ABSTRACT

SHERRILL, BRANDON LEE. Assessment of White-tailed Deer on Bald Head Island, North Carolina. (Under the direction of Christopher S. DePerno).

In recent years, the white-tailed deer (*Odocoileus virginianus*) population on Bald Head Island, North Carolina has increased. Bald Head Island is ~620 ha and is characterized by live oak (*Quercus virginiana*) maritime forest, dunes, tidal marsh, and urban development. Maritime forests are unique and important coastal habitats that are under significant threat from development, and in the absence of reproductive controls, white-tailed deer can negatively impact ecosystems through over-browsing. Preservation of maritime forest is important for barrier island conservation. Therefore, to provide empirical data that could impact deer management decisions, my objectives were to determine emigration, home range, cover type use, and population density of white-tailed deer on Bald Head Island. From 5 January through 31 March 2008 and 2 January through 31 January 2009, 12 females and one male were chemically immobilized and equipped with VHF radiocollars. From January 2008 through January 2010, a minimum of four visual locations were obtained per animal per month. We used a fixed kernel density estimator to calculate 90% (home range) and 50% (core area) utilization contours for radiocollared female deer (n = 11). To determine cover type use and selection, I used land cover data generated by the Southeast Gap Analysis Project and a Chi-square (χ^2) goodness-of fit test to determine differences between expected and observed use of cover types within home ranges. Significance levels for 95% confidence intervals were determined using the Bonferroni method. From May through August 2008 and 2009, spotlight surveys were conducted and used to generate

population estimates with a Lincoln-Peterson index. No radiocollared white-tailed deer migrated from Bald Head Island during the course of the study and average home range and core areas were 60.73 ha (SE = 5.63) and 15.00 ha (SE = 1.37), respectively. Maritime forest/shrub comprised ~275 ha (44%) of available habitat on Bald Head Island and were used by radiocollared deer at levels greater than available, whereas dune/grasslands were used less than available. All other cover types were used in proportion to availability. Population densities of white-tailed deer were 17 and 15 deer/km^2 for 2008 and 2009, respectively. Based on home range size and cover type selection and until additional research is conducted, I recommend that white-tailed deer populations be managed at current levels to prevent degradation of this important maritime forest ecosystem.

Additionally, white-tailed deer were screened for multiple pathogens to provide baseline data on exposure to zoonotic diseases. Blood was collected from eight deer in January through March 2008 and five deer in January 2009. Serum samples were tested for antibodies to *Anaplasma phagocytophilum*, *Borrelia burgdorferi*, and six serovars of *Leptospira interrogans*, and whole blood samples for DNA from *Bartonella* spp. and *B. burgdorferi*. Serum samples were screened using a polyvalent enzyme-linked immunosorbent assay (ELISA), an indirect fluorescent antibody (IFA) test, or a microscopic agglutination test (MAT). Whole blood samples were screened using conventional polymerase chain reaction (PCR) analysis. All sera were negative for *L. interrogans*, two serum samples tested positive for *A. phagocytophilum*, and one was positive for *B. burgdorferi*. Whole blood PCR results were negative for *Bartonella* spp. and *B. burgdorferi*.

Continued surveillance of wildlife disease is necessary to determine prevalence of specific pathogens, their impacts on the white-tailed deer population, and the risk of human exposure.

Assessment of White-tailed Deer on Bald Head Island, North Carolina

by
Brandon Lee Sherrill

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Fisheries, Wildlife, and Conservation Biology

Raleigh, North Carolina

2010

APPROVED BY:

Christopher S. DePerno Chair of Advisory Committee	Suzanne Kennedy-Stoskopf
Heather M. Cheshire	

DEDICATION

I dedicate my thesis to my Mom and Dad, for their love and support throughout my education; to all my siblings; and especially to Jessie Birckhead, for being a constant source of encouragement and always being willing to listen.

BIOGRAPHY

Brandon Lee Sherrill was born in Statesville, North Carolina on December 10, 1981 to parents Ted and Deborah Sherrill. He has a twin brother, Bryan, younger brother, Chris, and a younger sister, Lauren. Brandon grew up spending much of his free time outdoors, exploring the woods outside his home. He enjoyed fishing, hiking, and photographing nature. After graduating from South Iredell High School in 2000, Brandon spent several years deciding what path he should pursue at the collegiate level. He eventually determined his love of wildlife and the outdoors was leading him to a career in the sciences; preferably dealing with wildlife research and management. He graduated with a Bachelor degree in Fisheries and Wildlife Sciences in 2006 from North Carolina State University. After graduation, Brandon worked as a research technician for North Carolina State University at the Hill Demonstration Forest where he further developed his skills in wildlife research. After several years of working as a research technician, and in other jobs not related to wildlife, Brandon decided to return to school to earn a Master's degree to allow him more opportunities in the field of wildlife research and management. He began his graduate career at North Carolina State University in the Fisheries, Wildlife, and Conservation Biology Program in January 2008. Upon graduation, Brandon would like to pursue a career in wildlife management in a state or federal agency.

ACKNOWLEDGMENTS

This research was funded by the Village of Bald Head Island, North Carolina State University's Department of Forestry and Environmental Resources, Fisheries, Wildlife, and Conservation Biology Program, and the University of North Carolina at Wilmington's Department of Environmental Science. I thank Dr. Chris S. DePerno, Dr. Anthony C. Snider, Dr. Suzanne Kennedy-Stoskopf, and Dr. Heather M. Cheshire for their assistance in the field and with data analysis during this project. A special thanks to Paula Gillikin for her guidance and expertise while collecting our sample of white-tailed deer (and also to Lookout). Dr. Michael Stoskopf and Dr. Sathya Chinnadurai were vital during our initial sampling period, both in the field and via email, by answering numerous questions regarding immobilizing drugs. I thank Dr. John Taggart for his assistance characterizing vegetative communities on Bald Head Island.

A special thanks to all of the undergraduate and graduate students that helped out in field during data collection. The following students helped with the chemical immobilization of white-tailed deer or with collection of telemetry locations: Andy Almeter, Jessie Birckhead, Colter Chitwood, Jimmy Dodson, Lauren Fields, John Henry Harrelson, Doug Noonan, Mike Nunnery, Liz Rivers, and numerous students from UNCW's research techniques course. In addition, I would like to extend my gratitude to the Bald Head Island Conservancy for their constant support of our project through the supply of golf carts, spotlights, and housing. Maureen Dewire, Dr. Suzanne Dorsey, Brett DeGregorio (and especially Nico), and Dr. Thomas Hancock were all very helpful during my stays in the dormitory. Also, I thank the interns at the conservancy who conducted numerous spotlight surveys of white-tailed deer.

There are multiple residents of Bald Head Island that deserve mention for their contributions to the project. Thanks to the George and Martha Hayworth, Doug and Jane Oakley, and James and Margaret Leutze for allowing our team of researchers to use their homes for extended periods of time. Also, I would like to extend a very special thanks to the late Anne Pickering for her enduring support and for the delicious food she provided at the end of some of our long, cold nights in the field.

I thank Cindy Burke for all of her hard work and for her kind spirit in the office. As our program secretary, Cindy was always there to help sort out paperwork, provide guidance, and was always willing to listen to all my stories and problems. Also, I would like to thank all of the faculty and graduate students at the Turner House for all the wonderful years in North Carolina State University's Fisheries, Wildlife, and Conservation Biology Program.

Finally, I would like to thank my family and friends for all their support in my educational career. Daddy, thanks for always being there to talk to and to answer questions I couldn't figure out on my own, and especially for the financial support when the graduate stipend just wasn't enough to get me through the month. Mama, thanks for all your love, and for always being concerned for my well-being. To all my siblings, thanks for being around and hanging out when I could make it back home, as infrequent as it may have been. Colter, thanks for being my "brother" in the office and for being my hunting companion in the woods. Of course, I can't thank Colter without mentioning John Henry. John, thanks for all the years of swapping stories (hunting related and otherwise) and for being a good friend.

Most importantly, I want to thank Jessie for all your love and support. Graduate school would have been much less manageable without having you to listen to all of my stories regarding field work, teaching, and just the everyday events that make up the life of a graduate student.

TABLE OF CONTENTS

LIST OF TABLES

Assessment of White-tailed Deer on Bald Head Island, North Carolina

Introduction:

White-tailed deer (*Odocoileus virginianus*) have the potential to negatively impact forest systems, and in the absence of reproductive controls can negatively impact ecosystems through over-browsing. Over the last decade, the public, the Village of Bald Head Island, and the Bald Head Island Conservancy have become increasingly concerned with the density of the white-tailed deer population on Bald Head Island, North Carolina. During the early 2000's, white-tailed deer density began to increase on Bald Head Island which prompted concern regarding the potential impacts to the maritime forest, the predominant vegetative community of this barrier island. Further, there was a lack of reproductive controls on the white-tailed deer population as hunting was prohibited and there were no natural predators. Hence, to provide managers with empirical data necessary to effectively manage the white-tailed deer population and preserve the integrity of the maritime forest, I conducted research on the white-tailed deer population on Bald Head Island.

From January 2008 to January 2010, I radiocollared 13 white-tailed deer to evaluate emigration, home range, cover type use, and population density on Bald Head Island. Emigration of white-tailed deer could potentially impact management decisions on population control methods (i.e., annual culls, immunocontraception, etc.) implemented by managers. Also, deer home range and cover type use could have implications for conserving maritime forest if deer selectively use this forest over other available habitat. Higher proportionate use of maritime forest, coupled with increased deer density, could negatively impact forest regeneration through over-browsing, thereby hindering the conservation of the maritime forest ecosystem.

Additionally, Bald Head Island managers were interested in determining if white-tailed deer had been exposed to diseases that could have potential health implications for humans and pets on the island. Surveillance of wildlife disease can be an important component in wildlife management if there is public concern over potential exposure risks to wildlife related diseases. Therefore, I surveyed white-tailed deer on Bald Head Island for the presence of select pathogens that have zoonotic potential. Whole blood samples were tested, using polymerase chain reaction (PCR) methods, for *Bartonella* spp. and *Borrelia burgdorferi*. Also, I tested serum samples for total antibodies to six different serovars of *Leptospira interrogans* using a microscopic agglutination test (MAT). Serum samples were tested for antibodies to *Anaplasma phagocytophilum* and *Borrelia burgdorferi* using a polyvalent enzyme-linked assay (ELISA) or an indirect fluorescent antibody (IFA) staining method.

Finally, I provided data on the morphological characteristics of captured white-tailed deer for Bald Head Island managers. I collected measurements on white-tailed deer body weight, total body length, body circumference, and hind foot length. This information could prove useful in future studies of white-tailed deer on Bald Head Island, or in comparative studies conducted in other localities.

White-tailed Deer on a Barrier Island: Implications for Preserving an Ecologically Important Maritime Forest

Brandon L. Sherrill, North Carolina State University, Department of Forestry and Environmental Resources, Fisheries, Wildlife, and Conservation Biology Program, Turner House, Box 7646 Raleigh, NC 27695-7646
Anthony G. Snider, University of North Carolina Wilmington, Department of Environmental Studies, 601 S. College Rd., Wilmington, NC 28403
Christopher S. DePerno, North Carolina State University, Department of Forestry and Environmental Resources, Fisheries, Wildlife, and Conservation Biology Program, Turner House, Box 7646 Raleigh, NC 27695

Abstract:

In recent years, the white-tailed deer (Odocoileus virginianus) population on Bald Head Island, North Carolina has increased, threatening a unique maritime forest in southeastern North Carolina. Bald Head Island is ~620 ha and is characterized by live oak (Quercus virginiana) maritime forest, dunes, tidal marsh, and urban development. Preservation of maritime forest is important for barrier island conservation. Maritime forests are important coastal habitats that are under significant threat from development, and in the absence of reproductive controls, white-tailed deer can negatively impact ecosystems through over-browsing. Therefore, our objectives were to determine emigration, home range, cover type use and selection, and population density of white-tailed deer on Bald Head Island to provide baseline information which could impact deer management decisions. From 5 January through 31 March 2008 and 2 January through 31 January 2009, 12 females and one male were chemically immobilized and equipped with VHF radiocollars. From January 2008 through January 2010, a minimum of four visual locations were obtained per animal per month. We used a fixed kernel density estimator to calculate 90% (home range) and 50%

(core area) utilization contours for radiocollared female deer (n = 11). To determine cover type use and selection, we used land cover data generated by the Southeast Gap Analysis Project and a Chi-square (χ^2) goodness-of fit test to determine differences between expected and observed use of cover types within home ranges. Significance levels for 95% confidence intervals were determined using the Bonferroni method. From May through August 2008 and 2009, spotlight surveys were conducted and used to generate population estimates using Lincoln-Peterson index. No radiocollared white-tailed deer migrated from Bald Head Island during the course of the study and average home range and core areas were 60.73 ha (SE = 5.63) and 15.00 ha (SE = 1.37), respectively. Maritime forest/shrub comprised ~275 ha (44%) of available habitat on Bald Head Island and were used by radiocollared deer at levels greater than available, whereas dune/grasslands were used less than available. All other cover types were used in proportion to availability. Population densities of white-tailed deer were 17 and 15 deer/km^2 for 2008 and 2009, respectively. Based on home range size and cover type selection, and until additional research is conducted, we recommend that white-tailed deer populations be managed at current levels to prevent degradation of important maritime forest habitat.

Key words: Bald Head Island, home range, live oak, maritime forest, Odocoileus virginianus, Quercus virginiana, white-tailed deer

Proc. Annu. Conf. Southeast. Assoc. Fish and Wildl. Agencies : -

---

White-tailed deer (Odocoileus virginianus), in the absence of predators or other reproductive controls, can negatively impact the growth rate and survival of tree seedlings and saplings, shrubs, and herbaceous plants through selective foraging, thereby altering plant species diversity, structural heterogeneity, productivity, succession, and forest regeneration (Huntly 1991, Russell et al. 2001, Horsley et al. 2003, Côté et al. 2004, Forrester et al. 2006). Further, deer can reduce natural diversity of plant communities through monopolization of resources, introduction and spread of disease, and by shifting relative abundance of plant species and causing local extinctions (Temple 1990, Garrott 1993).

In recent years, the white-tailed deer population on Bald Head Island, North Carolina has increased, threatening maritime live oak (Quercus virginiana) forest which is a relatively rare and unique habitat, typically restricted to narrow areas along the inland coastline and barrier islands (Wells 1939, Bourdeau and Oosting 1959, Bellis and Keough 1995). Also, Bald Head Island represents the most northerly range of the cabbage palmetto (Sabal palmetto) (Wells 1939). Natural disturbances inherent to maritime forests, combined with increased urban development and recreational pressure, have contributed to the decline of maritime forest (USFWS 1997, Forrester and Leopold 2006). On Bald Head Island, ~70 ha of maritime forests are preserved through the North Carolina Coastal Reserve (North Carolina Coastal Reserve 2010).

Often, white-tailed deer management is necessary to reduce the population and level of impact on natural ecosystems and private property; however, management of deer populations incites emotional and political conflict among individuals who want to reduce deer population numbers (Diamond 1992, Diefenbach et al. 1997, Russell et al. 2001), individuals who oppose hunting or culling deer (McShea and Rappole 1997, Russell et al. 2001), and land managers who distrust human intervention in "natural" processes within wildlife refuges and preserves (Diamond 1992). Staff from the Bald Head Island Conservancy, a non-profit organization created to protect, preserve, and promote the natural environment of the island, along with researchers from the University of North Carolina at Wilmington, have hypothesized, based on anecdotal evidence and preliminary research, that white-tailed deer negatively impact live oak recruitment on Bald Head Island (S. Dorsey, Bald Head Island Conservancy, pers. commun.). Therefore, to limit the potential impact of white-tailed deer on maritime forest, the Village of Bald Head (i.e., the governmental administration) implemented population control measures to stabilize and possibly reduce white-tailed deer density on the island. During 2003, 2005-2007, and 2009, culling was conducted resulting in the removal of 559 individuals (average = 111.8, range = 71-149 deer/year). Due to increased social and political conflict over the public acceptability and safety concerns of culling, management officials decided to evaluate immunocontraception, a non-lethal control method, as an alternative to lethal control programs to manage the white-tailed deer population. Effective implementation of an immunocontraception program requires quantitative knowledge of the target population (i.e., population size, immigration, emigration, etc.) to project the success of population control measures (Seagle and Close 1996). Migration is an important parameter to consider when using immunocontraceptives, as it can have significant impacts on control of small populations (Seagle and Close 1996). Therefore, our objectives were to determine emigration, home range, cover type use and selection, and population density of white-tailed deer on Bald Head Island to provide managers with baseline data on the population to facilitate more informed management decisions and thereby potentially limit negative impacts to the maritime forest.

STUDY AREA

Bald Head Island was located at the mouth of the Cape Fear River in Brunswick County, North Carolina and was the largest of three relict beach ridges (Bald Head Island, Middle Island, and Bluff Island) collectively referred to as the Smith Island Complex (Cooper and Satterthwaite 1964). Bald Head Island was bounded on the south and east by the Atlantic Ocean, the west by the Cape Fear River, and the north by tidal marsh. The Smith Island Complex was connected to the mainland to the north by a narrow stretch of beach due to the closing of inlets along the coastline between the island complex and Fort Fisher. Bald Head Island, composed of approximately 620 ha of upland habitat, was ~5.6 km long and ~1.2 km wide consisting of successive stages of maritime forest/shrub, dune/grassland, tidal marsh, and urban development (Cooper and Satterthwaite 1964, Ray et al. 2001). Maritime forest/shrub comprised ~275 ha (44%) of Bald Head Island and was characterized by live oak, laurel oak (Quercus hemisphaerica), cabbage palmetto (Sabal palmetto), redbay (Persea borbonia), Carolina laurelcherry (Prunus caroliniana), American holly (Ilex opaca), yaupon (Ilex vomitoria), devilwood (Osmanthus americanus), loblolly pine (Pinus taeda), red mulberry (Morus rubra), wax myrtle (Morella cerifera), eastern redcedar (Juniperus virginiana), American beautyberry (Callicarpa americana), and dogwood (Cornus florida) (Oosting 1954, Bourdeau and Oosting 1959, Cooper and Satterthwaite 1964). Dune/grassland, covered with seaoats (Uniola paniculata) and other salt-resistant herbs, represented ~171 ha (28%) of available habitat and transitioned into open shrub zones of eastern redcedar, wax myrtle and catbrier (Smilax auriculata) (Cooper and Satterthwaite

1964, J. Taggart, University of North Carolina Wilmington, pers. commun.). Tidal marsh consisted of saltmarsh cordgrass (Spartina alterniflora), black needlerush (Juncus roemericanus), and a transitional fringe of saltgrass (Distichlis spicata), sea ox-eye (Borrichia frutescens), and seacoast marshelder (Iva imbricate) and occupied the low saline soils between Bald Head Island and the relict islands to the north (Cooper and Satterthwaite 1964, J. Taggart, University of North Carolina Wilmington, pers. commun.). Developed areas comprised ~85 ha (14%) of the available habitat on Bald Head Island. During the last century, white-tailed deer were removed to control competition with livestock that once occupied Bald Head Island, and were not reported in two comprehensive mammalian surveys conducted in 1964 and 1970 (Ray et al. 2001). The current white-tailed deer population likely immigrated to the island after development began in the mid-1980's (Ray et al. 2001).

METHODS

During January-March 2008 and January 2009, we captured white-tailed deer using a CO_2 powered dart rifle (Model JM Standard, Dan-Inject, Inc., Børkop, Denmark) and a cartridge-fired dart rifle (Pneu-Dart, Williamsport, Pennsylvania, USA) to administer anesthetic drug combinations of Telazol® (1:1 tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and XYLA-JECT® (xylazine hydrocholoride, Phoenix Pharmaceutical, Inc., St. Joseph, Missouri, USA). We immobilized darted deer with an intramuscular injection of 4.4 mg/kg of Telazol® and 2.2 mg/kg of xylazine hydrochloride (Kilpatrick and Spohr 1999, Kreeger et al. 2002). Immobilizing drugs were administered with disposable, 2-cc wire-barbed darts equipped with radiotransmitters (Pneudart, Williamsport, Pennsylvania, USA). If a deer was not fully chemically immobilized when located, we administered 2 mg/kg of KETASET® (ketamine hydrocholride, Fort Dodge Animal Health, Fort Dodge, Iowa, USA) intramuscularly by syringe.

Once immobilized, we applied eye ointment and a blindfold, and monitored body temperature, respiration, pulse rate, and blood oxygen saturation. We excised the dart, flushed the wound with Betadine® (povidone-iodine, Purdue Pharma, L.P., Stamford, Connecticut, USA), and applied antibiotic cream (Neosporin®, Johnson & Johnson, Inc., New Brunswick, New Jersey, USA). Also, as a precautionary measure we administered a 3 ml subcutaneous injection of Bio-Mycin® 200, a broad spectrum antibiotic (oxytetracycline, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, Missouri, USA). We determined sex and age and deer were classified as fawn (<1 yr old), yearling (≥1-<2 yr old), or adult (>2 yr old). We placed a uniquely numbered cattle tag and piglet tag (National Band and Tag, Co., Newport, Kentucky, USA) in the right and left ears, respectively, and fitted each deer with a mortality-sensing VHF radiocollar (TenXsys, Inc., Eagle, Idaho, USA). After processing was complete, we intravenously administered yohimbine hydrochloride at 0.125 mg/kg (YOBINE®; Wildlife Laboratories, Inc., Fort Collins, Colorado, USA). We monitored deer until they were able to regain muscular control to stand and/or leave the processing site. The research protocol was reviewed and approved by the Institutional Animal Care and Use Committee at the University of North Carolina at Wilmington (#2007-017).

From January 2008 through January 2010, we visually located all radiocollared deer a minimum of four times per month to obtain an adequate number of locations per individual (Seaman et al. 1999) for home range analysis using a 2-element antenna and portable radio receiver (Telonics TR-4, Mesa, AZ, USA). Limited funding restricted our ability to conduct research on the island (i.e., transportation, ferry travel, accommodations, etc.) which impacted the number of locations we could obtain per individual. We conducted radio telemetry only during diurnal time periods. Kernohan et al. (1996) failed to detect differences between white-tailed deer home range estimates from diurnal and 24-hr habitat use; therefore, we believe home range estimates from combined, diurnal and nocturnal, telemetry locations would not differ from diurnal-only home range estimates and would produce similar habitat use estimates. Further, we randomized the order in which we tracked individuals during diurnal telemetry sessions to reduce temporal bias within our samples. We recorded locations with a hand-held GPS unit, entered coordinates into ArcMap 9.3.1 (Environmental Systems Research Institute, Inc., Redlands, California, USA) and generated home range and core area estimates with 90% and 50% utilization contours, respectively, using 'Fixed Kernel Density Estimator' and 'Percent Volume Contour' in Hawth's Analysis Tools (Seaman et al. 1999, Beyer 2004, Börger et al. 2006). We tested home range size for normality using Lilliefor's test for normal distribution (Kilpatrick and Spohr 2000). We compared home range size between years for deer with two years of telemetry data using a paired t-test ($P < 0.05$). If home range size did not differ between years, we pooled all locations from individual deer to calculate landscape measurements.

We used land cover data generated by the Southeast Gap Analysis Program (USGS National Gap Analysis Program 2008) in ArcMAP to classify cover type use and availability as open water, development, maritime forest/shrub, dune/grassland, and tidal marsh.

Estimated radiocollared deer cover type use was determined as the average of percent coverage of cover types incorporated within home ranges for the entire study period. A Chi-square (χ^2) goodness-of fit test was used to determine differences between expected and observed use of cover types within home ranges (Neu et al. 1974, Byers et al. 1984, Jelinski 1991). Significance levels for 95% confidence intervals were determined using the Bonferroni method (Neu et al. 1974, Byers et al. 1984).

We conducted spotlight surveys over an established 10 km route from May through September 2008 and 2009. We conducted surveys approximately one hour after sunset using a golf cart traveling ~8 km/hour. We recorded the number deer seen and noted when marked deer (i.e., radiocollared and ear tagged) were spotted. We calculated population estimates using Lincoln-Peterson index [$\tilde{N} = \frac{M(n+1)}{(m+1)}$, $\widetilde{Var} = \left[\frac{M^2(n+1)(n-m)}{(m+1)^2(m+2)}\right]$, $SE = \sqrt{\widetilde{Var}}$, $95\%\ CI = \tilde{N} \pm 1.96\sqrt{\widetilde{Var}}$] via mark-resight data.

RESULTS

During this study, 13 [2008 (n = 8) and 2009 (n = 5)] white-tailed deer were captured. In 2008, we captured one adult male along with one fawn, one yearling, and five adult females. In 2009, we captured one fawn, one yearling, and three adult females. In 2008, the radiocollar of the one male captured failed one week after deployment and in 2009, one female deer was injured from a vehicle collision and euthanized two weeks after being collared; neither deer were included in the analyses.

All radiocollared female deer (n = 11) were located on Bald Head Island or on small hammocks (islands) in marshes between Bald Head and Middle Islands throughout the two year survey period; no radiocollared deer emigrated from Bald Head Island to the mainland. We collected an average of 70 locations (range = 23-89) per individual for home range analysis. Mean 90% home range was 60.73 ha (SE = 5.63, range = 38-93 ha) and mean 50% core area was 15.00 ha (SE = 1.37, range = 9-22 ha) for all monitored deer. No differences were detected in annual home range size ($t = 1.85$, $df = 6$, $P = 0.11$) for deer with two years of data, therefore, we pooled telemetry locations to estimate home range estimates and landscape measurements. Maritime forest/shrub was used by radiocollared deer at levels greater than available, whereas dune/grassland was used less than available (Table 1). Open water, developed, and tidal marsh cover types were used in proportion to availability (Table 1).

In 2008, 30 spotlight surveys were conducted and we estimated the population at 106.5 (SE = 17.8, CI = ± 34.9) equating to ~17 deer/km^2. In 2009, 34 surveys were conducted and we estimated the population at 93.4 (SE = 27.8, CI = ± 54.5) equating to ~15 deer/km^2.

DISCUSSION

In recent decades, deer populations in urban, suburban, and natural areas have increased, and there is evidence of damage to forest vegetation, crops, and wildlife habitat attributable to deer (Horsley et al. 2003). This increase has escalated the need for intensive management of this species; however, social and political acceptability of lethal control methods for wildlife populations often dictates the need for alternative, non-lethal, control programs. Our research focused on deer home range and emigration to provide baseline data to effectively manage deer using non-lethal methods. During this study, no radiocollared deer emigrated from the Smith Island Complex as female deer often show site fidelity across seasons and years (Beier and McCullough 1990). Home ranges of white-tailed deer on Bald Head Island were confined to the island and the surrounding marsh and hammocks. Our home range estimates for white-tailed deer were similar to those generated by studies conducted on some suburban and exurban populations (Cornicelli et al. 1996, Kilpatrick and Spohr 2000, Etter et al. 2002), larger than estimates from other urban and suburban populations (Grund et al. 2002, Porter et al. 2004), but smaller than estimates from rural populations (Tierson et al. 1985, Nixon et al. 1991, Campbell et al. 2004). Home range estimates vary significantly by locality and analysis method; therefore, conclusions from comparisons between studies should be made with caution. White-tailed deer could immigrate to Bald Head Island from the mainland through the river and marshes located to the west/northwest, or down the beach from the north; however, further research is necessary to document movement of deer to Bald Head Island.

Barrier islands in the southeastern United States are usually considered to be low quality habitat for white-tailed deer and even the best quality southern forest systems sustain white-tailed deer densities of ~19 deer/km^2 (Stransky 1969, Osborne et al. 1992); however, some of these island habitats have supported densities as high as 40 deer/km^2, despite low deer reproductive rates, infertile soils, poor-quality forage, and high annual harvest (Osborne et al. 1992). In 1999, spotlight surveys on Bald Head and Middle Islands indicated a deer density of ~21 deer/km^2 (Ray et al. 2001). However, during the mid-2000's, anecdotal evidence (i.e., from Bald Head Island Conservancy staff and island residents) and data from spotlight surveys conducted by other researchers indicated an increase in the white-tailed deer population and by 2004 the deer density was ~80 deer/km^2 (M. Dewire, Bald Head Island Conservancy, pers. commun.). Concern over impacts of increased deer density led Bald Head Island managers to implement annual deer culls in 2003, 2005-2007, and 2009 to reduce the population. Interestingly, after several years of culling, our population estimates from 2008-2009 indicated the white-tailed deer density was between 15-17 deer/km^2, suggesting that culling was effective in reducing the population.

Although we present Lincoln-Peterson estimates from spotlight surveys, these estimates are simply an index of the population and spotlight surveys can have limited value to managers for obtaining accurate estimates of abundance of white-tailed deer populations (Rakestraw et al. 1998, Collier et al. 2007). McCullough and Hirth (1988) concluded that it is difficult to derive accurate estimates of white-tailed deer by mark-resight methods; but the methods are useful for monitoring trends in populations over time if biases are consistent. We provided Bald Head island managers with population size estimates as an index by which to gauge the temporal success of population control programs. Seagle and Close (1996) suggested that simple population indices are acceptable for monitoring success of management programs where intensive population management for a maximum sustainable harvest is not a priority. Future estimates of white-tailed deer populations should account for biases associated with this survey technique, and possibly incorporate additional techniques (e.g., camera surveys, forward looking infrared, etc.).

Increased urban development on barrier islands, including Bald Head Island, has significantly impacted maritime forests. Although white-tailed deer have been culled and a preserve created to protect the maritime forest, increased browsing pressure from white-tailed deer could prevent recruitment of live oak seedlings, thereby altering the vegetative structure of this unique forest type. Our results revealed that female white-tailed deer selected maritime forest/shrub at levels greater than available which could potentially impact forest regeneration. Also, increased development on Bald Head Island could cause deer to use maritime forest/shrub even more disproportionally, accelerating forest degradation.

Preservation of the maritime forest is important and should incorporate white-tailed deer management, and account for urban development and the social carrying capacity of deer on the island. To assess the ecological impact white-tailed deer have on the maritime forest of Bald Head Island, future research must incorporate detailed vegetation studies and diet analyses of white-tailed deer to determine the carrying capacity of the island. This information, along with more precise estimates of population density will allow for sound white-tailed deer management.

MANAGEMENT IMPLICATIONS

Although controversial, lethal control methods have been effective at maintaining the deer population at a level that maintains the integrity of the maritime forest. The use of immunocontraception has been proposed as an alternative means of population control on Bald Head Island. For birth control methods to be effective, emigration of white-tailed deer from Bald Head Island needs to be minimal. Our results indicated that radiocollared white-tailed deer are year round residents on Bald Head Island; however, less is known about the movement of white-tailed deer on the mainland. Our population estimates of white-tailed deer densities are consistent with what barrier islands can sustain based on available research (Stransky 1969, Osborne et al. 1992). At the current population densities, no data, or anecdotal evidence, has been presented to suggest that deer are causing extensive damage to the maritime forest (i.e., browse lines). Based on our research, white-tailed deer select maritime/shrub over other available cover types which could potentially threaten this forest system if deer density increases. Therefore, until further research is conducted, such as deer diet analysis and vegetation surveys to quantify changes in structure and composition, we recommend maintaining the deer population at current levels. Also, we recommend that managers continue current population surveys and attempt to reduce confidence intervals around population estimates. White-tailed deer management will depend on the Village of Bald Head Island's objectives, the social carrying capacity of deer, deer density, and available habitat. Integration of research and white-tailed deer management will be necessary to ensure the integrity of the unique and fragile maritime forest is maintained.

ACKNOWLEDGMENTS

We would like to thank undergraduate and graduate students from North Carolina State University and University of North Carolina at Wilmington that volunteered their time to assist in data collection. Also, we thank Drs. M. Stoskopf and S. Kennedy-Stoskopf for their consultation in the field and assistance in the lab, Dr. S. Dorsey and M. Dewire for their assistance on Bald Head Island, and P. Gillikin for her assistance and knowledge in the field. This study was funded by the Village of Bald Head Island, the Fisheries and Wildlife Sciences Program at North Carolina State University, the Department of Environmental

Studies at the University of North Carolina at Wilmington, and the Bald Head Island Conservancy. We thank M.C. Chitwood, S. Kennedy-Stoskopf, and H. Cheshire for comments on previous drafts.

LITERATURE CITED

Beier, P., and D.R. McCullough. 1990. Factors influencing white-tailed deer activity and habitat use. Wildlife Monographs 109:1-51

Bellis, V.J., and J.R. Keough. 1995. Ecology of maritime forests of the Southern Atlantic Coast: a community profile. Biological Report 30. U.S. Department of the Interior, National Biological Service, Washington, D.C.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. http://www.spatialecology.com/htools.

Börger, L., N. Franconi, G. De Michele, A. Gantz, F. Meschi, A. Manica, S. Lovari, and T. Coulson. 2006. Effects of sampling regime on the mean and variance of home range size estimates. Journal of Animal Ecology 75:1393-1405.

Bourdeau, P.F., and H.J. Oosting. 1959. The maritime live oak forest in North Carolina. Ecology 40:148-152.

Byers, C.R., R.K. Steinhorst, and P.R. Krausman. 1984. Clarification of a technique for analysis of utilization-availability data. The Journal of Wildlife Management 48:1050-1053.

Campbell, T.A., B.R. Laseter, W.M. Ford, and K.V. Miller. 2004. Topographic home ranges of white-tailed deer in the central Appalachians. Southeastern Naturalist

3:654-652.

Collier, B.A., S.S. Ditchkoff, J.B. Raglin, and J.M. Smith. 2007. Detection probability and sources of variation in white-tailed deer spotlight surveys. Journal of Wildlife Management 71:277-281.

Cooper, A.W., and S. Satterthwaite. 1964. Smith Island and the Cape Fear Peninsula: a comprehensive report on an outstanding natural area. Wildlife Preserves, Inc., Raleigh, North Carolina, USA.

Cornicelli, L.A., A. Woolf, and J.L. Roseberry. 1996. White-tailed deer use of a suburban environment in southern Illinois. Transactions of the Illinois State Academy of Science 89:93-103.

Côté, S.D., T.P. Rooney, J. Tremblay, C. Dussault, and D. M. Waller. 2004. Ecological impacts of deer overabundance. Annual Reviews of Ecology, Evolution, and Systematics 35:113-147.

Diamond, J. 1992. Must we shoot to save nature? Natural History 8:2-8.

Diefenbach, D.R., W.L. Palmer, and W.K. Shope. 1997. Attitudes of Pennsylvania sportsmen towards managing white-tailed deer to protect the ecological integrity of forests. Wildlife Society Bulletin 25:244-251.

Etter, D.R., K.M. Hollis, T.R. Van Deelen, D.R. Ludwig, J.E. Chelsvig, C.L. Anchor, and R.E. Warner. 2002. Survival and movements of white-tailed deer in suburban Chicago, Illinois. Journal of Wildlife Management 66:500-510.

Forrester, J.A., and D.J. Leopold. 2006. Extant and potential vegetation of an old-growth maritime Ilex opaca forest. Plant Ecology 183:349-359.

_____, _____, and H.B. Underwood. 2006. Isolating the effects of white-tailed deer on the vegetation dynamics of a rare maritime American holly forest. American Midland Naturalist 156:135-150.

Garrott, R.A., P.J. White, and C.A. Vanderbilt White. 1993. Overabundance: an issue for conservation biologists? Conservation Biology 7:946-949.

Grund, M.D., J.B. McAninch, and E.P. Wiggers. 2002. Seasonal movements and habitat use of female white-tailed deer associated with an urban park. Journal of Wildlife Management 66:123-130.

Horsley, S.B., S.L. Stout, and D.S. DeCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13:98-118.

Huntly, N. 1991. Herbivores and the dynamics of communities and ecosystems. Annual Review of Ecology and Systematics 22:477-503.

Jelinski, D.E. 1991. On the use of chi-square analyses in studies of resource utilization. Canadian Journal of Forest Research 21:58-65.

Kernohan, B.J., J.A. Jenks, D.E. Naugle, and J.J. Millspaugh. 1996. Estimating 24-h habitat use patterns of white-tailed deer from diurnal use. Journal of Environmental Management 48:299-303.

Kilpatrick, H.J., and S.M. Spohr. 1999. Telazol-Xylazine versus Ketamine-Xylazine: a field evaluation for immobilizing white-tailed deer. Wildlife Society Bulletin 27:566-570.

_____, and _____. 2000. Movements of female white-tailed deer in a suburban landscape: a management perspective. Wildlife Society Bulletin 28:1038-1045.

Kreeger, T.J., J.M. Arnemo, and J.P. Raath. 2002. Handbook of wildlife chemical immobilization: international edition. Wildlife Pharmaceuticals, Fort Collins, Colorado.

McCullough, D.R., and D.H. Hirth. 1988. Evaluation of the Peterson-Lincoln estimator for a white-tailed deer population. Journal of Wildlife Management 52:534-544.

McShea, W.J., and J.H. Rappole. 1997. The science and politics of managing deer within a protected area. Wildlife Society Bulletin 25:443-446.

Neu, C.W., C.R. Byers, and J.M. Peek. 1974. A technique for analysis of utilization-availability data. The Journal of Wildlife Management 38:541-545.

Nixon, C.M., L.P. Hansen, P.A. Brewer, and J.E. Chelsvig. 1991. Ecology of white-tailed deer in an intensively farmed region of Illinois. Wildlife Monographs 118:1-77.

North Carolina Coastal Reserve (NCCR). 2010. Bald Head Woods. NCCR. http://www.nccoastalreserve.net/About-The-Reserve/Reserve-Sites/Bald-Head Woods/86.aspx.

Oosting, H.J. 1954. Ecological processes and vegetation of the maritime strand in the southeastern United States. Botanical Review 20:226-262.

Porter, W.F., H.B. Underwood, and J.L. Woodard. 2004. Movement behavior, dispersal, and the potential for localized movement of deer in a suburban environment. Journal of Wildlife Management 68:247-256.

Rakestraw, D.L., R.J. Stapper, D.B. Fagre, and N.J. Silvy. 1998. A comparison of precision for three deer survey techniques. Proceedings of the Southeastern Association of Fish and Wildlife Agencies 52:283-293.

Ray, D.K., E.G. Bolen, and W.M.D. Webster. 2001. Characteristics of a barrier island deer population in the southeastern United States. The Journal of the Elisha Mitchell Scientific Society 117:113-122.

Russell, F.L., D.B. Zippin, and N.L. Fowler. 2001. Effects of white-tailed deer (Odocoileus virginianus) on plants, plant populations and communities: a review. American Midland Naturalist 146:1-26.

Seagle, S.W., and J.D. Close. 1996. Modeling white-tailed deer Odocoileus virginianus population control by contraception. Biological Conservation 76:87-91.

Seaman, D. E., J.J. Millspaugh, B.J. Kernohan, G.C. Brundige, K.J. Raedeke, and R.A. Gitzen. 1999. Effects of sample size on kernel home range estimates. Journal of Wildlife Management 63:739-747.

Stransky, J.J. 1969. Deer habitat quality for major forest types in the South. Pages 42-45 in L.K. Halls, editor. White-tailed deer in the southern forest habitat. Proceedings of a symposium at Nacogdoches, Texas. U.S. Forest Service, Southern Forest Experiment Station.

Temple, S.A. 1990. The nasty necessity: eradicating exotics. Conservation Biology 5:113-115.

Tierson, W.C., G.F. Mattfeld, R.W. Sage, Jr., and D.F. Behrend. 1985. Seasonal movements and home ranges of white-tailed deer in the Adirondacks. Journal of Wildlife Management 49:760-769.

United States Fish and Wildlife Service (USFWS). 1997. Significant habitats and habitat complexes of the New York Bight Watershed. Southern New England – New York

Bight Coastal Ecosystems Program. Charleston, Rhode Island.

Wells, B.W. 1939. A new forest climax: the salt spray climax of Smith Island, N. C. Bulletin of the Torrey Botanical Club 66:629-634.

U.S. Geological Survey (USGS) National Gap Analysis Program. 2008. Provisional Southeast GAP Regional Land Cover 2001. Biodiversity and Spatial Information Center, North Carolina Cooperative Fish and Wildlife Research Unit, NC State University. http://www.basic.ncsu.edu/segap/

Table 1: Use-availability data and simultaneous confidence intervals using the Bonferroni approach for cover type use by female white-tailed deer (n = 11) on Bald Head Island, North Carolina**,** 2008 – 2010.

Cover type	**Total area (ha)**	**Expected proportion of use**	**Actual proportion of use**	**Bonferroni intervals for P**
Open Water	6.6	0.011	0.009	$-0.015 \leq P \leq 0.033$
Developed	85.3	0.138	0.084	$0.014 \leq P \leq 0.154$
Maritime Forest/Shrub	276.3	0.445	0.668	$0.550 \leq P \leq 0.790$*
Dune/Grassland	177.1	0.285	0.113	$0.034 \leq P \leq 0.192$*
Tidal Marsh	74.7	0.121	0.126	$0.043 \leq P \leq 0.210$
Total	620.0	1.000	1.000	

* Indicates a significant difference at the 0.05 level

Survey of Zoonotic Pathogens in White-tailed Deer on Bald Head Island, North Carolina

Abstract:

White-tailed deer (*Odocoileus virginianus*) on Bald Head Island, North Carolina, USA, a barrier island that has experienced steady urban development over the past several decades, were screened for multiple zoonotic pathogens. Blood was collected from eight deer in January through March 2008 and five deer in January 2009. We tested serum samples for antibodies to *Anaplasma phagocytophilum*, *Borrelia burgdorferi*, and six serovars of *Leptospira interrogans*, and whole blood samples for DNA from *Bartonella* spp. and *B. burgdorferi*. Serum samples were screened using either a polyvalent enzyme-linked immunosorbent assay (ELISA), an indirect fluorescent antibody (IFA) staining method, or a microscopic agglutination test (MAT). Whole blood samples were screened using conventional polymerase chain reaction (PCR) analysis. All sera were negative for *L. interrogans*, two serum samples tested positive for *A. phagocytophilum*, and one was positive for *B. burgdorferi*. Whole blood PCR results were negative for *Bartonella* spp. and *B. burgdorferi*. Continued surveillance of wildlife disease is necessary to determine prevalence of specific pathogens, their impacts on the white-tailed deer population, and the risk of exposure to humans and pets on Bald Head Island.

Surveillance is an integral component to identify and manage zoonotic diseases (Belant and Deese, 2010). Bald Head Island, North Carolina, USA (~33°51‘N, ~77°59‘W) is an affluent golf course community with a relatively high density white-tailed deer population. Residential development began during the 1980's, and by the early 2000's the number white-tailed deer on the island increased to a level that required managers to implement a population control program (i.e., annual culls) (Sherrill et al., In Press). As deer density increased, concerns related to deer impacts to forested habitat and public health (i.e., risk of disease exposure to humans and pets) also increased; therefore, during January-March 2008 and January 2009, I captured white-tailed deer using a CO_2 powered dart rifle (Model JM Standard, Dan-Inject, Inc., Børkop, Denmark) or a cartridge-fired dart rifle (Pneu-Dart, Williamsport, Pennsylvania, USA) to collect blood samples to test for the presence of select pathogens. I immobilized deer with an intramuscular injection of 4.4 mg/kg of Telazol® (1:1 tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and 2.2 mg/kg of XYLA-JECT® (xylazine hydrocholoride, Phoenix Pharmaceutical, Inc., St. Joseph, Missouri, USA) (Kreeger et al., 2002, Sherrill et al., In Press). I collected blood samples via jugular venipuncture to obtain a minimum of 6 ml for whole blood and 10 ml to be centrifuged for serum to analyze for presence of select pathogens. Serum samples were centrifuged within 30 minutes after collection, and all samples were frozen. Additionally, external parasite loads were evaluated and individuals were assigned a qualitative health score (i.e., poor, fair. good, excellent) based on overall physical condition. Parasite loads and health scores were evaluated simply to provide Bald Head Island managers with a subjective assessment of the overall health of the white-tailed deer population. The research protocol was reviewed and approved by the Institutional Animal Care and Use Committee at the University of North Carolina at Wilmington (#2007-017).

I sent serum to the Connecticut Agricultural Experiment Station to detect total antibodies to strain 2591 and recombinant antigen VlsE (VlsE1-HIS) of *Borrelia burgdorferi*, and separate recombinant protein (p) 44 antigen of *Anaplasma phagocytophilum* using a polyvalent enzyme-linked immunosorbent assay (ELISA) (Magnarelli et al., 1999, 2004). Also, indirect fluorescent antibody (IFA) staining methods were used to detect antibodies to strain NCH-1 of *A. phagocytophilum* (Magnarelli et al., 1999). I sent serum samples to the Michigan State University Diagnostic Center for Population and Animal Health to be tested for agglutinating antibodies against *Leptospira interrogans* (serovars *bratislava*, *canicola*, *grippotyphosa*, *hardjo*, *icterohemorrhagica*, and *pomona*) using a microscopic agglutination test (MAT) (Cole et al., 1973). I sent whole blood samples to North Carolina State University College of Veterinary Medicine to screen for *Bartonella* spp. (Diniz et al., 2007) and *B. burgdorferi* (Maggi et al., In Press) using polymerase chain reaction (PCR) analyses.

During this study, 13 [2008 (n = 8) and 2009 (n = 5)] white-tailed deer were chemically immobilized and radiocollared. In 2008, I captured one adult male along with one fawn, one yearling, and five adult females. In 2009, I captured one fawn, one yearling, and three adult females. All test results for *Bartonella* spp. and *L. interrogans* were negative. One female was seropositive for the p44 recombinant *A. phagocytophilum* antigen with antibody titers of 1:320. The male was seropositive for p44 recombinant antigen and strain NCH-1 of *A. phagocytophilum* with antibody titers of 1:256 and 1:320, respectively. All PCR results from whole blood samples were negative for *B. burgdorferi*; however, the male serum sample positive for *A. phagocytophilum* was also positive for the VlsE-1 recombinant *B. burgdorferi* antigen with antibody titers of 1:640. All antibody-positive and –negative sera were retested to assess reproducibility of results. Further, qualitative health scores of all chemically immobilized deer were evaluated as good (n = 2) or excellent (n = 11) and parasite loads were low.

Human exposure to Lyme disease, human granulocytic ehrlichiosis (HGE), and other zoonotic pathogens is a concern for residents in close proximity to high density deer populations. *Borrelia burgdorferi*, the causative agent of Lyme disease (Frank et al., 1998), and *A. phagocytophilum*, the agent of HGE (Walker and Dumler, 1996), have been reported in regions where the black-legged tick (*Ixodes scapularis*) occurs, and white-tailed deer are important hosts for motile stages of this tick (Magnarelli et al., 2004). Deer can serve as reservoir hosts of infectious diseases, and as sentinels for human diseases; therefore, epidemiologic surveillance can be useful in identifying potential exposure risks to zoonotic diseases (Wolf et al., 2008).

Serological results for *A. phagocytophilum* and *B. burgdorferi* indicate the occurrence of these pathogens on Bald Head Island. Although our sample size is relatively small, it represents approximately 12-14% of the white-tailed deer population on Bald Head Island (Sherrill et al., In Press). Future research should incorporate increased sampling and investigate primary vectors of these pathogens to determine prevalence of disease on Bald Head Island and provide a measure of relative risk of exposure to wildlife and humans. I believe initial results from my analyses indicate there is the potential for human exposure to these pathogens.

This project was funded by the Village of Bald Head Island, North Carolina State University, and the University of North Carolina at Wilmington. I thank the numerous undergraduate and graduate students from both universities who volunteered on this project. In addition, I thank staff at the Bald Head Island Conservancy for their support.

LITERATURE CITED

Belant, J. L. and A. R. Deese. 2010. Importance of wildlife disease surveillance. Human Wildlife Interactions 4:165-169.

Cole, J. R., Jr., C. R. Sulzer, and A. R. Pursell. 1973. Improved microtechnique for the leptospiral microscopic agglutination test. Applied Microbiology 25:976-980.

Diniz, P. P. V. P, R. C. Maggi, D. S. Schwartz, M. B. Cadenas, J. M. Bradley, B. Hegarty, and E. B. Breitschwerdt. 2007. Canine bartonellosis: serological and molecular prevalence in Brazil and evidence of co-infection with *Bartonella henselae* and *Bartonella vinsonii* subsp. *berkhoffii*. Veterinary Research 38: 697-710.

Frank, D. H., D. Fish, and F. H. Moy. 1998. Landscape features associated with Lyme disease risk in a suburban residential environment. Landscape Ecology 13:27-36.

Kreeger, T.J., J.M. Arnemo, and J.P. Raath. 2002. Handbook of wildlife chemical immobilization: international edition. Wildlife Pharmaceuticals, Fort Collins, Colorado.

Maggi, R. G., S. Reichelt, M. Toliver, B. Engber. In Press. *Borrelia* species in *Ixodes affinis* and *Ixodes scapularis* ticks collected from the Coastal Plain of North Carolina. Ticks and Tick Borne Diseases.

Magnarelli, L. A., J. W. IJdo, K. C. Stafford III, and E. Fikrig. 1999. Infections of granulocytic ehrlichiae and *Borrelia burgdorferi* in white-tailed deer in Connecticut.

Journal of Wildlife Diseases 35:266-274.

_____, _____, U. Ramakrishnan, D. W. Henderson, K. C. Stafford III, and E. Fikrig. 2004. Use of recombinant antigens of *Borrelia burgdorferi* and *Anaplasma phagocytophilum* in enzyme-linked immunosorbent assays to detect antibodies in white-tailed deer. Journal of Wildlife Diseases 40:249-258.

Sherrill, B. L., A. Snider, and C. S. DePerno. In Press. White-tailed deer on a barrier island: Implications for preserving an ecologically important maritime forest. Proceedings of the Annual Conference of the Southeastern Association of Fish and Wildlife Agencies.

Walker, D. H., and J. S. Dumler. 1996. Emergence of the ehrlichiosis as human health problems. Emerging Infectious Diseases 2:18-29.

Wolf, K. N., C. S. DePerno, J. A. Jenks, M. K. Stoskopf, S. Kennedy-Stoskopf, C. C. Swanson, T. J. Brinkman, R. G. Osborn, and J. A. Tardiff. 2008. Selenium status and antibodies to selected pathogens in white-tailed deer (*Odocoileus virginianus*) in southern Minnesota. Journal of Wildlife Diseases 44:181-187.

Conclusions

Baseline information collected on white-tailed deer on Bald Head Island will allow managers to more effectively manage the deer population. I determined that radiocollared white-tailed deer remained resident on Bald Head Island through the duration of the sampling period which could have implications for determining appropriate population control methods. Additionally, white-tailed deer used maritime forest at a higher proportion than it is available. If deer density continues to increase, there is the potential for negative impacts to vegetation through over-browsing which could prove detrimental to conservation efforts in maintaining the integrity of the maritime forest.

Exposure to zoonotic diseases is often a concern in areas where wildlife populations are in close proximity to humans. On Bald Head Island, I sampled white-tailed deer for several pathogens to determine if I could detect the presence of disease. Tests for *Bartonella* spp. and *Leptospira interrogans* were negative for all samples. Two deer tested positive for *Anaplasma phagocytophilum* and one tested positive for *Borrelia burgdorferi*. Given my results, there is the potential for human, and pet, exposure to diseases related to white-tailed deer. However, additional research is necessary to determine the actual prevalence of diseases and their potential impacts to human health.

Future research should attempt to quantify the actual impacts white-tailed deer have on the maritime forest. Vegetation studies within the forest should determine if white-tailed deer browsing alters the diversity and abundance of species within the forest community. Additionally, deer diet analyses should be conducted to determine if deer selectively forage on specific plant species within the maritime forest. This could include microhistological analysis of deer fecal samples or examination of rumen content to identify plant species that were consumed. Also, managers should continue to monitor the density of the deer population to determine the carrying capacity of the island, and to provide an index to gauge the effectiveness of population control methods.

I encourage the managers of Bald Head Island to consider the information provided in this thesis, along with information from future research, when determining management options for controlling the white-tailed deer population. Public perception and opinion often drive the decision-making process regarding the management of wildlife populations; however, it is important to incorporate empirical data, obtained through scientific research, in any decision making process. Managers will have to balance the natural and social carrying capacity of white-tailed deer on Bald Head Island to effectively manage this population and conserve the ecologically important maritime forest.

APPENDICES

Appendix A

Report: A Brief Survey of Morphological Characteristics of White-tailed Deer on Bald Head Island, North Carolina

BACKGROUND

External white-tailed deer morphology can vary by geographic region and be affected by genetics, food availability and population density (Wolverton et al. 2009). On Bald Head Island, North Carolina I chemically immobilized white-tailed deer to estimate movement, home range, cover type use, and to assess the presence of select pathogens. Additionally, I collected several external measurements to provide baseline data on white-tailed deer morphology.

Bald Head Island was located at the mouth of the Cape Fear River in Brunswick County, North Carolina and was the largest of three relict beach ridges (Bald Head Island, Middle Island, and Bluff Island) collectively referred to as the Smith Island Complex (Cooper and Satterthwaite 1964). Bald Head Island was bounded on the south and east by the Atlantic Ocean, the west by the Cape Fear River, and the north by tidal marsh. The Smith Island Complex was connected to the mainland to the north by a narrow stretch of beach due to the closing of inlets along the coastline between the island complex and Fort Fisher. Bald Head Island, composed of approximately 620 ha of upland habitat, was 5.6 km long and 1.2 km wide consisting of successive stages of maritime forest/shrub, dune/grassland, tidal marsh, and urban development (Cooper and Satterthwaite 1964, Ray et al. 2001).

METHODS

White-tailed deer were chemically immobilized (as described in Chapter 1) from January-March 2008 and January 2009. Once immobilized, I applied eye ointment and a blindfold, and monitored body temperature, respiration, pulse rate, and blood oxygen saturation. I determined sex and age and deer were classified as fawn (<1 yr old), yearling (≥1-<2 yr old), or adult (>2 yr old). I placed a uniquely numbered cattle tag and piglet tag (National Band and Tag, Co., Newport, Kentucky, USA) in the right and left ears, respectively, and fitted each deer with a mortality-sensing VHF radiocollar (TenXsys, Inc., Eagle, Idaho, USA).

I measured several morphological characteristics of captured white-tailed deer including body weight, total body length (along the curve of the spine, from tip of snout to base of tail), body circumference (at the sternum), and hind foot length (from point of hock to tip of hoof). The research protocol was reviewed and approved by the Institutional Animal Care and Use Committee at the University of North Carolina at Wilmington (#2007-017).

RESULTS

Measurements collected from immobilized white-tailed deer varied by individual (Table 1). Body weight was not collected for one male and one adult female, but all other morphological characteristics were measured for each individual. Average adult female body weight, total body length, body circumference, and hind foot length were 39.8 kg (SE = 1.2), 122.6 cm (SE = 2.1), 84.5 cm (SE = 0.7), and 40.7 cm (SE = 0.3), respectively. Average yearling female body weight, total body length, body circumference, and hind foot length were 31.8 kg (SE = 5.5), 116.8 cm (SE = 9.8), 76.0 cm (SE = 4.6), and 39.2 cm (SE = 0.9), respectively. Average fawn female body weight, total body length, body circumference, and hind foot length were 26.6 kg (SE = 0.3), 117.0 cm (SE = 3.5), 73.8 cm (SE = 2.3), and 39.2 cm (SE = 0.3), respectively.

DISCUSSION

Bald Head Island provided a favorable location for a deer population study because predation, automobile collisions, and emigration are minimal and hunting is absent. This study provided useful baseline information of white-tailed deer on Bald Head Island, which can be used in future research to observe changes in morphology on a temporal scale, or compare insular populations to those in mainland habitats. Geographic distribution and genetics can influence white-tailed deer morphology; genetically isolated large mammal populations on islands are characteristically smaller than mainland populations, especially when population density is high and food resources are over-exploited (Brisbin and Lenarz 1984). White-tailed deer density on Bald Head Island has been relatively high for the past decade and mangers have implemented yearly culls to control the population level. Increased deer density, and the impact to food resources, may be affecting deer morphology; however, increased sampling over multiple years will be necessary to quantify changes in morphology and to determine the contributing factors.

LITERATURE CITED

Brisbin, I.L., Jr., and M.S. Lenarz. 1984. Morphological comparisons of insular and mainland populations of southeastern white-tailed deer. Journal of Mammalogy 65:44-50.

Cooper, A.W., and S. Satterthwaite. 1964. Smith Island and the Cape Fear Peninsula: a comprehensive report on an outstanding natural area. Wildlife Preserves, Inc., Raleigh, North Carolina, USA.

Ray, D.K., E.G. Bolen, and W.M.D. Webster. 2001. Characteristics of a barrier island deer population in the southeastern United States. The Journal of the Elisha Mitchell Scientific Society 117:113-122.

Wolverton, S., M.A. Huston, J.H. Kennedy, and K. Cagle. 2009. Conformation to Bergmann's rule in white-tailed deer can be explained by food availability. American Midland Naturalist 162: 403-417.

Table 1: Morphological measurements of white-tailed deer sampled on Bald Head Island, North Carolina from 2008-2009.

Sex	Age	Body weight (kg)	Total body length (cm)	Body circumference (cm)	Hind foot length (cm)
Male	Adult	-	143.5	108	46.5
Female	Adult	40.4	122	85.5	41
Female	Adult	-	119.8	85	40.5
Female	Adult	39.9	128.3	87.5	42.5
Female	Adult	42.6	133	86	41.5
Female	Adult	37.6	120.9	82.5	40.3
Female	Adult	40.8	118	84.5	40.7
Female	Adult	43.5	124.5	84	39.8
Female	Adult	34	114	81	39.5
Female	Yearling	26.3	107	71.4	38.3
Female	Yearling	37.2	126.5	80.5	40
Female	Fawn	26.3	113.5	76	39.5
Female	Fawn	26.8	120.5	71.5	38.9