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

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Abstract: The white-tailed deer (*Odocoileus virginianus*) population on Bald Head Island 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 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/km² 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

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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 et al. 1993).

In recent years, the white-tailed deer population on Bald Head Island, North Carolina, has increased, the 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). Notably, 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 pri-

vate property; however, management of deer populations incites emotional and political conflict between 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, personal communication). 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 ($\bar{x}$ = 111.8/year, 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 potentially limiting the 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 Corncake Inlet in 1999 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, personal communication). 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, personal communication). 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-1980s (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., Borkop, Denmark) and a cartridge-fired dart rifle (Pneu-Dart, Williamsport, Pennsylvania) to administer anesthetic drug combinations of Telazol (1:1 tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Health, Fort Dodge, Iowa) and XYLA-JECT (xylazine hydrocholoride, Phoenix Pharmaceutical, Inc., St. Joseph, Missouri). 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). If a deer was not fully chemically immobilized when located, we administered 2 mg/kg of Ketaset (ketamine hydrochloride, Fort Dodge Animal Health, Fort Dodge, Iowa) 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), and applied antibiotic cream (Neosporin, Johnson and Johnson, Inc., New Brunswick, New Jersey). 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). 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) in the right and left ears, respectively, and fitted each deer with a mortality-sensing VHF radiocollar (TenXsys, Inc., Eagle, Idaho). After processing was complete, we intravenously administered yohimbine hydrochloride at 0.125 mg/kg (Yobine; Wildlife Laboratories, Inc., Fort Collins, Colorado). 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 two-element antenna and portable radio receiver (Telonics TR-4, Mesa, Arizona). 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 cover type use estimates. Further, we randomized the order 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) 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 via mark-resight data:

$$\widehat{N} = \frac{M(n+1)}{(m+1)},\ \widehat{Var} = \left[\frac{M^2(n+1)(n-m)}{(m+1)^2(m+2)}\right],$$

$$SE = \sqrt{\widehat{Var}},\ 95\%,\ CI = \widehat{N} \pm 1.96\sqrt{\widehat{Var}}$$

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 pe-

Table 1. Use-availability data and 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	$-0.015 \le P \le 0.033$
Developed	85.3	0.138	0.084	$0.014 \le P \le 0.154$
Maritime forest/shrub	276.3	0.445	0.668	$0.550 \le P \le 0.790$[a]
Dune/grassland	177.1	0.285	0.113	$0.034 \le P \le 0.192$[a]
Tidal marsh	74.7	0.121	0.126	$0.043 \le P \le 0.210$
Total	620.0	1.000	1.000	

a. Indicates a significant difference at the 0.05 level

riod; 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 can only 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, by the early years of the 2000s, 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: by 2004 the deer density was ~80 deer/km^2 (M. Dewire, Bald Head Island Conservancy, personal communication). 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, they 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).

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, movement of white-tailed deer to and from Bald Head Island needs to be minimal. Our results indicated that radiocollared white-tailed deer did not emigrate from Bald Head Island; however, uncertainty exists regarding movement of white-tailed deer from the mainland to Bald Head Island. Immigration of white-tailed deer could decrease the efficacy of population control. Based on our research, white-tailed deer select maritime forest/shrub over other available cover types which could potentially threaten this forest system if deer density increases. However, no data, or anecdotal evidence, has been presented to suggest that deer are causing extensive damage to the maritime forest (i.e., browse lines). Therefore, until additional research is conducted (e.g., deer diet analysis and vegetation surveys) to quantify white-tailed deer habitat use, we recommend maintaining deer density between 15–17 deer/km^2 which is consistent with what barrier islands can sustain based on available research (Stransky 1969, Osborne et al. 1992. 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 Islands 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.

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