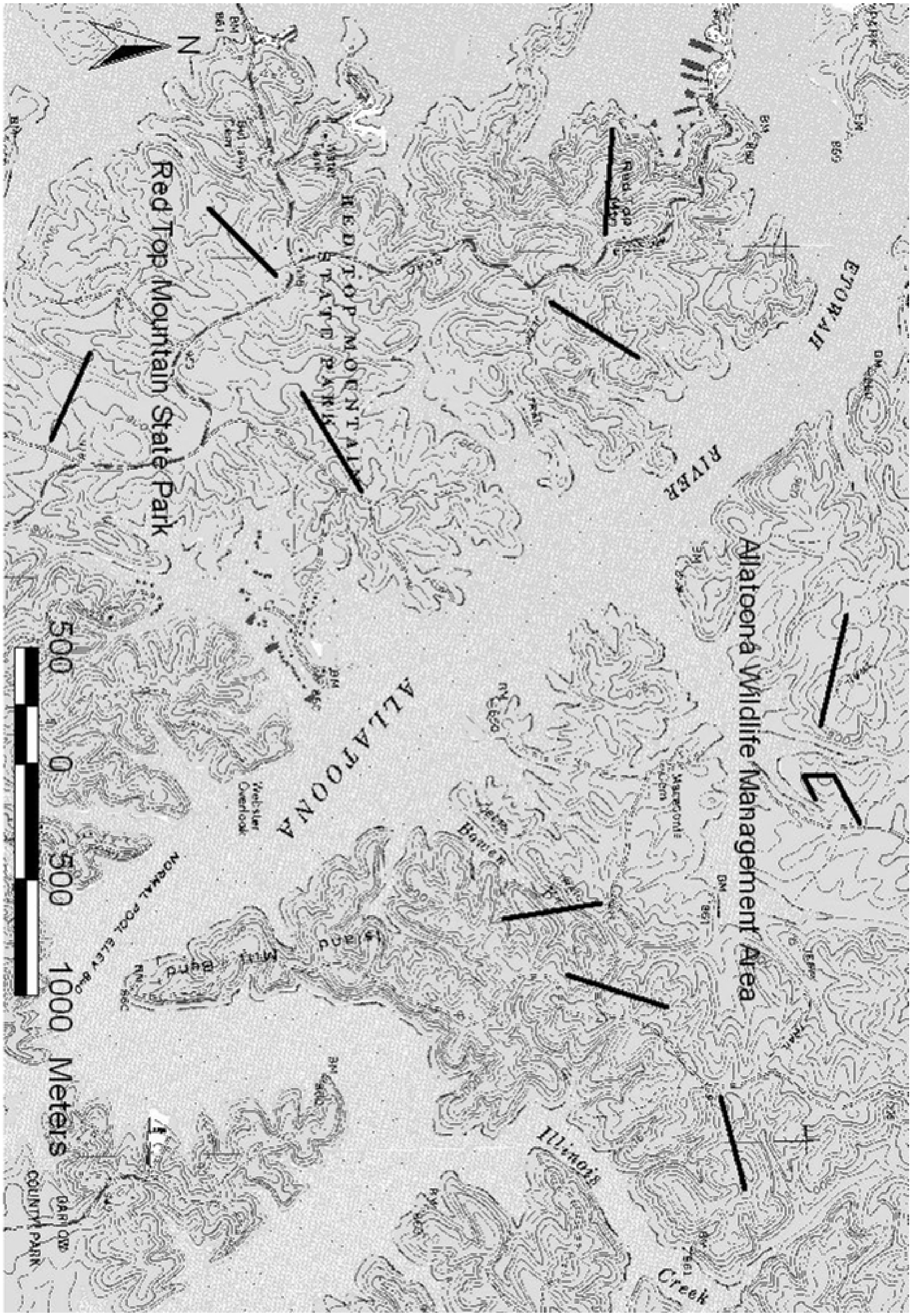

Table 2. Understory plant species occurrence (#/50 plots) in 2003 and 2004 on Red Top Mountain State Park and Allatoona Wildlife Management Area in Bartow County, Georgia.

	AWMA 2003	AWMA 2004	RTMSP 2003	RTMSP 2004
Acer rubrum	4	11	2	8
Aesculus sp.	1			
Agalinis purpurea				1
Amaranthus sp.				1
Amphacarpaea bracteata	1			
Andropogon sp.	1	6	4	
Aristida purpurasens		8		11
Arundinaria gigantea				1
Asarum canadense		4		2
Asimina sp.	1			
Asplenium platyneuron		1		
Aster sp.	2	1		
Bignonia capriolata	1			
Carya tomentosa	12	1	1	1
Celtis laevigata	1			
Celtis tenuifolia				2
Centrosema virginianum				1
Cercis canadensis	3	1	1	
Chamaecrista nictitans				
Chasmanthium sp.	1	3		3
Chasmanthium latifolium				1
Chimaphila maculata	7	7	4	4
Cladonia sp.				1
Clitoria mariana	4	5		1
Cornus florida	2	2		2
Crataegus sp.	1			
Desmodium obtusum		1		
Desmodium sp.	1	1		1
Desmodium strictum		2		
Dichanthelium commutatum	15	12	13	5
Duchesnea indica	1			
Elephantopus sp.		3		
Erichtites hieracifolia			5	
Euonymus americana	1			
Euphorbia sp.	2			
Fagus grandifolia	2			
Geranium sp.		1		
Goodyera pubescens	1			1
Helianthus annuus		2		
Hexastylis sp.	9		2	
Hypericum hypericoides		2		1
Ilex opaca	1	1		1
Ipomoea sp.			1	
Lactuca sp.	2			1
Lespedeza cuneata	1		4	
Lespedeza procumbens				1

Liquidambar styraciflua	4	5	4	3
Liriodendron tulipifera				5
Lonicera japonica	2	1		
Microstegium vimineum	3			1
Mitchella repens		1		
Muhlenbergia schreberi		1		
Nyssa sylvatica	6		1	1
Oxalis sp.			3	
Panicum sp.			7	
Parthenocissus quiquefolia	1		1	
Pinus sp.	7	4	5	6
Pityopsis graminifolia	2	6	1	3
Polystichum acrostichoides	6	2	3	3
Potentilla simplex			1	
Prunus serotina	8	4	1	
Pteridium aqualinum	5	7		
Quercus prinus	6		2	
Quercus sp.	2	4		1
Quercus stellata	4	6		4
Quercus velutina	1	1		2
Quercus alba	3	1	1	
Quercus falcata	1			
Quercus nigra		4		
Quercus umbellata	11		1	
Rhus copallinum		1		
Rubus sp.		2		
Saccharum alopecuroides	1	1	5	1
Sassafras albidum	1		1	
Smilax bona-nox	1	4		
Smilax glauca	1	11	3	9
Smilax rotundifolia		2		3
Smilax sp.	25	8	3	1
Solidago sp.	2	2		
Tephrosia spicata	1	2		
Toxicodendron radicans	2			
Unknown forb	1		3	
Uknown grass	21	21		1
Ulmus alata	1	1	2	1
Vaccinium stamineum	2	1		
Vaccinium angustifolium				1
Vaccinium arboreum	28	17	8	4
Viburnum sp.	15	2	11	
Vitis rotundifolia	3	8		2

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Appendix 2

Health status of deer on a Georgia state park

Unmanaged populations of deer on many state and national parks have reached extremely high densities (Warren 1991). Adverse effects resulting from high densities include negative interactions with humans and damage vegetative communities. As the severity of ecosystem damage increases and habitat quality declines, the physical condition of deer causing the damage declines as well. One such population of deer reached a state of overabundance due to lack of population control (i.e. hunting, predation) for greater than 15 years. Red Top Mountain State Park (RTMSP), located in Cartersville, Georgia, had an isolated and overabundant deer herd whose health was declining. To determine the health status of deer on RTMSP we conducted a herd health assessment.

Methods

We assessed deer herd health on RTMSP in October 2003 before the herd reduction. Five adult deer (2 males and 3 females) were harvested and necropsied to determine general health parameters and parasite loads (Nettles 1981, Davidson et al. 1982). Kidney fat indices were determined by trimming fat to each end of the kidney, separating the fat and outer membrane from the kidney, and then weighing the kidney with and without the fat to determine a ratio. Tail fat was determined subjectively by palpating the base of the tail for padding of fat around bones. Abomasal parasite counts were determined by rinsing the abomasum and contents through a micro-screen to filter out parasites, which are then counted.

Results and Discussion

Mean abomasal counts of the five adult deer sampled on October 6, 2003 was 1,196 (SE=225) (Table 1), indicating the deer herd was near or had exceeded biological carrying capacity (Eve and Kellogg 1977, Eve 1981, Davidson et al. 1982). Kidney fat indices ranged from 7.0 to 38.8 ($\bar{x}$ =15.86, SE=5.8), indicative of poor nutritional condition for adult deer during autumn (Warren and Kirkpatrick 1982). Additional analyses of rumen contents, parasite loads, and blood serology are presented in tables 2, 3, and 4.

Table 1. Biological data collected from five white-tailed deer on Red Top Mountain State Park, Cartersville, Georgia.

Variable	**RTF - 1**	**RTF - 2**	**RTF - 3**	**RTM - 1**	**RTM - 2**
Age (years)	7.5+	2.5	3.5	3.5	1.5
Sex	F	F	F	M	M
Live Weight (kg)	34	34	38	54	29
Physical Condition	Poor	Poor	Poor	Fair	Poor
KFI	10.0	7.0	9.4	38.8	7.7
Lactation	Yes	Yes	Yes	NA	NA
Arthropod Infestations	Louse flies - medium	Louse flies - medium	Louse flies - medium	Louse flies - medium	Louse flies - medium
APC	1860	1600	980	760	780
Lung Worms	2	2	1	8	6
Fly Larvae (Lung Wash)	6	2	19	8	20
Rumen Analysis					
Green Woody Plant Leaves (%)	25	70	50	trace	70
Dead Woody Plant Leaves (%)	-	trace	trace	-	trace
Grass (%)	50	trace	-	trace	trace
Herbaceous Plant Matter (%)	-	-	trace	-	-
Acorns (*Quercus montana) (%)*	12.5	trace	-	100	30
Muscadine (fruit) (%)	-	-	50	-	trace
Crab Apple (fruit) (%)	12.5	30	trace	-	trace
Corn (%)	trace	-	-	-	-

Table 2. Green woody plant species identified in rumen analysis from five white-tailed deer on Red Top Mountain State Park, Cartersville, Georgia.

RTF – 1:	*Vitus* spp., *Quercus* spp., *Oxydendron arboreum, Prunus serotina, Acer rubrum.*
RTF – 2:	*Vitus* spp., *Quercus* spp., *Smilax* spp.
RTF – 3:	*Lonicera japonica*, *Albizia julibrissin*, *Smilax* spp.
RTM – 1:	*Vitus* spp., *Quercus* spp.
RTM – 2:	*Vitus* spp., *Quercus* spp.

Table 3. Parasites collected from five white-tailed deer on Red Top Mountain State Park, Carterville, Georgia.

Location	Helminth	Range	Prevalence	Average
Lungs	D. viviparus			
Abdominal cavity	S. yehi	0-8	40%	2.6
Esophagus	G. pulchrum	40-60+	100	-
Abomasum	N. odocoilei			
	O. dikmansi			
	O. mossi			

Table 4. Serology report from five white-tailed deer on Red Top Mountain State Park, Cartersville, Georgia.

Animal	**B. abortus Card**	**IBR SN**	**BVD Type 1 SN**	**PI3 SN**	**BT AGID**	**EHD AGID**
RTF-1	Negative	Negative	Negative	Negative	Negative	Negative
RTF-2	Negative	Negative	Negative	Negative	Negative	Negative
RTF-3	Negative	Negative	Negative	Negative	Negative	Weak Positive
RTM-1	Negative	Negative	Negative	Negative	Weak Positive	Negative
RTM-2	Negative	Negative	Negative	Negative	Negative	Negative

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