ECOLOGY OF WHITE-TAILED DEER AND BOBCATS ON KIAWAH ISLAND, SOUTH CAROLINA: IMPLICATIONS FOR SUBURBAN HABITAT PRESERVATION

by

SHANE BENJAMIN ROBERTS

(Under the Direction of Robert J. Warren)

ABSTRACT

This project was designed to integrate previous wildlife research and better understand the complex ecology of white-tailed deer (*Odocoileus virginianus*) and bobcats (*Lynx rufus*) on Kiawah Island, South Carolina, as affected by humans and their developments, and use this knowledge to prioritize habitat preservation efforts within this suburban environment. We radio-monitored a sample of adult does and neonatal fawns during 2002−2005 and the majority of the island's bobcat population during 2004−2005. Bobcat predation was the major factor limiting deer population growth and variation in individual bobcat prey selection and the habitat configuration of the island played important roles in this relationship. Deer home ranges were small and adult doe survival was high, illuminating the importance of some form of deer population control. Bobcat home ranges were relatively small and reproduction appeared adequate to replace mortality losses, although movement rate data suggested bobcats were avoiding interactions with humans. Shrub was the most important habitat type for bobcats, although they also selected developed areas at night, potentially to exploit additional food resources. We observed a significant relationship between the portion of a bobcat's home and core range in shrub habitat and range size, suggesting alteration of these important habitats could have negative effects on bobcat abundance. We modified an existing index of bobcat habitat suitability to consider the food, cover, and reproduction requirements of bobcats. Data suggested the index performed well in identifying important habitats for bobcats on the island and we showed how the index could be used to prioritize the habitat preservation efforts of a local conservation organization. We also describe how this organization has used the bobcat as an icon to stimulate community interest in the preservation of wildlife habitat on the island. Overall, our data suggest deer and bobcats have adapted well to Kiawah Island's suburban landscape to date, but without significant habitat preservation efforts the future fragmentation of large undeveloped areas and shrub habitats could have negative effects on bobcat abundance, and in turn, this important predator-prey relationship.

INDEX WORDS: bobcat, habitat preservation, habitat suitability, habitat use, home range, icon, interactions, *Lynx rufus*, *Odocoileus virginianus*, predation, suburban, survival, white-tailed deer

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CHAPTER 1

INTRODUCTION, LITERATURE REVIEW, OBJECTIVES, AND DISSERTATION FORMAT

Introduction

Human population growth and associated urban sprawl are creating environments in which wildlife and humans are sharing space at an ever-increasing rate. Habitat-generalist species, like the white-tailed deer (*Odocoileus virginianus*), often thrive in these areas due to abundant, landscaped food resources (Swihart et al. 1995). Predatory species like the bobcat (*Lynx rufus*), are often more sensitive to habitat fragmentation and typically avoid interactions with humans (Crooks 2002, Tigas et al. 2002, Riley et al. 2003, Riley 2006). Without some form of control, suburban deer populations often grow to a level of biological or social overabundance, resulting in ecological damage, property damage from deer-vehicle collisions and landscape shrubbery browsing, and human safety concerns about disease and deer-vehicle collisions (see Alverson et al. 1988, Warren 1991, McAninch 1995, McShea et al. 1997, Warren 1997). In many situations, natural control of suburban deer populations (i.e., predation) may be preferred to intensive management efforts (e.g., sharpshooting, hunting, fertility control), which may be expensive and socially unacceptable to residents. However, human and pet safety concerns often arise when predators capable of influencing deer population growth (e.g., coyotes [*Canis latrans*], cougars [*Puma concolor*], bobcats, black bears [*Ursus americanus*]) inhabit developed areas (Adams et al. 2006).

In general, little is known about large predator ecology and deer recruitment in suburban settings. Even less in known about the habitat requirements of predators in and around suburban environments and the role habitat plays in predator-prey dynamics within these areas. We designed this study to investigate the ecology and interactions of deer and bobcats in a suburban setting, where they coexist in what appears to be abundant densities, and to identify habitats that may be important to maintaining this natural predator-prey dynamic and this bobcat population as development continues.

Literature Review

Fawn Survival

Numerous studies throughout the United States have investigated survival rates and mortality sources of fawns in rural habitats (Cook et al. 1971, Garner et al. 1976, Carroll and Brown 1977, Epstein et al. 1983, Huegel et al. 1985, Nielson and Woolf 1987, Boulay 1992, Sams et al. 1996, Bowman et al. 1998, Long et al. 1998, Ballard et al. 1999, Vreeland et al. 2004, Pusateri Burroughs et al. 2006); however, only 1 research project to date has specifically examined white-tailed deer fawn survival in a suburban setting (Saalfeld 2006). Fawn survival in rural areas is quite variable across studies and regions, ranging from about 12% during a study in Oklahoma (Garner et al. 1976) to 75% during a study in Michigan (Pusateri Burroughs et al. 2006). Predation is typically the main source of mortality across studies and landscapes. In their review of temperate neonatal ungulate mortality research, Linnell et al. (1995) noted that black bears, wolves (*Canis lupus*), coyotes, bobcats, red foxes (*Vulpes vulpes*), gray foxes (*Urocyon cinereoargenteus*), alligators (*Alligator mississippiensis*), and domestic dogs are documented predators of white-tailed deer fawns.

In a suburban area around Auburn, Alabama, Saalfeld (2006) found relatively low fawn survival to 8 weeks of age (33%), mainly due to coyote predation. Overall, coyote predation is the most important source of white-tailed deer fawn mortality in the U.S., accounting for the majority of mortalities (42%−71%) in most studies where coyotes occur (Cook et al. 1971, Garner et al. 1976, Carroll and Brown 1977, Epstein et al. 1983, Huegel et al. 1985, Nielsen and Woolf 1987, Boulay 1992, Bowman et al. 1998, Long et al. 1998, Ballard et al. 1999). Although most studies conducted where bobcats are present have documented some bobcat predation on white-tailed deer fawns, only 2 observed bobcats accounting for >25% of overall fawn mortality (Epstein et al. 1983, 1985; Boulay 1992). Bobcats were responsible for at least 32% of all non-captured-related fawn mortalities during the Esptein et al. (1983, 1985) study on 2 coastal barrier islands north of Charleston, South Carolina and 58% of all mortalities during Boulay's (1992) study in the Florida everglades. Coyotes did not inhabit either of these study sites during the research. Epstein et al. (1983) also was the only study to report red fox, gray fox, and alligator predation on fawns, although Shoop and Ruckdeschel (1990) documented deer remains in 9% of alligator scats and described several observations of alligators feeding on deer carcasses on Cumberland Island, Georgia.

Mortalities due to disease and starvation also occur fairly frequently in fawn survival studies and have been cited as the most important sources of mortality in at least 2 (Sams et al. 1996, Vreeland et al. 2004). "Accidental" mortalities (e.g., drowning, agricultural machinery) are also fairly common (Linnell et al. 1995). Deer-vehicle collisions also can be an important source of fawn mortality in roaded areas and were responsible for 18% of fawn mortalities on Mount Desert Island, Maine (Long et al. 1998).

Because predators play such a prominent role in white-tailed deer recruitment, fawn survival may be influenced by the availability of alternative prey species in many situations (Linnell et al. 1995). Coyotes and bobcats, the most important fawn predators in most areas, are considered opportunistic in their feeding habits (Bekoff and Gese 2003, Anderson and Lovallo 2003) and therefore may exhibit a functional response to prey availability. Patterson et al. (1998) found that coyotes in Nova Scotia fed less on white-tailed deer and more on snowshoe hare (*Lepus americanus*) when hares were abundant. However, they found that this relationship was not directly proportional and coyotes continued to regularly feed on deer when hare populations were dense. Hamlin et al. (1984) reported a significant relationship between microtine rodent abundance and coyote predation on mule deer (*O. hemionus*) fawns. Similarly, Baker et al. (2001) and Blankenship (2000) documented shifts in bobcat diet in response to staple prey (rodent and lagomorph) abundance, with an increased use of staple prey items when abundance was high and a general diversification of diet when staple prey abundance was low.

Research also has suggested that birth mass, activity patterns, and habitat characteristics may influence fawn survival rates. Vreeland et al. (2004) found that fawns with a higher mass at capture were more likely to survive. At least 2 other studies have also documented a positive relationship between mass and survival in white-tailed deer fawns (Verme 1977, Kunkel and Mech 1994). Deer fawns are largely defenseless during the first 2 weeks of life, relying on cryptic coloration and minimal activity to avoid predation (Mech 1984). Therefore, it seems reasonable that increased activity may increase the likelihood of detection by visual predators like the coyote or bobcat. Jackson et al. (1972), Bartush and Lewis (1978), and Schwede et al. (1992) documented differences in activity patterns of fawns between the sexes. All 3 studies concluded that male fawns were more active than females. However, sex was not an important factor in the single study of suburban fawn survival (Saalfeld 2006). Garner et al. (1976) noted on their study site in Oklahoma that bobcat predation usually occurred once fawns became associated with forest edges or steeper slopes. Vreeland et al. (2004) used year- and study site-specific buffers to examine the relationship between fawn survival to 9 weeks of age and habitat composition, although none of the habitat metrics they investigated (habitat diversity, edge density) were significantly related to survival. They surmised that landscape-scale habitat characteristics and predator density might have more influence on fawn survival than home range-scale habitat characteristics. Saalfeld (2006) believe the fairly open, sparse vegetation cover at their suburban study site led to high predation rates by coyotes.

Adult Doe Survival

Although adult doe survival is relatively high in most suburban areas, survival appears to be quite site- and region-specific. Porter et al. (2004) reported an annual adult doe survival rate of 62% in a suburban area in New York. In a suburban area near St. Louis, Missouri, Hansen and Beringer (2003) reported an annual doe survival rate of approximately 80%. Etter et al. (2002) reported an 83% survival rate for adult does in a suburb around Chicago, Illinois. Deer-vehicle collisions were usually the most important source of adult deer mortality in these areas (66% near Chicago, Illinois [Etter et al. 2002]; 89% near St. Louis, Missouri [Hansen and Beringer 2003]; 44% in Irondequoit, New York [Porter et al. 2004]). Suburban does also died from hunter harvest (legal and illegal) and wounding loss, collisions with trains, disease, predation, and accidents (e.g., getting caught in a fence, drowning; Etter et al. 2002, Hansen and Beringer 2003, Porter et al. 2004). These studies suggest that adult doe survival in suburban areas is almost entirely dependent on anthropogenic factors.

Doe and Fawn Home Ranges

Adult doe home ranges are quite variable in suburban environments throughout the U.S., ranging from 26−158 ha (Swihart et al. 1995, Cornicelli et al. 1996, Henderson et al. 2000, Kilpatrick and Spohr 2000, Picollo et al. 2000, Etter et al. 2002, Grund et al. 2002). Some studies have suggested that deer density may play an important role in home range size. Henderson et al. (2000) observed an increase in adult doe spring home ranges (29 ha to 40 ha) after a 50% reduction in herd density. Conversely, Swihart et al. (1995) observed larger annual home ranges (158 ha) in a lower-density deer herd when compared to a higher-density herd (67 ha). There are undoubtedly numerous area- and region-specific nutritional, habitat, and human disturbance characteristics that can influence suburban adult deer home range sizes. Deer in southern ecosystems typically exhibit high site fidelity to a home range (Marchinton and Hirth 1984), although seasonal changes may be apparent as studies have documented smaller summer home ranges when compared to other seasons (Cornicelli et al. 1996, Etter et al. 2002, Grund et al. 2002). Since does will often contract their summer movements around their milk-dependent neonatal fawns, this trend is fairly intuitive (Bartush and Lewis 1978, Schwede et al. 1994, D'Angelo et al. 2004). Fawn home ranges typically increase in size as they mature and become dependent on vegetation food-sources (Garner and Morrison 1977, Epstein et al. 1985, Pusateri Burroughs 2006).

Bobcat Ecology

Bobcats occur in most of the lower 48 states, with the exception of Delaware, although their distribution is restricted in many agriculturally dominated Midwestern and Great Lakes states (Woolf and Hubert 1998, Anderson and Lovallo 2003). With the exception of short breeding encounters, bobcats are mostly solitary (Anderson and Lovallo 2003). Most research suggests bobcats within a population organize themselves socially and spatially based on a land tenure system, where relatively exclusive home and core ranges are indirectly defended from same-sex conspecifics through scat and urine scent markings and are only transferred after the death of a resident (Bailey 1974, Litvaitis et al. 1987, Anderson 1988, Lovallo and Anderson 1995). However, recent research suggests bobcats may exhibit a more complex social system in which not all home ranges are held for life, bobcats may actively contest the home range "rights" of a same-sex resident, and territoriality may be less pronounced under certain circumstances (Chamberlain and Leopold 2001, Benson et al. 2004, Diefenbach et al. 2006). Population density, prey abundance, weather, age, and the distribution of important resources can all lead to increased social interactions among individuals and apparent violations of strictly territorial social system (Bailey 1974, Conner et al. 1999, Nielsen and Woolf 2001*b*, Cochrane et al. 2006, Benson et al. 2006, Diefenbach et al. 2006). For example, Diefenbach et al. (2006) observed a relatively large amount of intrasexual home range and core range overlap in a dense, reintroduced population of bobcats on Cumberland Island, Georgia.

Male bobcat home ranges in undeveloped areas of the southeast range from approximately 260 ha (Miller and Speake 1979) to over 4,200 ha (Kitchings and Story 1979), while home ranges of females can be from 100 ha (Hall and Newsom 1976) to over 2,200 ha (Lancia et al. 1986). Male and female bobcat home range sizes are generally considered responses to breeding opportunities and habitat quality, respectively (Anderson and Lovallo 2003), although they can also be influenced by any of the social interaction factors mentioned above. Male bobcats attempt to include as many females as possible within their home range (Anderson and Lovallo 2003). This is evident in the higher amount of intersexual overlap, compared to intrasexual overlap, observed in many studies (Fendley and Buie 1986, Chamberlain and Leopold 2001, Nielsen and Woolf 2001*b*, Cochrane et al. 2006). However, prey availability also plays a role in male home range size. Knick (1990) observed a 5-fold increase in male home range size after a severe decline in lagomorph abundance. Female bobcats are solely responsible for raising offspring, and therefore their home ranges must provide an abundance of prey (i.e., high quality habitat) to meet energetic demands of the female and kittens (Anderson and Lovallo 2003). Many researchers have reported a significant inverse relationship between female home range size and habitat quality or prey abundance (Litvaitis et al. 1986, Knick 1990, Lovallo et al. 2001, Benson et al. 2006). Additionally, Conner et al.

(1999) and Chamberlain and Leopold (2001) suggested resident female age can affect home range size and the amount of overlap they tolerate from adjacent females, since older females are more familiar with their territory and can more efficiently obtain resources from it.

Female bobcats are capable of reproducing yearly throughout their life span (Crowe 1975), although increased population density can lead to decreases in reproduction (Lembeck and Gould 1979, Diefenbach et al. 2006). Litters size ranges from 1−5 kittens, but the average is usually 2−3 (McCord and Cardoza 1982, Anderson and Lovallo 2003). Female bobcats in the southeastern U.S. typically den in hollow stumps, uprooted trees, and areas of thick understory vegetation (Lancia et al. 1982, Boyle and Fendley 1987, Griffin 2001). Annual survival is relatively high (>75%) in bobcat populations that are not subjected to hunting or trapping pressure (Griffin 2001, Nielsen and Woolf 2002, Riley et al. 2003), but is often lower in those that are harvested (Fuller et al. 1985, Rolley 1985, Knick 1990, Fuller et al. 1995).

Bobcats typically exhibit bimodal activity patterns with peaks in activity coinciding with crepuscular peaks in prey activity and subsequent decreases in diurnal and nocturnal activity (Fendley and Buie 1986, Griffith and Fendley 1986, Lancia et al. 1986, Bradley and Fagre 1988, Chamberlain et al. 1998), although Chamberlain et al. (2003) noted that bobcat movement rates were highest during the nocturnal time period. Bobcats typically prefer shrubby, or otherwise dense early-succession, habitats (Hall and Newsom 1976, Rolley and Warde 1985, Heller and Fendley 1986, Litvaitis et al. 1986, Anderson 1990, Kolowski and Woolf 2002). Selection of these thick habitats is likely due to increased prey availability, cover, or both (Boyle and Fendley 1987, Kolowski and Woolf 2002).

Suburban Bobcat Ecology

Few studies have specifically examined bobcat ecology with respect to human activity and development (Harrison 1998, Nielsen and Woolf 2001*a*, Crooks 2002, Tigas et al. 2002, Riley et al. 2003, George and Crooks 2006, Riley 2006). In the first investigation of urban-associated bobcats, Harrison (1998) found that bobcats were using human-inhabited areas and were frequently observed in close proximity (<25 m) to houses. Nielsen and Woolf (2001*a*) reported that bobcats generally avoided homes and selected core ranges that included less human disturbance when compared to home ranges. During his track survey work in fragmented habitats in California, Crooks (2002) found that bobcats were moderately sensitive to fragmentation and concluded that bobcats can only persist in suburban areas that provide adequate connectivity between undeveloped habitats. Due to this sensitivity, he suggested the bobcat might be a useful indicator of the ecological functionality of a landscape. In a California nature reserve, George and Crooks (2006) found that bobcats were detected less frequently, and shifted their activity patterns to a more nocturnal schedule, in areas of high human use.

During the most extensive studies of suburban bobcat ecology to date, Tigas et al. (2002), Riley et al. (2003), and Riley (2006) documented varying levels of suburban avoidance, including absolute avoidance by some bobcats, and alterations in behavior (e.g., increased nocturnal movements) to minimize interactions with humans on their study sites in California. Bobcats included little development in their home ranges (7% of home range) during 1 study (Riley et al. 2003) and only incorporated developed areas that occurred within a park in another (Riley 2006). However, Tigas et al. (2002) and Riley et al. (2003) reported increased use of developed areas during nocturnal time periods and noticed that males were more likely to use development than females. Although no bobcats were located outside a park setting during the study, Riley (2006) also noticed the home ranges of male bobcats were closer to development than females.

Assessing Bobcat Habitat Suitability

Lancia et al. (1982) developed the first index of bobcat habitat suitability, using expert opinion to describe the relationship between the vegetation composition of 8 habitat types and 3 life requisites of bobcats (food, reproduction, cover). The basic premises behind these relationships was that food availability increased with increased ground cover in non-hardwood habitats and increased with mast production in hardwood forest types (i.e., provide food cover for rodent and lagomorph species), reproduction habitat was related to the abundance of den sites (i.e., root masses of downed trees, hollow trunks), and cover habitat was readily available in all but agricultural habitats. They assigned a value for each life requisite to each habitat type, based on these relationships, and devised a formula to calculate a habitat quality rating from these habitat-specific values and an index of habitat interspersion. They assessed the validity of the index with telemetry data collected from bobcats in North Carolina and found that it was relatively accurate in predicting (i.e., within 1 quartile of predicting) the frequency of bobcat use only about 55% of the time. However, evidence suggested they did not have all bobcats in the area radio-collared, which could have resulted in an apparent decrease in index accuracy when the index predicted high quality habitat where they did not have a bobcat collared (Lancia et al. 1982).

Boyle and Fendley (1987) developed a bobcat habitat suitability index (HSI) for the piedmont and coastal plain regions of the southeastern U.S. as part of the U.S. Fish and Wildlife Service's HSI series. The HSI used an index of food suitability as an overall measure of habitat suitability. They assumed the other general life requisites of a bobcat (water, cover, and reproduction) could be fulfilled in any undeveloped area of the southeastern U.S or within areas of adequate food suitability. The index required the estimation of 2 suitability index variables (SIV1 and SIV2). SIV1 related to the percentage of the sample area covered by grasses, forbs, or shrubs and SIV2 related to the percentage of the grass, forb, or shrub vegetation that was grasses or forbs. They described optimal bobcat habitat as an area of ≥ 90% grass, forb, or shrub ground cover with 50−70% of this vegetation in grasses or forbs. They believe this interspersion of vegetation provides optimal habitat for rodents (primarily cotton rats [*Sigmodon hispidus*]) and eastern cottontails (*Sylvilagus floridanus*), which are usually the main components of bobcat diets in the southeastern U.S., by providing adequate food resources and accessible escape cover from avian predators. Although this index was based on a variety of research results on bobcat ecology and prey species habitat use from the southeastern U.S., no external validation has been published.

More recently, researchers have used multivariate habitat models to assess bobcat habitat selection and subsequently predict bobcat habitat suitability in Pennsylvania (Lovallo et al. 2001) and Mississippi (Conner et al. 2001). Lovallo et al. (2001) used 2 approaches—Mahalanobis Distance and logistic regression—to predict sex-specific bobcat habitat suitability based on multiple vegetation type, slope, and aspect variables and compare these predictions to observed habitat use trends in radio-collared bobcats (i.e., tests of use versus availability). They found that both methods were fairly accurate in predicting suitable bobcat habitat (>70% of telemetry locations identified as suitable habitat for both sexes). They also compared the results of a statewide assessment of habitat suitability to survey results of wildlife conservation officers. Results suggested regions identified as quality bobcat habitat were perceived by officers to have more bobcats.

Conner et al. (2001) used sex-specific logistic regression models to predict suitable bobcat habitat based on vegetation type, stand condition with respect to harvest (e.g., pulpwood), elevation, slope, and a variety of distance measurements to vegetation types, edges, roads, and creeks. The best model for predicting female bobcat habitat suitability included variables for slope, stand condition, and 3 distance measurements to roads and creeks and it predicted 78.5% of female locations using cross-validation. The best model for predicting male bobcat habitat suitability included stand condition and a distance to road measurement and it predicted 77.5% of male locations using cross-validation. However, neither of these models was tested on an external data set (Conner et al. 2001).

Wildlife Research on Kiawah Island

Kiawah Island is a 3,500-ha coastal barrier island located approximately 25 km south of Charleston, South Carolina. Residential and resort development began on Kiawah Island in 1974. During the late 1990s, the island had <1,000 permanent residents, but was visited by thousands of tourists each year. The island was world-renowned for its luxurious resort accommodations, 15 km of oceanfront beach, and professional-level golf and tennis facilities. The development and influx of people had dramatically changed the landscape of the island. Much of the maritime forest had been replaced with homes and landscaped yards. However, many wildlife species, including white-tailed deer and bobcats, had apparently adapted to these changes in Kiawah Island’s landscape. Deer were commonly seen feeding in yards and open spaces near residential areas and, based on frequent observations by residents and island officials, bobcats also seemed relatively abundant. Limited private deer hunting (30−40 deer harvested per year) was conducted on undeveloped portions of the island until a 1995 municipal firearms ordinance prohibited the use of firearms on the island (J. Jordan, Town of Kiawah

Island, personal communication). No deer hunting (firearm or archery) has been conducted since.

To gather baseline biological and ecological data on the island's deer herd and bobcat food habits, the Town of Kiawah Island supported a University of Georgia (UGA) research project during 1996−1998. The project determined that the Kiawah Island deer herd was in excellent nutritional and reproductive condition, and deer densities on the island were about 35 deer/km^2 (Jordan 1998). It also determined that bobcat predation was one ecological factor helping to remove deer from the herd. However, it was noted that bobcats were more abundant in the less-developed eastern end of the island than in the more-developed western end. In addition, diet analysis showed that bobcats ate more deer fawns in the eastern end portion than in the western portion. Rodents made up the majority of prey consumed in both portions of the island (approximately 40% of total).

Following the original deer ecology study, the Town of Kiawah Island wanted to better understand the ecological role of bobcats in controlling the deer herd. Given that the remainder of the island would likely become fully developed during the next 10−20 years, officials believed data were needed so the Town could best anticipate and address the future needs for deer management. Island-wide scent station index surveys (Diefenbach et al. 1994), conducted annually since 1997, revealed a population of about 30 bobcats (1.4 bobcats/upland [non-salt marsh] km^2), with greater abundance on the less-developed eastern end of the island compared to the western end. There was concern that bobcats might be avoiding the greater development and human activity on the western end portion of the island, which would explain the apparent difference in deer use between portions of the island.

Therefore, the Town of Kiawah Island supported a second UGA wildlife research project. This radio-telemetry study was designed to specifically compare movement behavior, home range characteristics, survival, and food habits of bobcats between portions of Kiawah Island to assess how the continued development of the island might affect the bobcat population (Griffin 2001). During January–December 2000, 14 radio-collared bobcats (seven males and seven females) were monitored to compare reproduction, survival, and home range size between the portions. Bobcat reproductive success did not differ between portions. Three radio-collared bobcats died during this study, all from the more-developed portion of the island. Female bobcats on the more-developed portion had home ranges that were about 3 times as large as those of females on the less-developed portion, possibly reflecting a behavioral response to human activity or differences in prey availability. Bobcat food habits were compared with the previous data collected by Jordan (1998). The major difference observed between these data sets was in consumption of deer between portions of the island. Unlike previously, bobcats in both portions were consuming about equal amounts of deer in all seasons. Similar to previous findings, rodents made up the majority (about 40%) of prey consumed in both portions of the island.

A number of conclusions can be drawn from the wildlife studies conducted previously on Kiawah Island. First, the deer on Kiawah Island were relatively healthy, reproductively successful, and had adapted well to human activity. Second, bobcats preyed on the island's deer and tolerated human activity, but greater movements and mortality rates observed for bobcats in the more-developed versus less-developed areas of the island may have been the result of differences in human activity. Third, bobcats likely played a role in the regulation of Kiawah Island's deer herd.

Objectives

This project was designed to integrate previous wildlife research and better understand the complex ecology of white-tailed deer and bobcats on Kiawah Island, as affected by humans and their developments, and use this knowledge to focus habitat preservation efforts within this suburban environment. The specific objectives of the project were to:

1. Estimate deer fawn and doe survival rates, document mortality sources, investigate relationships between fawn survival and suburban habitat, and estimate seasonal and annual fawn and doe home ranges
2. Examine bobcat home range size, movements, survival, and reproduction as they compared to previous research conducted on Kiawah Island (Griffin 2001) and expand on this knowledge base by investigating the social interactions and habitat use of bobcats in this suburban setting
3. Modify an existing bobcat habitat suitability index model (Boyle and Fendley 1987) to incorporate habitat components potentially important to bobcats in human-altered environments, assess validity of the index using data collected from telemetry-monitored bobcats, and show how the index could be used to focus habitat preservation efforts at multiple spatial scales.

Dissertation Format

I wrote this dissertation in the manuscript format. Chapter 1 is an introductory chapter that summarizes past research on white-tailed deer survival and home range sizes in suburban environments, the general ecology of bobcats and their behavior in and around human-altered landscapes, habitat suitability indices for identifying quality bobcat habitat, and provides a brief summary of previous deer and bobcat ecology research conducted on Kiawah Island. Chapters

2−5 are manuscripts that will be submitted for publication. Chapter 2 investigates white-tailed deer fawn and doe survival and mortality sources, potential relationships between bobcat predation on deer fawns and demographic and habitat characteristics, and fawn and doe home range size. Chapter 3 investigates bobcat interactions, home range size, diel movements, survival, reproduction, and habitat use in this suburban landscape. Chapter 4 describes a modified index to bobcat habitat suitability that was developed to assist a local conservation organization focus its land preservation efforts. Chapter 5 describes how this conservation organization has used the bobcat as an icon to integrate our research with their education and fund-raising efforts to stimulate community interest in habitat preservation. Chapter 6 is a succinct review of all findings and conclusions and how they may be used for future management and habitat preservation efforts on Kiawah Island.

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CHAPTER 2

SURVIVAL AND HOME RANGES OF WHITE-TAILED DEER FAWNS AND DOES ON A DEVELOPED SOUTH CAROLINA BARRIER ISLAND[1]

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[1] Roberts, S. B., J. D. Jordan, and R. J. Warren. To be submitted to the *Journal of Wildlife Management*.

Abstract: Although recruitment is the driving force behind population growth, little research has been done on white-tailed deer (*Odocoileus virginianus*) fawn survival in suburban settings, environments where population growth often leads to negative human-deer interactions. We examined fawn and doe survival and home range size during 2002−2005 on Kiawah Island, South Carolina, a developed barrier island. Six-month fawn survival was low (21.1%) and varied among years. Bobcats (*Lynx rufus*) were responsible for 57%−82% of fawn mortalities each year and 67% of all mortalities. The majority of bobcat predation (66%) occurred within 2 weeks of birth and almost all (97%) occurred within 5 weeks. A logistic regression analysis suggested male fawns and fawns born in areas of higher habitat diversity were more likely to be killed by a bobcat within 2 weeks of birth. Observations of radio-collared bobcats suggest variation in prey selection between individuals may have led to yearly differences in fawn survival. Doe survival was 89.8% over all years and deer-vehicle collisions were the most important source of doe mortality (77%). Annual doe home ranges were relatively small ($\bar{x}$ = 35.5 ha) and seasonal home ranges were smaller during the summer when compared to spring and fall. Annual fawn home ranges were similar to does and generally increased with age. Home range estimates, coupled with a previous evaluation of herd health, suggest food is readily available to deer and the island's herd was quite healthy. Deer spotlight surveys conducted concurrently with this study suggested a fairly stable trend in deer density. Our results suggest low fawn survival, mainly due to extensive bobcat predation, was limiting population growth in this suburban deer herd.

Key Words: bobcat, development, fawn, home range, *Lynx rufus*, *Odocoileus virginianus*, predation, South Carolina, survival, white-tailed deer

Introduction

Human population growth and associated urban sprawl are creating environments in which wildlife and humans are sharing space at an ever-increasing rate. Many habitat-generalist species, like the white-tailed deer (*Odocoileus virginianus*), thrive in these areas due to abundant, landscaped food resources (Swihart et al. 1995). Management techniques employed in undeveloped settings (e.g., hunting) often are not feasible, or are socially unacceptable, in these suburban landscapes (see McAninch 1995, Warren 1997). Additionally, wildlife species inhabiting urban-suburban environments often exhibit different behavior and life history strategies than their rural counterparts (Ditchkoff et al. 2006). Understanding suburban deer ecology can help managers proactively manage suburban deer populations, better educate stakeholders, and better prepare for future management needs.

Numerous studies throughout the country have investigated survival rates and mortality sources of white-tailed deer fawns in rural habitats (Cook et al. 1971, Garner et al. 1976, Carroll and Brown 1977, Epstein et al. 1983, Huegel et al. 1985*a*, Nielson and Woolf 1987, Boulay 1992, Sams et al. 1996, Bowman et al. 1998, Long et al. 1998, Ballard et al. 1999, Vreeland et al. 2004, Pusateri Burroughs et al. 2006). However, only 1 other study to date has focused on fawn survival and mortality causes specifically in an urban-suburban setting (Saalfeld 2006). This study showed relatively low fawn survival to 8 weeks of age, mainly due to coyote (*Canis latrans*) predation. A larger number of studies have investigated suburban deer movements and adult survival (Swihart et al. 1995, Cornicelli et al. 1996, Tucker et al. 1996, Henderson et al. 2000, Kilpatrick and Spohr 2000, Picollo et al. 2000, Waddell 2000, Etter et al. 2002, Grund et al. 2002, Ricca et al. 2002, Hansen and Beringer 2003, Porter et al. 2004), although results seem to be highly site- or region-specific.

Kiawah Island, South Carolina is a resort-style development that supports both white-tailed deer and bobcats (*Lynx rufus*). Previous bobcat diet analysis conducted on the island suggested bobcat predation may have been an important factor in neonatal fawn survival (Jordan 1998, Griffin 2001). Few studies have documented a substantial amount of bobcat predation on neonatal white-tailed deer fawns (Garner et al. 1976, Epstein et al. 1983, Boulay 1992, Ricca et al. 2002). Our objectives were to estimate year-specific fawn and doe survival rates, document fawn mortality sources, investigate relationships between fawn mortality and suburban habitat, and estimate annual and seasonal doe and fawn home ranges.

Study Area

Natural and Developed Areas

We collected fawn survival data yearly from 2002−2005 and doe and fawn home range data from April 2002 to March 2003 on the western 1,100 ha (not including salt marsh) of Kiawah Island, South Carolina. Kiawah Island is a 3,500-ha coastal barrier island located approximately 25 km south of Charleston. Approximately 1,500 ha of the island was salt marsh (saltmarsh cordgrass [*Spartina alternifora*]) or brackish marsh (saltmeadow cordgrass [*Spartina patens*], salt grass [*Distichlis spicata*], seaside oxeye [*Borrichia frutescens*], black needlerush [*Juncus roemerianus*]). The remaining acreage was a mosaic of maritime forest (live oak [*Quercus virginiana*], slash pine [*Pinus elliottii*], and cabbage palmetto [*Sabal palmetto*]), maritime shrub thickets (sand live oak [*Q. geminate*], yaupon [*Ilex vomitoria*], wax myrtle [*Myrica cerifera*]), salt shrub thickets (seaside oxeye, marsh elder [*Iva frutescens*], wax myrtle, black needlerush), brackish and freshwater ponds, golf course, residential and resort development, and barren sand (Aulbach-Smith 1998). Kiawah Island is separated from other landmasses to the north and west by the Kiawah River and to the east by the Stono River. A 2-

lane road connects Kiawah Island to Seabrook Island at the narrowest point of the Kiawah River (~50m at low tide), crossing approximately 550m of salt marsh. From 2002 to 2005, Kiawah Island had a mean temperature of 27.6 ºC in July and 8.5 ºC in January, while precipitation averaged about 114 cm annually (N. Shea, Kiawah Island Community Association, unpublished data).

Residential and resort development began on Kiawah Island in 1974. During 2002−2005, this gated community had more than 1,100 permanent residents and was visited by thousands of tourists each year. Of the approximately 3,000 lots available for single-family homes on the island, about 2,000 were developed. Virtually all resort development (all resort hotels and villas and 4 of 5 18-hole golf courses), and the majority of developed residential lots (89%) were concentrated on the western 1,100 ha of the island. With the possible exception of a cleared walking path for real estate purposes, the vegetation on undeveloped lots was usually unaltered. Lots platted for single-family homes comprised 28% (567 ha) of the island's upland acreage, with a mean lot size of 0.19 ha (SE = 0.01 ha). The development and influx of people have dramatically changed the landscape of the island. Much of the maritime forest has been replaced with homes and landscaped yards, but construction regulations designed to bolster aesthetic appeal and maintain green space (Kiawah Island Architectural Review Board 2007) have preserved buffer areas between homes, canopy cover within each lot, and vegetation along marsh and pond edges, resulting in a mosaic of native and landscaped vegetation within developed areas.

Deer and Predator Populations

No hunting has been conducted on Kiawah Island since 1995, and hunting pressure prior to that year was minimal (30−40 deer harvested per year; J. Jordan, Town of Kiawah Island, personal communication). Standardized deer spotlight surveys have been conducted along a 28.3 km survey route since 1998 to monitor population density and demographics (Jordan 1998). During 2002−2005, winter (Dec−Jan) deer density estimates in the western-end study area (~11 km^2) averaged 16.0 deer/km^2 (SE = 2.2, range = 12.9 to 22.6; J. Jordan, Town of Kiawah Island, unpublished data). Jordan (1998) described the deer on Kiawah Island as being in "excellent nutritional and reproductive condition". He reported that Kiawah Island's deer had higher body weights, higher nutritional indicator values (e.g., kidney fat index), a higher number of fawns per doe in utero, and a higher portion of fawns breeding than other southeastern barrier island deer populations (Miller 1986, Osborn et al. 1992). He credited extensive landscape planting and fertilizing for creating an abundance of highly palatable, nutritious, cultivated food sources on the island.

Potential predators of deer fawns on Kiawah Island included bobcats (Epstein et al. 1983, Boulay 1992, Jordan 1998, Labisky and Boulay 1998, Griffin 2001), gray foxes (*Urocyon cinereoargenteus*; Epstein et al. 1983), and alligators (*Alligator mississippiensis*; Epstein et al. 1983, Shoop and Ruckdeschel 1990). Although there have been confirmed occurrences of coyotes in Charleston County, no coyotes have been documented on Kiawah Island (J. Jordan, Town of Kiawah Island, personal communication). According to standardized scent station surveys conducted during the winters (Jan−Feb) of 1998, 2000, 2001, and 2003−2005 and the bobcat abundance regression equation developed by Diefenbach et al. (1994), Kiawah Island supported a dense, relatively stable population of 30 (SE = 1.6) bobcats (~1.4 bobcats per upland [non-salt marsh] km^2; J. Jordan, Town of Kiawah Island, unpublished data). Although abundance estimates were not calculated, gray fox population trends were also monitored with scent station surveys during these years. These surveys suggested gray fox abundance had rebounded from a canine distemper outbreak in 1997−1998 and was stable to increasing during 2003−2005 (J. Jordan, Town of Kiawah Island, unpublished data). Alligator spotlight surveys conducted during the summers (Jul−Sept) of 2003−2005 suggested a mean population of 321 (SE = 34) alligators along a standardized route of 85 ponds (approximately 65% of the freshwater and brackish ponds on Kiawah Island) ranging from 0.04 to 12.78 ha in size (J. Jordan, Town of Kiawah Island, unpublished data).

Methods

Doe Capture

From 2002−2005, we captured adult does (≥ 1.5 years old) in the western end of Kiawah Island during January−March of each year. We used a pneumatic dart gun (Dan-inject, Inc., Borkop, Denmark), fitted with a Generation III, night-vision scope (NAIT Security Products, Inc., San Diego, Calif.) or a 3 x 9 rifle scope, firing 3cc disposable transmitter darts (Pneu-dart, Inc., Williamsport, Penn.) to capture uncollared does or 3cc disposable darts to capture does that had been previously collared. We attempted to recapture the same does each year, but we replaced mortalities and does we were unable to recapture with new captures to maintain a minimum number (n = 30) of monitored does annually. Darting allowed for the recapture of individual, collared does without involving non-target individuals. We darted does from a vehicle or treestand, or by using 2-man deer drives or stalking. Whole, shelled corn was used as an attractant at treestand and pre-determined roadside locations.

Does were immobilized with an intramuscular injection of xylazine hydrochloride (6−8 mg/kg body weight) and ketamine hydrochloride (3−4 mg/kg body weight). We used yohimbine hydrochloride (0.4–0.5 mg/kg body weight) as an antagonist to xylazine hydrochloride. Captured does were given an optical lubricant and blindfolded. We fitted each doe with a 480g

VHF radio-collar, equipped with an 8-hour, motion-sensitive mortality switch (M2520, Advanced Telemetry Systems, Isanti, Minn.) and a set of plastic, numbered eartags (Allflex, Inc., Dallas, Texas). Each doe also received a 15-g vaginal implant transmitter (VIT, Bowman and Jacobson 1998, Cartensen et al. 2003) programmed with a temperature-sensitive pulse rate (M3930, Advanced Telemetry Systems, Isanti, Minn.). When the temperature of the VIT fell below 30ºC, signaling expulsion from the doe, the pulse-rate changed from 40 pulses per minute (PPM) to 80 PPM. VITs allowed us to locate neonatal fawns within a few hours of birth.

We inserted VITs using a 275 mm long, 2-piece applicator made of a 22 mm (outside diameter) piece of cross-linked polyethylene tubing (PEX, Zurh Plumbing Products, Erie, Pennsylvania) for the external applicator and a 16 mm (outside diameter) piece of PEX tubing for the internal plunger. We folded the silicone wings of the VIT in and inserted the VIT, antenna first, into the applicator. We inserted the applicator, VIT wings first, into the vagina of the doe until it reached the cervix, then retracted it slightly to leave the VIT just short of the cervix. Then we used the internal plunger to push the VIT out of the applicator, allowing the silicone wings to expand. We cut the VIT antenna approx. 2 cm past the vulva (Johnstone-Yellin et al. 2006) during 2002, but left the antennas longer (3−4 cm) in 2003−2005. We washed the VIT applicator and plunger with soap and water and soaked them in 90% isopropyl alcohol between uses.

Radio-collared does that were recaptured in subsequent years received a new VIT and a general physical examination of body, radio-collar, and eartag condition. We assumed all captured adult does were pregnant and made no attempt to assess pregnancy during the capture process. During August−September of each year, we recaptured all does that had not fawned, or otherwise expelled the VIT, to remove the VIT prior to breeding.

Fawn Capture and Monitoring

We monitored each VIT 2−3 times per day (every 8−12 hours) starting 1 April of each year, using a truck-mounted whip antenna and a scanning receiver (Advanced Telemetry Systems, Isanti, Minn.). When we detected an expelled VIT, we homed on the signal using a hand-held, 3-element yagi antenna and a scanning receiver. If the doe and VIT were at different locations, we approached the doe first. Since we typically monitored VITs every 8 hours, we assumed the fawn(s) would still be with the doe at the birth site, which may not be at the VIT location if the VIT was expelled during early labor prior to parturition. If we didn't find a fawn(s) with the doe, we approached the VIT location. If we didn't find a fawn(s) at either location, we began searching between the doe and VIT locations. If either location showed evidence of birth (bed site, fluid on ground), we focused our search efforts around that location. We radio-collared all fawns that we found, but spent little time (<10 minutes) searching for additional fawns if only one fawn was located initially, in an attempt to limit human presence at the site.

We captured neonatal fawns by hand. We wore latex gloves when handling fawns and limited handling time (<10 minutes). Captured fawns were fitted with a 68g, expandable radio-transmitter collar equipped with a 4-hour, motion-sensitive mortality switch (M4210, Advanced Telemetry Systems, Isanti, Minn.). Fawn collars were designed to expand as the fawn grew and then fall off after approximately one year of wear (Diefenbach et al. 2003). We described the capture location (see Radio Telemetry and Home Range Analysis section on methodology for determining X-Y coordinates of site), conducted a general physical examination of the fawn, recorded the sex, and placed the fawn upright in a nylon bag or net and weighed with a digital scale (± 0.03 kg). The University of Georgia Institutional Animal Care and Use Committee approved the project protocol for doe and fawn capture (IACUC #A2002-10113-M1).

We monitored fawn survival at least once every 12 hours from capture until 1 August and 1−7 times per week from 1 August until transmitter failure or collar release each year. When we detected a mortality signal, we attempted to locate the fawn and determine its status. If a carcass was found, we conducted a field necropsy to determine cause of death. We documented evidence of predation (e.g., bite and claw mark measurements and location, subcutaneous hemorrhaging, chewed bones or extremities, disposition of carcass [in water, cached, etc.], portions of carcass consumed) and compared it to published literature when needed (Garner et al. 1976, McCord and Cardoza 1982, Epstein et al. 1983, Wade and Bowns 1984, Labisky and Boulay 1998) to determine the predator responsible. We also searched the immediate area for predator hair, scat, tracks, and signs of disturbance. Carcasses of predator-killed fawns were left at the kill site to avoid influencing predation rates. If no carcass was recovered, but the collar showed evidence of mortality (i.e., dried blood), we classified it as an unknown mortality; otherwise we assumed the collar was prematurely dropped and the animal was censored. If a fawn was emaciated and had no milk in the digestive tract, we classified the cause of death as starvation. We grouped recovery of collars into one of 6 categories: bobcat predation, alligator predation, deer-vehicle collision, starvation, other, and censor (included prematurely dropped collars, permanent loss of contact with a collar, and fawns surviving the study period).

Radiotelemetry and Home Range Analysis

We collected locations of radio-collared does 1−7 times per week during 1 April 2002–30 March 2003, and locations of radio-collared fawns 1−7 times per week from birth to death, collar drop, or 30 March 2003, using a hand-held, 3-element yagi antenna and a scanning receiver

(Advanced Telemetry Systems, Inc., Isanti, Minn.). We progressively shifted the start time of each monitoring session in 2-hour increments, allowing for the collection of locations throughout the diel period. Kiawah Island's extensive network of public roads, paved bike paths, and boardwalks allowed us to locate collared deer without using triangulation. We estimated locations by homing from landmarks (e.g., lot boundaries) and we recorded a description of each estimated location (e.g., 30 m south and 15 m east of Kiawah Island Parkway x Governor's Drive Intersection). We used a Geographic Information System (GIS) to estimate Universal Transverse Mercator (UTM) coordinates from these location descriptions. We used the measurement tool in ArcView 3.2 (Environmental Systems Research Institute, Inc., Redlands, Calif.) with a georeferenced property boundary map and digital orthophotography (1-m spatial resolution) of Kiawah Island to estimate locations. We stayed in publicly accessible areas while using this homing technique to minimize researcher impact on behavior. Deer on the island are routinely exposed to human activity on roads, bike paths, and boardwalks; therefore, our presence likely represented little, if any, disturbance to these deer.

We tested the accuracy of this homing technique by having a colleague place 20 test collars at randomly selected locations throughout the island. Each observer estimated the location of each test collar and we obtained the UTM coordinates of the estimated locations using the technique described above. We determined the exact coordinates (± 3 m) of each test collar using a Trimble Pro XR global positioning system (Trimble, Sunnyvale, Calif.) and base station. The distance (m) between the known and estimated locations was calculated as the telemetry error for that test collar. Error estimates from each test collar and observer were averaged to create an overall telemetry error rate. Using this methodology, the overall telemetry error rate included the error associated with the estimated location's description and the error associated with estimating the UTM coordinates in the GIS.

We used Home Range Tools (HRT, Rodgers et al. 2005) for ArcGIS 9 (Environmental Systems Research Institute, Inc., Redlands, Calif.) to calculate annual and seasonal 95% and 50% fixed kernel (FK, Worton 1989) and 95% minimum convex polygon (MCP) home ranges for does and fawns with ≥ 30 locations per season (Seaman et al. 1999). Within the HRT program, we used least squares cross-validation (LSCV) to select the smoothing factor for FK home ranges (Silverman 1986). We delineated 4, 3-month seasons to roughly coincide with seasonal events that potentially affect behavior and movements of does and fawns: spring (Apr−Jun) corresponded to the fawning season, summer (Jul−Sept) to the period when does were lactating and fawns were dependent on the doe's milk, fall (Oct−Dec) to the breeding season, and winter (Jan−Mar) to gestation. We used a repeated-measures analysis of variance (ANOVA; PROC ANOVA, REPEATED statement, SAS v. 9.1, Statistical Analysis System, Cary, N.C.) to test for seasonal differences in doe and fawn home ranges and post-hoc Tukey's Honestly Significant Difference (Tukey's HSD) multiple comparison tests to examine differences between specific seasons. We considered all statistical tests significant at $\alpha = 0.05$.

Birth Site Habitat Assessment

Because the majority of fawn mortality (63%) and bobcat predation on fawns (66%) occurred within 2 weeks of birth, we investigated whether habitat composition around the birth site influenced fawn mortality from bobcat predation during this time period. Fawns dying within 2 weeks of birth during 2002 had few telemetry locations with which to calculate a home range and telemetry locations were not taken on fawns during 2003−2005. Therefore, we used a method similar to Vreeland et al. (2004) to assess habitat composition in a circular buffer around each fawn birth site. Vreeland et al. (2004) used year and site-specific median home range size of fawns surviving ≥ 9 weeks to create buffers. MCP home ranges incorporating 100% of fawn locations for fawns surviving ≥ 2 weeks during 2002 were small ($\bar{x}$ = 2.7 ha) and highly variable (SE = 1.0 ha, range = 0.0 to 11.7 ha). To ensure we assessed habitat in an area that encompassed the majority of fawn activity, we measured the distance (m) between the birth site and the farthest telemetry location from the birth site, for each fawn surviving ≥ 2 weeks in 2002, using the measurement tool in ArcGIS 9.1. Then we calculated the median distance, weighted by the number of telemetry locations used in the distance calculation (range = 8 to 19 locations), over all fawns surviving ≥ 2 weeks during 2002 (*n* = 14). We used this weighted median distance (242 m) as the radius to buffer all fawn birth sites (2002−2005) in ArcGIS 9.1, creating 18.4-ha circular buffers around each fawn birth site.

We used a GIS to evaluate habitat composition within each fawn birth site buffer. We used a georeferenced plat map, municipal building permit dates (Town of Kiawah Island, Kiawah Island, South Carolina) and infrared digital orthophotography (1-m spatial resolution, taken in March of 2005), to delineate 10 habitat types (forest, shrub [salt shrub and maritime shrub], open dunes [mix of sand and native grasses], salt marsh, sand, open-altered [e.g., parks], golf course, developed areas [developed residential and commercial properties], water, and roads) in ArcGIS 9. We assumed that native vegetation in unaltered areas was similar between all years, as there were no fires, major tropical storms, or forestry activities on the island during these years. We considered a lot "developed" after a municipal building permit was issued. Building permit dates, coupled with the georeferenced plat map, allowed us to create year-specific habitat conditions within birth site buffer.

We converted vector polygons to a 5-m raster grid to facilitate habitat analyses, using the features-to-raster tool in ArcGIS 9.1. We used Hawth's Analysis Tools (Beyer 2004) for ArcGIS 9 to calculate zonal statistics of raster cells (summary of the number of cells of each habitat type) within each fawn site buffer. We used this cell summary to calculate 3 habitat metrics within the birth site buffer that we felt could potentially influence fawn mortality from bobcat predation: percent in preferred bobcat habitat (PERCBOB), percent in developed or road habitat (PERCDEVRD), and Simpson's Diversity Index (SDI). We considered open water unusable and removed it from all habitat calculations.

Boyle and Fendley (1987) describe preferred bobcat habitat in the southeastern U.S. as areas with ≥ 90% grass, forb, or shrub ground cover with 50−70% of the vegetation in grasses and/or forbs. According to the authors, this interspersion of vegetation provides optimal habitat for rodents (primarily cotton rats [*Sigmodon hispidus*]) and rabbits (*Sylvilagus* spp.), which are major components of the bobcat diet. Bobcats are opportunistic predators that will take a variety of prey species (McCord and Cardoza 1982), so we hypothesized that bobcats would be more likely to encounter and kill fawns born in areas comprised of a higher portion of preferred bobcat habitat, as they likely hunt these areas more frequently for their staple prey base. Based on concurrent examinations of bobcat habitat use (Chapter 3) and habitat suitability (Chapter 4), shrubs were the most preferred and most suitable habitat type for bobcats on the island. Therefore, we calculated the portion of the birth site buffer that was in shrub habitat (PERCBOB). Griffin (2001) conducted a study of general bobcat ecology on Kiawah Island during 2000. His results suggested bobcat ecology was negatively affected by residential and resort development (e.g., larger home ranges and movement rates in a more-developed portion of the island). Therefore, we hypothesized that the portion of a birth site buffer in developed or road habitats (PERCDEVRD) may increase the probability a fawn would survive bobcat predation to 2 weeks of age. We also hypothesized that an increase in habitat diversity within a fawn site buffer would concentrate understory hiding cover for fawns and optimal habitat for rodents and rabbits along edges, thereby increasing the likelihood of a bobcat encountering a fawn. We used Simpson's Diversity Index (Simpson 1949) to measure diversity with each birth site buffer. In this situation, the traditional Simpson's Diversity Index is interpreted as the probability (0.0−1.0) that 2 randomly selected, 5-m grid cells within a birth site buffer will be the same habitat type. A lower index value equates to higher estimated diversity within the buffer. To ease interpretation, we calculated 1 − Simpson's Diversity Index (SDI) so the index is interpreted as the probability that 2 randomly selected, 5-m grid cells within a birth site buffer will be different habitat types. Therefore, as the SDI value increases, the estimated diversity within the buffer also increases. We standardized SDI estimates by dividing each estimate's deviation from the sample mean by the standard deviation of the sample, so that differences would be reflected in standard deviations.

Survival Analyses

We used the Kaplan-Meier product-limit estimator (KM) to calculate annual doe survival estimates and 26 week and annual (birth to 30 March each year) fawn survival estimates (Kaplan and Meier 1958, Pollock et al. 1989). Six month and annual survival estimates are common in other deer fawn survival studies, allowing for comparisons between studies (Garner et al. 1976, Huegel et al. 1985*a*, Nielson and Woolf 1987, Boulay 1992, Bowman et al. 1998, Long et al. 1998, Vreeland et al. 2004, Pusateri Burroughs et al. 2006). Because we monitored fawns as infrequently as once per week during the fall and winter each year, we analyzed mortality in 1-week intervals (e.g., a fawn dying 13 days after capture would have died in week 2). When we lost contact with a radio-collar or a radio-collar was recovered with no sign of mortality, the fawn was censored on the last day contact was made or the day of radio-collar recovery, respectively. All surviving fawns were censored at the end of the survival analysis period.

KM analysis assumes that samples are selected randomly, experimental units are independent, observation periods are independent, working radio collars are always located, censoring is random, and radio collars do not influence survival (Winterstein et al. 2001). We originally planned to use the staggered-entry KM design, but an additional assumption of that design is that animals added to the sample have the same survival function as those already being monitored (Pollock et al. 1989). Due to the extended period over which we caught fawns each year (early April to early July), we felt this assumption would be violated. Therefore, we did not use a staggered-entry design, all fawns entered the survival analysis at birth, and time in the KM analysis refers to fawn age (in weeks) as opposed to calendar date. Considering that we analyzed survival in 1-week intervals (the maximum time between monitoring periods), we believe we satisfied the assumption of independent observation periods. However, we radio-collared all fawns found at a birth site (twins and single fawns) which could potentially violate the assumption of independent experimental units as there may be some survival dependence between members of a family group (Winterstein et al. 2001). Winterstein et al. (2001:358) state that “violation of this assumption should not cause bias, but it will make the estimates appear more precise.” We have no reason to believe that we might have violated any of the remaining assumptions of KM analysis. We estimated annual doe survival from 1 April (start of VIT monitoring) each year through 30 March of the following year, in 1-week intervals.

We report 95% confidence intervals (CI, Pollock et al. 1989) on 26-week and annual KM survival estimates (presented as percentages) to compare fawn survival between years. We used log-rank tests (see Pollock et al. 1989, Winterstein et al. 2001) to test for differences in overall survival functions between males and females, twin fawns and single fawns, and years. To examine the effect of violating the independent experimental unit assumption on our results and conclusions, we repeated log-rank and 95% CI comparisons using a subset of fawns in which 1 randomly selected fawn was removed from each twin group. We also used 95% CI and log-rank tests to examine differences in survival from specific mortality sources with adequate sample sizes (≥ 25 occurrences, Winterstein et al. 2001) between males and females, twins and single fawns, and years. When testing for differences in survival from specific mortality sources, we censored all fawns dying from other mortality sources (i.e., not the source of interest) at the time of death. We used ANOVA and t-tests to examine differences in birth mass (kg) between years and fawns dying from specific mortality sources and other fawns, respectively. To determine whether causes of mortality were the same between years, we used a chi-square homogeneity test (Sokal and Rohlf 1995). We pooled sources of mortality when year-specific counts would have resulted in expected values <5.

We also developed logistic regression models, incorporating a random effect for year (PROC NLMIXED, SAS v. 9.1, Statistical Analysis System, Cary, N.C.), to investigate the effect of habitat metrics on fawn mortality due to bobcat predation during the first 2 week of life (Snijders and Bosker 1999, Larsen et al. 2000). Random-effects logistic regression models, a form of hierarchical logistic regression model, are useful when investigating the relationship between explanatory variables and outcomes when outcomes are potentially non-independent due to some group-level effect (Snijders and Bosker 1999, Larsen et al. 2000). We used a plot of residuals, grouped by year, from a global (i.e., included all predictor variables) logistic regression model without random effects (PROC LOGISTIC, SAS v. 9.1) to investigate dependence between years. We also tested for differences in residuals between years with an ANOVA. In random-effects models, random effects are interpreted with median odds ratios (MOR) and fixed effects are interpreted with MORs and interval odds ratios (IOR; Larsen et al. 2000). The MOR for the random effect is an estimate of the heterogeneity between years, and is interpreted as the median odds ratio between 2 identical (i.e., same predictors), randomly selected fawns in years with the highest and lowest probability of dying from bobcat predation (Larsen et al. 2000). The MOR for a fixed effect is interpreted as the median effect of changing a covariate value by 1 (Larsen et al. 2000; e.g., the median effect of increasing birth mass by 1 kg on the probability a fawn will die from bobcat predation). The IOR is not a confidence interval, but is a measure of the joint effect of a fixed effect and the heterogeneity among years (Larsen et al. 2000). For example, there is an 80% probability the odds ratio between 2 randomly chosen measurements will be contained in an 80% IOR. Following the example of Larsen et al. (2000), we used an 80% IOR to discuss variation with respect to each fixed effect MOR.

This logistic regression framework allowed us to account for variation among years, while examining the influence of the habitat variables (PERCBOB, PERCDEVRD, SDI), grouping variables (SEX, TWIN), and an individual covariate (MASS) on fawn mortality from bobcat predation. SEX was the fawn's sex (0 = female, 1 = male), TWIN differentiated between single fawns and fawns from a twin group (0 = single, 1 = twin), and MASS was a continuous variable of fawn birth mass. We used the subset of fawns in which 1 randomly selected fawn was removed from each twin group in logistic regression analyses. Even a relatively small relationship between litter size and the probability that a fawn survived bobcat predation could influence results from habitat analyses, since birth site habitat buffers of twin fawns would have the exact same habitat composition. We examined models incorporating all combinations of uncorrelated (Pearson's r, $P > 0.05$) predictor variables, and interactions, that we felt could influence fawns surviving bobcat predation. We used a SAS macro developed by J. Peterson (Georgia Cooperative Fish and Wildlife Research Unit, University of Georgia, Athens) to calculate Akaike's Information Criterion corrected for small sample size (AIC_c, Burnham and Anderson 1998) for each candidate model and rank models according to ΔAIC_c. We report results from the best fitting model ($\Delta AIC_c = 0$).

Results

We monitored the reproduction of 54 individual does, for at least 1 year, from 2002−2005 (Appendix I). We monitored 30 does in each of the 4 years with a VIT, for a total of 120 monitored VITs. Eleven VITs were removed from does that weren't pregnant (no physical evidence of pregnancy at recapture), 9 VITs were expelled prior to parturition, 5 VITs led to aborted/mummified fetuses, and we permanently lost contact with 1 VIT in 2002. Three VITs were expelled shortly after capture and these does were recaptured and the VIT was re-inserted. One of these 3 does expelled the VIT again prior to parturition and the other 2 were not pregnant (recaptured in late August to remove VIT). There were a similar number of prematurely expelled VITs each year (2 in 2002, 2 in 2003, 3 in 2004, 2 in 2005); therefore, we assumed differences in antenna length between 2002 and 2003−2005 had no effect on the likelihood of a VIT being expelled (i.e., VIT was not more-easily pulled out by the doe or an accompanying doe when the antenna was longer). We assumed a VIT was expelled prior to parturition when there was no sign of parturition at the VIT or doe locations and the doe showed no behavior associated with parturition or newborn fawn-rearing (Ozoga et al. 1982, Huegel et al. 1985*b*). If there was physical or behavioral evidence of parturition, we assumed fawns were born but not located.

The 5 unsuccessful parturition sites had a total of 8 mummified fetuses (3 sets of twins, 2 single fawns). A single, fully developed, dead fawn (2.2 kg) was also found at a successful birth site (1 apparently healthy, live fawn and 1 dead fawn) in 2003. A field necropsy showed no evidence of trauma and the fawn was assumed to have died at, or slightly before, parturition. The doe with the failed VIT in 2002 was observed on several occasions, after the VIT signal was lost, with a young fawn.

The 98 VITs that were expelled due to parturition led to successful fawn captures at 87 birth sites. At these birth sites, we collared a total of 134 fawns (27 in 2002, 38 in 2003, 31 in 2004, and 38 in 2005). We collared 69 males (12 in 2002, 14 in 2003, 19 in 2004, and 24 in 2005) and 65 females (15 in 2002, 24 in 2003, 12 in 2004, and 14 in 2005). The difference in sex ratio between years approached statistical significance ($\chi^2_3 = 7.06$, $P = 0.070$); but since locating fawns with VITs provided a random sample of fawns, we assumed this potential difference in sex ratio between years was representative of the population. We collared 94 twins (20 in 2002, 26 in 2003, 18 in 2004, and 30 in 2005) and 40 single fawns (7 in 2002, 12 in 2003, 13 in 2004, and 8 in 2005). There was no difference in the proportions of twins and single fawns between years ($\chi^2_3 = 3.82$, $P = 0.282$). Median fawning date was 10 May in 2002 (range = 19 April to 4 June), 13 May in 2003 (range = 8 April to 3 July), 21 May in 2004 (range = 18 April to 27 June), and 23 May in 2005 (range = 11 April to 26 June). Mean birth mass was 2.4 kg (SE = 0.08 kg) in 2002, 2.5 kg (SE = 0.07 kg) in 2003, 2.6 kg (SE = 0.08 kg) in 2004, and 2.6 kg (SE = 0.07 kg) in 2005. The difference in mean birth mass between years approached significance ($F_{3,130} = 2.27$, $P = 0.083$). Male fawns ($\bar{x} = 2.6$ kg, SE = 0.05 kg, range = 1.5 to 3.9 kg) were heavier than females ($\bar{x} = 2.5$ kg, SE = 0.05 kg, range = 1.4 to 3.3 kg; $t_{132} = -2.17$, $P = 0.032$)

and twins ($\bar{x}$ = 2.5 kg, SE = 0.04 kg, range = 1.4 to 3.3 kg) were lighter than single fawns ($\bar{x}$ = 2.8 kg, SE = 0.08 kg, range = 1.4 to 3.9 kg; $t_{132} = 3.77$, $P < 0.001$).

Sources of Mortality

Fawns—A total of 105 fawns died during annual monitoring (Table 2.1), of which 102 (97%) died within 26 weeks of birth (Figure 2.1). The three mortalities occurring after 26 weeks were deer-vehicle collisions during 2003 (2 at 36 weeks) and 2005 (1 at 28 weeks). We were unable to detect a difference in birth mass between fawns surviving and fawns dying within 26 weeks of birth ($t_{132} = 1.46$, $P = 0.147$). Proportions of mortality sources did not differ between years ($\chi^2_3 = 4.49$, $P = 0.213$). Bobcats were responsible for 67% (70 of 105) of all mortalities, accounting for as little as 57% (16 of 28) and as much as 82% (23 of 28) of mortalities in a year. Sixty-six percent of bobcat predation (46 of 70) occurred within 2 weeks of birth, and 97% (68 of 70) occurred within 5 weeks of birth. Birth mass did not differ between fawns killed by bobcats ($\bar{x}$ = 2.6 kg, SE = 0.1 kg) and other fawns ($\bar{x}$ = 2.5 kg, SE = 0.1; $t_{132} = -0.85$, P = 0.396). Alligators were the only other predator of fawns during this project and were responsible for 8% (8 of 105) of mortalities, all of which occurred within 7 weeks of birth. Deer- vehicle collisions, starvation and other sources were responsible for 10% (10 of 105), 7% (7 of 105), and 10% (10 of 105) of mortalities, respectively. All starvation mortalities occurred within 2 weeks of birth, indicating abandonment or an inability of the doe to feed the fawn(s). On average, fawns that eventually died from starvation had lower birth masses ($\bar{x}$ = 1.9 kg, SE = 0.2 kg) than other fawns ($\bar{x}$ = 2.6 kg, SE = 0.1; $t_{132} = -4.27$, $P < 0.001$).

Does—Eighteen radio-collared does died during monitoring from 2002−2005. Five of these mortalities were related to capture (2 drowned in ponds, 2 presumably died from capture myopathy, and 1 died from bobcat predation). The doe killed by a bobcat was found dead within

20 m of her capture location. The doe was upright and moving post-immobilization, but presumably bedded back down after we left and was subsequently killed by a bobcat. This was the only documented case of a bobcat killing an adult deer during the project. Capture-related mortalities were not included in the survival analyses. Deer-vehicle collisions accounted for 77% (10 of 13) of the remaining doe mortalities. One doe drowned in a water treatment facility pond, 1 was killed by an alligator, and 1 died of unknown causes.

Survival

Fawns— Removing 1 randomly selected fawn from each twin group, to accommodate the independent experimental unit assumption of KM, did not alter the conclusions of the survival analysis. Therefore, we chose to include all fawns (twins and singles) in the overall analysis of survival.

Of the 134 radio-collared fawns, 10 were censored during the project due to premature collar release ($n = 7$) or permanent loss of contact with a collar ($n = 3$), and only 19 survived to the end of their annual monitoring period. Overall survival was 21.1% (95% CI = 13.4%−28.7%) to 26 weeks of age and 18.2% (95% CI = 10.8%−25.6%) annually (Figure 2.2, Table 2.2). Survival functions to 26 weeks of age differed between years (log-rank $\chi^2_3 = 8.75$, $P = 0.033$; Figure 2.3). Annual survival functions between years approached statistical significance (log-rank $\chi^2_3 = 7.49$, $P = 0.058$). There was no difference in annual survival functions between sexes (log-rank $\chi^2_1 = 0.52$, $P = 0.471$) or between twins and single fawns (log-rank $\chi^2_1 = 1.05$, $P = 0.306$).

Bobcat predation was the only mortality source with a large enough sample size (≥ 25 occurrences) to examine differences between years, sexes, and twins and single fawns. Because 66% and 97% of bobcat predation occurred within 2 and 5 weeks of birth, respectively, we examined differences in fawn survival between groups during this time period. Five-week functions of fawn survival from bobcat predation differed between years (log-rank $\chi^2_3 = 10.95$, $P = 0.012$). Survival from bobcat predation to 5 weeks of age was 37.0% (95% CI = 24.4%−49.6%) for males, 46.4% (95% CI = 31.5%−61.3%) for females, 43.1% (95% CI = 30.8%−55.3%) for twins, and 37.8% (95% CI = 22.2%−53.5%) for single fawns over all years. There was no difference in 5-week survival functions between sexes (log-rank $\chi^2_1 = 2.14$, $P = 0.144$) or between twins and single fawns (log-rank $\chi^2_1 = 0.27$, $P = 0.601$). Two-week functions of fawn survival from bobcat predation differed between years (log-rank $\chi^2_3 = 13.23$, $P = 0.004$; Figure 2.4). Survival from bobcat predation to 2 weeks of age was 54.3% (95% CI = 43.1%−65.5%) for males, 74.3% (95% CI = 62.9%−85.7%) for females, 66.4% (95% CI = 56.4%−76.4%) for twins, and 58.2% (95% CI = 43.7%−72.7%) for single fawns, over all years. There was no difference in survival functions between twins and single fawns (log-rank $\chi^2_1 = 0.93$, $P = 0.336$), but there was a difference between the sexes (log-rank $\chi^2_1 = 4.81$, $P = 0.028$; Figure 2.5).

Mean SDI was 0.655 (SE = 0.015, range = 0.093 to 0.812), mean PERCBOB was 0.076 (SE = 0.007, range = 0.000 to 0.440), and mean PERCDEVRD was 0.441 (SE = 0.019, range = 0.000 to 0.890) over all fawn birth site buffers. Examination of the residual plot from the global logistic regression model of fawn mortality from bobcat predation to 2 weeks of age, without a random effect for year, suggested dependence among years (means and CIs of residuals by year departed from 0). ANOVA also suggested residuals differed between years ($F_{3,83} = 4.20$, $P = 0.007$), justifying the use of models incorporating a random effect for year. There was a significant correlation between TWIN and MASS (Pearson's $r = -0.380$, $P < 0.001$) and between

PERCBOB and PERCDEVRD (Pearson's r = −0.532, $P < 0.001$); therefore these variables were not included together in any candidate model.

The best-fitting, random-effects logistic regression model ($\Delta AIC_c = 0$) contained SEX and SDI (Table 2.3). Examination of a box plot of residuals, grouped by year, suggested the model adequately fit the data. The random effect of year was significant, and the random effect MOR indicated that a randomly selected fawn born in the year with the highest probability of mortality from bobcat predation was 3.02 times more likely to die from bobcat predation than an identical fawn (i.e., exact same fixed effects) born in the year with the lowest probability of mortality from bobcat predation. Both SEX and SDI were significant contributors to explaining fawn mortality from bobcat predation. In identical years (i.e., random effect held constant), a male fawn was 4.63 times more likely to be killed by a bobcat than a female fawn. The IOR suggested, with 80% probability, a randomly selected male fawn was from 1.77 times less likely to 38.48 times more likely to die from bobcat predation than a randomly selected female fawn. In identical years, a fawn was 4.34 times more likely to die from bobcat predation with each 1 standard deviation increase in SDI (SD = 0.136). The 80% IOR estimated a fawn was from 1.89 times less likely to 36.07 times more likely to die from bobcat predation with each 1 standard deviation increase in SDI. The IORs for SEX and SDI were wide and showed a slight inconsistency in effect, suggesting other factors we did not consider in this analysis significantly affected the probability of a fawn dying from bobcat predation within 2 weeks of birth.

Does—We monitored the survival of ≥ 30 radio-collared does each year, since collared does not used for VIT monitoring (i.e., does we weren't able to recapture each year) were still monitored for survival. We permanently lost contact with 2 does during survival monitoring, and they were censored in the survival analysis. Doe annual survival was 90.0% (95% CI =

79.3%−100%) in 2002, 83.3% (95% CI = 70.0%−96.7%) in 2003, 93.8% (95% CI = 85.4%−100%) in 2004, and 91.7% (95% CI = 82.6%−100%) in 2005. Annual doe survival was 89.8% (95% CI = 84.6%−94.1%) over all years.

Home Range

Kiawah's extensive network of roads and paved bike paths allowed us to locate collared deer fairly accurately ($\bar{x}$ = 12.8 m, SE = 2.2 m; straight-line distance between estimated and true location of test collars). Normal probability plots suggested home range data were not normally distributed, therefore we log-transformed all home range estimates (does and fawns) prior to analysis to meet the assumptions of ANOVA. Does and fawns had <30 locations during the winter season, therefore, we did not estimate winter season home ranges. However, locations collected during the winter season were included in the calculation of annual home ranges.

Annual doe home range estimates were quite different between the 95% MCP ($\bar{x}$ = 35.5 ha) and 95% FK ($\bar{x}$ = 18.9 ha) estimation methods. The same was true for annual fawn home ranges estimated with 95% MCP ($\bar{x}$ = 35.3 ha) and 95% FK ($\bar{x}$ = 7.7 ha). Although it does not identify areas with an increased probability of use within the home range (i.e., no utilization distribution [UD]), we believe the 95% MCP method produced more biologically realistic estimates of overall home range size. For numerous does and fawns, the FK method with a LSCV-selected smoothing factor produced severely undersmoothed home ranges. These undersmoothed home ranges were represented as small, disjunct UD patches around individual locations or small groups of locations. Kernohan et al. (2001) describe the undersmoothing that can occur when using a LSCV-selected smoothing factor. They state that when LSCV produces an estimated UD that is severely undersmoothed, its accuracy in representing the actual UD is questionable. For this reason, we only present and discuss 95% MCP doe and fawn home range estimates.

From 1 April 2002–30 March 2003, we took 4,611 radiolocations from 29 adult does to calculate annual and seasonal home range estimates (Table 2.4). There was a difference in 95% MCP seasonal home ranges ($F_{2,54} = 9.82$, $P < 0.001$). Summer home ranges were smaller than spring and fall home ranges, which did not differ. We used a total of 1,170 telemetry locations to calculate annual and seasonal home range estimates for fawns. We report mean annual and seasonal fawn home range estimates for all fawns with ≥ 30 location per season, although only 3 fawns lived long enough to gather location data in all 3 seasons (Table 2.5). For these 3 fawns, 95% MCP home ranges did not differ between seasons ($F_{2,4} = 3.19$, $P = 0.149$), although there was a general increase in home range size with age. When all fawns with ≥ 30 locations in the spring and summer seasons were used to compare the 2 seasons, there was no difference.

Discussion

We had a fawn capture success rate of 89% (87 of 98 searches around VITs expelled due to parturition) using VITs on this project. We had more success with VITs than Bowman and Jacobsen (1998; 57% [4 of 7]) and similar success to Cartensen et al. (2003; 89% [16 of 18]) and Saalfeld (2006; 97% [28 of 29]), for does that expelled their functioning VIT during parturition. We had an overall success rate (i.e., birth sites where at least 1 fawn was found compared to total VITs used) of 73% (87 of 120), while Bowman and Jacobsen (1998), Cartensen et al. (2003), and Saalfeld (2006) had overall success rates of 31% (4 of 13, where efforts to locate VITs were uninterrupted), 57% (16 of 28), and 61% (28 of 46), respectively. Four of Cartensen et al. (2003) VITs were destroyed by predators feeding on does, which did not occur in the other studies. If these are removed, their overall success increases to 67% (16 of 24). Premature expulsion of the

VIT, transmitter failure, and implantation of does that are not pregnant accounted for the majority of unsuccessful efforts over all 4 studies. Cartensen et al. (2003) were successful in implanting only pregnant does by using a mobile ultrasound unit. Our success with VITs reaffirms their use as a viable option for locating neonatal fawns at birth sites when adult doe capture and frequent telemetry monitoring (<12 hours between monitoring sessions) are possible.

Sources of Mortality

Approximately 91% (96 of 105) of all fawn mortalities occurred within 7 weeks of birth. Bobcats killed 56% (70 of 124) of all fawns that we were able to monitor until death or conclusion of the study. Bobcat predation accounted for 67% (70 of 105) of all deer fawn mortalities and 89% (70 of 79) of predator-related mortalities (see Survival section for year-specific discussion of bobcat predation). This is the highest rate of bobcat predation on white-tailed deer fawns documented in the U.S. to date. All bobcat predation occurred within 12 weeks of birth, with 47% (33 of 70) occurring during the first week, suggesting studies of fawn survival where fawns weren't captured near birth potentially missed a significant portion of mortality.

Numerous studies throughout the U.S. have documented bobcat predation on white-tailed deer fawns (Cook et al. 1971, Garner et al. 1976, Carroll and Brown 1977, Epstein et al. 1983, Boulay 1992, Sams et al. 1996, Ballard et al. 1999, Vreeland et al. 2004), although only 2 observed bobcats accounting for >25% of overall fawn mortality (Epstein et al. 1983, Boulay 1992). Bobcats were responsible for at least 32% (12 of 38) of all non-capture-related fawn mortalities in the Esptein et al. (1983, 1985) study on 2 coastal barrier islands in South Carolina and 58% (31 of 53) of all mortalities during Boulay's (1992) study in the Florida everglades. Other than geography, there was 1 pronounced difference between results from these 3 studies (including this study) and the other fawn mortality studies referenced above: a lack of coyote predation. With the exception of Sams et al. (1996) and Vreeland et al. (2004), which documented natural causes other than predation (e.g., emaciation, disease) as the primary mortality sources, coyote predation was the primary source of mortality in these studies (range = 54% to 71% of all mortalities). Of the fawn survival studies we reviewed that documented coyote predation but no bobcat predation, coyote predation accounted for between 42% and 69% of all mortalities (Huegel et al. 1985*a*, Nielson and Woolf 1987, Bowman et al. 1998, Long et al. 1998, Saalfeld 2006). The only other study that specifically investigated fawn survival in a suburban setting (Saalfeld 2006) found that approximately 43% of mortalities were caused by coyotes, with no bobcat predation.

In a study of sympatric bobcats and coyotes in California, Neale et al. (2001) showed that bobcats consumed relatively more rodents and lagomorphs, while coyotes consumed relatively more ungulates. They concluded this resulted from fundamental niche differences as opposed to interspecific competition. In a study of sympatric coyote and bobcat populations in Florida, Thornton et al. (2004) found a similar diet separation between the species, with coyotes taking relatively more ungulates than bobcats. In Maine, Litvaitis and Harrison (1989) found that bobcats relied less on deer and more on snowshoe hares (*Lepus americanus*) after the area was colonized by coyotes. In a study of Columbian white-tailed deer (*O. v. leucurus*) fawn mortality in Oregon, Ricca et al. (2002) surmised that bobcat predation may have been compensating for a lack of coyotes on their study site, although they could not completely eliminate the possibility of coyote predation since 30% of mortalities (11 of 37) were attributed to unknown predators.

Bobcats are generally considered opportunistic predators (McCord and Cardoza 1982) that may exhibit a functional response in diet composition to abundance of prey species (Baker et al. 2001). Niche breadth in this dense bobcat population has apparently responded positively to a virtually unexploited abundance of suburban deer fawns in the absence of resource competition with other major terrestrial predators. Epstein et al. (1983) reported that red (*Vulpes vulpes*) and gray foxes preyed upon fawns, each of which was responsible for 5% (2 of 38) of all mortalities. Although gray foxes appeared fairly abundant on Kiawah Island during this study, we did not detect any canid predation of deer fawns. Therefore, we do not consider them a significant predatory threat to deer fawns on the island.

Alligators were the only other predator of deer on Kiawah Island, accounting for approximately 8% (8 of 105) of fawn and doe (1 of 13) mortalities. The doe was the only carcass we were able to examine post-mortem. The doe was found dead approximately 50 m from a pond containing at least 1 alligator (2.5−3m in length). A field necropsy revealed a severely broken hind leg with large puncture marks and hemorrhaging consistent with an alligator bite. The doe apparently escaped the initial attack and subsequently died from its injuries. On many other occasions, we observed alligators feeding on deer carcasses, although we never actually witnessed an alligator predating a deer. Because we were unable to retrieve any of the fawn carcasses we recorded as alligator predation, it is possible that drowned fawns that were subsequently scavenged by an alligator were mistakenly categorized as alligator-caused mortalities. It also was impossible for us to tell if fawns fell in the water and were subsequently killed, or if they were taken from the bank. Linnell et al. (1995) cited numerous sources to support their claim that neonatal ungulates have a "propensity for drowning." Since alligators are attracted by movements in the water, and Kiawah Island supports a very abundant alligator population, we assumed the majority of fawns that fell in ponds were killed by alligators prior to drowning. All fawns we categorized as alligator mortalities were physically being held by an alligator when we detected the mortality. On numerous occasions we were unable to see the carcass, but we lost contact with the radio-collar when the alligator submerged itself, indicating the radio-collar was inside the alligator.

All mortalities identified as alligator predation occurred within 7 weeks of birth. Most ponds on Kiawah Island have buffers of native vegetation along at least a portion of the periphery, which likely provided good hiding cover for newborn fawns. This habitat configuration potentially located many neonatal fawns adjacent to ponds for extended periods of time while fawns were hiding between feedings. Epstein et al. (1983) reported alligator predation on deer fawns in coastal South Carolina, with alligators responsible for 5% (2 of 38) of all mortalities. Shoop and Ruckdeschel (1990) documented deer remains in 9% (3 of 33) of alligator scats and described several observations of alligators feeding on deer carcasses on Cumberland Island, Georgia. They also suggested the majority of predation on terrestrial mammals was by large alligators (>1.8m), which was consistent with our observations. All of the alligators we observed feeding on deer fawns were ≥ 2 m long.

Deer-vehicle collisions were the second most important source of fawn mortality and the most important source of doe mortality, accounting for 10% (10 of 105) and 77% (10 of 13) of mortalities, respectively. Most vehicle-caused fawn mortalities (8 of 10) occurred after 7 weeks of age, likely due to increased movements associated with maturation or the breeding season (Beier and McCullough 1990). Deer-vehicle collisions were responsible for 18% of fawn mortalities on Mount Desert Island, Maine (Long et al. 1998), 66% (19 of 29) of doe mortalities in a suburban area around Chicago, Illinois (Etter et al. 2002), 89% of doe mortalities in a suburban area near St. Louis, Missouri (Hansen and Beringer 2003), and 44% (11 of 25) of all fawn, yearling, and adult doe mortalities in Irondequoit, New York (Porter et al. 2004).

All mortalities due to starvation (*n* = 7) occurred within 2 weeks of birth, indicating abandonment or an inability of the doe to nurse the fawn(s). In each instance, recovered fawn carcasses were emaciated and showed no signs of nursing (i.e., milk in the digestive tract). We have no reason to believe these abandonments were related to capture activities. In their examination of capture-related abandonment in white-tailed deer neonates, Carstensen Powell et al. (2005) suggested the risk was low and that unnecessarily censoring early mortalities (≤ 4 days of birth) could result in underestimated mortality rates. Birth masses of fawns dying from starvation were significantly lower than masses of other fawns, indicating decreased physical condition at birth. Besides general observations, we did not collect specific data on the physical condition of collared does and how it may have related to neonate physical condition and starvation. During the VIT-removal recapture of a doe in 2002, we noticed the doe's udder was abnormally firm, although there was no evidence of lactation. We assumed the doe had an unidentified infection. The following year, this doe gave birth to 2 fawns, both of which died of starvation within 2 days.

The remainder of deer mortalities were caused by drowning (5 fawns, 1 doe), unknown causes (4 fawns, 1 doe), and unknown predation (1 fawn). Three fawns and 1 doe drowned in a water-treatment facility pond. The pond had steep banks lined with a slick, hard plastic that apparently prevented escape once a deer had fallen in. Measures have been taken since our field work ended to improve fencing around this facility. Two fawns, both of which were born on small high-ground patches in the salt marsh, drowned on rising tides after getting stuck in salt marsh mud at low tide. The 4 fawns and 1 doe dying of unknown causes showed no physical signs of predation, trauma, starvation, or heavy parasite load, but—since no toxicology, pathology, or histology samples were taken—we cannot speculate on their cause of death. The remains of the fawn dying from unknown predation showed evidence of predation (i.e., hemorrhaging), but avian scavenging made an accurate categorization of mortality impossible.

Survival

Based on the current literature, neonatal white-tailed deer fawn survival is highly variable across the U.S., ranging from a low of approximately 12% during a study in Oklahoma (Garner et al. 1976) to a high of approximately 75% during a recent study in Michigan (Pusateri Burroughs et al. 2006). Great care must be taken when comparing survival rates between studies due to differing capture protocols, lengths of study, survival rate estimation methodologies, predator populations, amounts of hunting pressure, and other regional or site-specific differences. For this reason, we limit comparisons of survival rates in the following discussion to studies conducted in the southeastern U.S. and we attempt to highlight important differences in protocol and survival rate estimation method when appropriate. One of the most important differences between this study and the others we use for comparison was the use of VITs. Bowman et al. (1998) and Saalfeld (2006) were the only other white-tailed deer fawn survival studies conducted in the southeastern U.S. to use VITs. Therefore, survival estimates from other studies should be viewed as conservative, as they potentially missed some mortality by collaring fawns ≥ 1 day old.

Over all 4 years of this project, 26-week fawn survival was 21% and annual fawn survival was 18%. Epstein et al. (1985) used a direct proportion of mortality (i.e., number dead divided by number monitored) to estimate 2−3 month survival (varied depending on when the fawn was captured) at approximately 16% (7 of 45) in South Carolina. Based on our interpretation of Figure 1 in their paper, mean fawn age at capture was approximately 8 days. Boulay (1992) estimated annual fawn survival in the Florida everglades at approximately 26%, using staggered-entry KM. Thirty-nine percent of the fawns used in that analysis were ≤ 4 weeks old at capture. It is likely that survival estimates during both of these studies would have been significantly lower if they were able to collar fawns at birth. Bowman et al. (1998) estimated 6-month fawn survival on a seasonally flooded island in Mississippi at 72% using KM. They surmised that low predation rates, and thus increased survival, resulted from the seasonally flooded nature of the study site. In a suburban area around Auburn, Alabama, Saalfeld (2006) estimated 8-week fawn survival at 33% using the known fates analysis in program MARK (White and Burnham 1999).

Survival functions of fawns to 26 weeks of age differed between years, suggesting significant temporal variation in survival patterns. This was likely a reflection of differences in bobcat predation between years. Differences between years in bobcat-specific survival functions to 2 and 5 weeks of age support this theory. Seasonal bobcat diet analyses conducted on Kiawah Island (Jordan 1998; Griffin 2001; K. Holcomb, University of Georgia, unpublished data) suggest rodents (particularly cotton rats [*Sigmodon hispidus*]) comprised at least 40% of bobcat diets during all seasons and up to 60% of diets during the spring and summer when newborn fawns are available. Baker et al. (2001) and Blankenship (2000) documented shifts in bobcat diet in response to staple prey (rodent and lagomorph) abundance, with an increased use of staple prey items when abundance was high and a general diversification of bobcat diets when staple prey abundance was low. It is possible that yearly differences in cotton rat abundance may have been related to differences in fawn survival from bobcat predation during 2003−2005. Data we collected during a small-scale rodent trapping effort in July of 2003−2005 (see Chapter 4 for methods) suggested that cotton rat abundance was lowest during 2004 (cotton rat captures/total trap night effort [C/E] = 0.012) when fawn survival from bobcat predation to 5 weeks of age was the lowest (17.7%), and was higher in 2003 and 2005 (C/E = 0.020 and 0.019, respectively) when fawn survival was higher (54.5% and 50.3%, respectively), possibly indicating an increased use of deer fawns in response to decreased cotton rat abundance.

However, individual variation in bobcat predatory behavior may have been equally, or more, important to temporal differences in fawn survival than staple prey abundance. During January−February of 2004, we radio-collared 16 bobcats on Kiawah Island to examine their general ecology, habitat use, and interactions with white-tailed deer (Chapter 3). The lowest fawn survival from bobcat predation to 5 weeks of age (17.7%, 95% CI = 4.9−30.6%) occurred during 2004. During 2004 and 2005, we scanned the radio-collar frequencies of all radio-collared bobcats before homing on fawn mortality signals. In 2004, we located 1 adult male bobcat (bobcat #795) near 35% (8 of 23) of all mortalities identified as bobcat predation and 62% (8 of 13) of bobcat kills within his 438-ha home range (95% MCP). Bobcat #795 was with, or <30 m from, 7 of these 8 carcasses and was <100 m from the other. In 3 cases, we located bobcat #795 with the deceased fawn prior to the fawn's radio collar switching to a mortality signal (i.e., the collar had not been motionless for >4 hours). No other radio-collared bobcats were in the vicinity of these 8 fawn carcasses. Although this bobcat's presence at the site is not proof of predation, the circumstantial evidence is fairly strong. Five other radio-collared bobcats (2 adult females, 1 juvenile female, 1 adult male, and 1 juvenile male) were located at or near bobcat-killed fawns during 2004, but none of these was located at >3 kill sites. Because we frequently monitored radio-collared fawns during the summer months (every 8−12 hours), we assumed bobcats located near bobcat-killed fawns were responsible for the mortality. Bobcat #795 drowned in the previously mentioned water treatment facility pond in December of 2004. After the loss of this bobcat, fawn survival from bobcat predation to 5 weeks of age increased to

50.3% (95% CI = 29.3−71.2%) during 2005. Six different radio-collared bobcats (3 males, 3 females [all collared bobcats were considered adults in 2005]) were located at or near 8 of 16 bobcat-killed fawns during 2005, however none of these individuals was located at >2 kill sites. We have no data to explain the apparent disproportional use of fawns by bobcat #795 during 2004, and since we only categorized radio-collared bobcats into general age classes (juvenile [<1 year] or adult [>1 year]) during capture in 2004, we cannot speculate on the exact age or ecology (i.e., home range size and location) of bobcat #795 during 2003 when fawn survival (54.5%, 95% CI = 35.9−73.1%) was significantly higher than 2004. These observations suggest variation in prey selection between individual bobcats, changes in staple prey abundance, or a combination of both likely contributed to temporal variation in deer fawn survival we observed on Kiawah Island.

The best random-effects logistic regression model showed that the random effect of year, and the fixed effects of fawn sex (SEX) and habitat diversity (SDI) around the birth site, were important factors in explaining fawn mortality from bobcat predation within 2 weeks of birth. However, there was a large amount of variability, and a slight inconsistency, in the effect of fawn sex and habitat diversity when 80% IORs for these fixed effects incorporated the heterogeneity among years. Therefore, it should be noted that other factors we did not consider in this analysis were likely significant contributors to the probability a fawn would be killed by a bobcat within 2 weeks of birth. As we discussed above, the variation between years was likely due to individual variation in bobcat prey selection, or a combination of individual prey selection and differences in staple prey abundance.

The MOR of the best logistic regression model estimated that a randomly selected male fawn was 4.63 times more likely to be killed by a bobcat within 2 weeks than a randomly selected female fawn, when the random effect of year was held constant. Jackson et al. (1972), Bartush and Lewis (1978), and Schwede et al. (1992) documented differences in activity patterns of fawns between the sexes. All 3 studies concluded that male fawns were more active than females. Jackson et al. (1972) and Bartush and Lewis (1978) detected differences in activity patterns between the sexes from capture (youngest fawn captured was 3 days old in Jackson et al. [1972] and 1 day old in Bartush and Lewis [1978]). Conversely, Schwede et al. (1992) did not detect differences in activity until the fawns were 3−4 weeks old. We did not collect data on activity patterns of fawns, but this assumed difference could explain why young male fawns were more likely to be killed by a bobcat than female fawns. White-tailed deer fawns are largely defenseless during the first 2 weeks of life, relying on cryptic coloration and minimal activity to avoid predation (Mech 1984). Any increase in activity would likely increase the probability of predation from a visually-oriented predator like the bobcat.

When the random effect of year was held constant, the MOR of the best logistic regression model estimated that a fawn was 4.34 times more likely to die from bobcat predation with each 1 standard deviation increase in SDI. Garner et al. (1976) noted that bobcat predation on their study site in Oklahoma usually occurred once fawns became associated with forest edges or steeper slopes. Based on our methodology for classifying habitat in this suburban landscape, an increase in habitat diversity would generally correspond to an increase in edge habitat and fragmentation. Since many of the habitat types (roads, sand, open dunes, salt marsh, golf course) would usually not provide good hiding cover for newborn fawns, and hiding cover within the developed habitat type would be concentrated along aesthetic buffers, this increase in diversity would likely concentrate preferred fawn bedding sites along edges, buffers, or in smaller patches of undeveloped habitat. These linear and patchy habitats are frequently used by bobcats on

Kiawah Island for daytime cover and travel corridors (see Chapters 3 & 4). We believe this habitat mosaic, and associated spatial concentration of preferred fawn bedding sites, may have increased the efficacy of a bobcat hunting these areas and increased the likelihood of an encounter between a hiding fawn and a bobcat using these areas as travel corridors. The fragmented suburban habitat of Kiawah Island is probably a major contributing factor to the high bobcat predation rate as a whole, with a localized increase in edge habitat and fragmentation around a fawn birth site likely increasing a bobcat's foraging efficacy even more.

The best regression model in Vreeland et al. (2004) suggested mass at capture and study site were the only factors they examined that significantly influenced survival. At least 2 other studies have documented a positive relationship between mass and survival in white-tailed deer fawns (Verme 1977, Kunkel and Mech 1994). We were unable to detect any significant difference in birth mass between fawns that died and surviving fawns or fawns that were killed by bobcats and all other fawns. Additionally, birth mass was not retained in our best regression model. Twin fawns are typically separated shortly after birth (Marchinton and Hirth 1984), although they are likely still more spatially associated with each other than they are with other fawns. Since we were unable to detect a difference in survival, or risk of dying from bobcat predation, between twins and single fawns, we assume the dense bobcat population and habitat configuration of Kiawah Island played a larger role in mortality than the potential influence of spatially associated twin fawns.

Survival of collared does was 89.8% over all years and did not differ between years. Porter et al. (2004) reported an annual adult doe survival rate of 62% in a suburban area in New York. Ricca et al. (2002) reported an average annual survival rate of Columbian white-tailed deer does on their Oregon study site, part of which was considered suburban, of 74%. In a suburban area near St. Louis, Missouri, Hansen and Beringer (2003) reported an annual doe survival rate of approximately 80%. Etter et al. (2002) reported an 83% survival rate for adult does in a suburb around Chicago, Illinois. Annual survival of does at Chickamauga Battlefield Park in Georgia was 76.2% (Tucker et al. 1996). The relatively high doe survival rate on Kiawah Island was likely due to the high nutritional condition and relatively low disease and parasite occurrence observed by Jordan (1998). Although deer-vehicle collisions killed 10 does during this project, mortality was minimal annually and we recorded no deaths due to disease or starvation.

Home Range

Annual and seasonal home ranges for does on Kiawah Island were similar to smaller than home ranges in other suburban-urban areas of the country (Table 2.6). Some studies have suggested that deer density may play an important role in determining home range sizes of suburban deer. There were approximately 23 deer/km^2 in the Kiawah Island study area during 2002 (J. Jordan, Town of Kiawah Island, unpublished data). Henderson et al. (2000) observed an increase in adult doe spring home ranges after a 50% reduction in herd density (29 ha spring home range when density was 49 deer/km^2 to 40 ha spring home range when density was 20 deer/km^2). Conversely, Swihart et al. (1995) observed larger annual home ranges in a lower-density deer herd (158 ha, density = 8 deer/km^2) when compared to a higher-density herd (67 ha, density = 73 deer/km^2). Although the relationship between deer density and home range in suburban environments is somewhat unclear, it likely depends on a variety of area- and region-specific nutritional, habitat, and human disturbance characteristics. Doe home ranges during the summer season were smaller than home ranges during the spring or fall seasons. The majority of studies we used for comparison observed this same trend. Lactating does tend to focus their movements around their milk-dependent neonatal fawns during this time period (Bartush and Lewis 1978, Schwede et al. 1994, D'Angelo et al. 2004).

For the 3 fawns we were able to track for all seasons, mean annual fawn home range size was similar to mean annual doe home range size. Seasonal home range sizes did not differ for fawns, likely due to sample size and high variability in movements between the 3 fawns we were able to track. There was a general increase in mean home range sizes for fawns as they became older. By the summer season, fawn home range size (21 ha) was similar to doe home range size (17 ha). Other studies have observed this same positive relationship between fawn home range size and age (Garner and Morrison 1977, Epstein et al. 1985, Pusateri Burroughs 2006). These results are fairly predicable, as fawn home ranges typically mimic the home range of the doe as they mature (Marchinton and Hirth 1984).

Deer in southern ecosystems typically exhibit high site fidelity to a home range (Marchinton and Hirth 1984). Examination of home ranges from Kiawah Island does and fawns showed little to no evidence of seasonal shifts in home range centers, therefore, we did not specifically investigate site fidelity. Home range data collected during this study, coupled with the deer herd health data collected by Jordan (1998), suggests small home ranges of Kiawah Island deer are likely a response to an abundance of nutritional, cultivated food resources.

Management Implications

When results from this study are compared with the declining to stabilizing trend in deer density observed through seasonal spotlight surveys during 2002−2005 (J. Jordan, Town of Kiawah Island, unpublished data), it appears that low fawn survival is limiting growth in this suburban deer herd. Our study is the first to document bobcat predation as the major limiting factor in the population dynamics of a suburban deer herd and the first to identify the effect an individual bobcat can have on fawn recruitment. There is a general lack of literature on white-tailed deer fawn survival and mortality sources in suburban settings. Many suburban environments, with their rich food resources and little to no hunting pressure, facilitate the irruptive behavior of ungulate populations (McCullough 1997). Since recruitment is the driving force behind population growth, accurate information on fawn survival and mortality is crucial to sound, effective management in these settings. Future research should continue investigations of deer-predator interactions, predator ecology, and the effect of habitat fragmentation in suburban landscapes, as these dynamics are likely site-, region-, and species-specific. Whereas our observations on suburban bobcat predation might be considered unique, once there is a better understanding of the role, ecology, and habitat needs of predators in suburban environments, this information could potentially be incorporated into suburban development plans to facilitate natural predator-prey dynamics, at least in those developments where natural predators are tolerated and valued (as on Kiawah Island). Since many reactive deer population control methods are infeasible, or highly controversial, in suburban settings (e.g., hunting, sharpshooting), proactive strategies based on knowledge of predator-prey dynamics may prove to be useful, less-controversial tools in the control of suburban deer.

Acknowledgments

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Table 2.1. Number of white-tailed deer fawn mortalities, by mortality cause and year (portion of yearly mortality), for 134 fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

Source	**2002**	**2003**	**2004**	**2005**	**Totals**
Bobcat	15 (0.65)	16 (0.57)	23 (0.82)	16 (0.62)	70 (0.67)
Vehicle	4 (0.17)	4 (0.14)	0	2 (0.08)	10 (0.10)
Alligator	3 (0.13)	2 (0.07)	0	3 (0.12)	8 (0.08)
Starvation	0	3 (0.11)	3 (0.11)	1 (0.04)	7 (0.07)
Other[a]	1 (0.04)	3 (0.11)	2 (0.07)	4 (0.15)	10 (0.10)
Total mortalities	23	28	28	26	105
Censor[b]	1	3	1	5	10
Surviving	3	7	2	7	19
n	27	38	31	38	134

Note: not all proportions sum to 1.0 due to rounding error.

[a] Includes fawns dying from unknown causes (*n* = 4), unknown predation (*n* = 1), and drowning (*n* = 5).

[b] Includes premature collar releases and permanent loss of contact with radio collar.

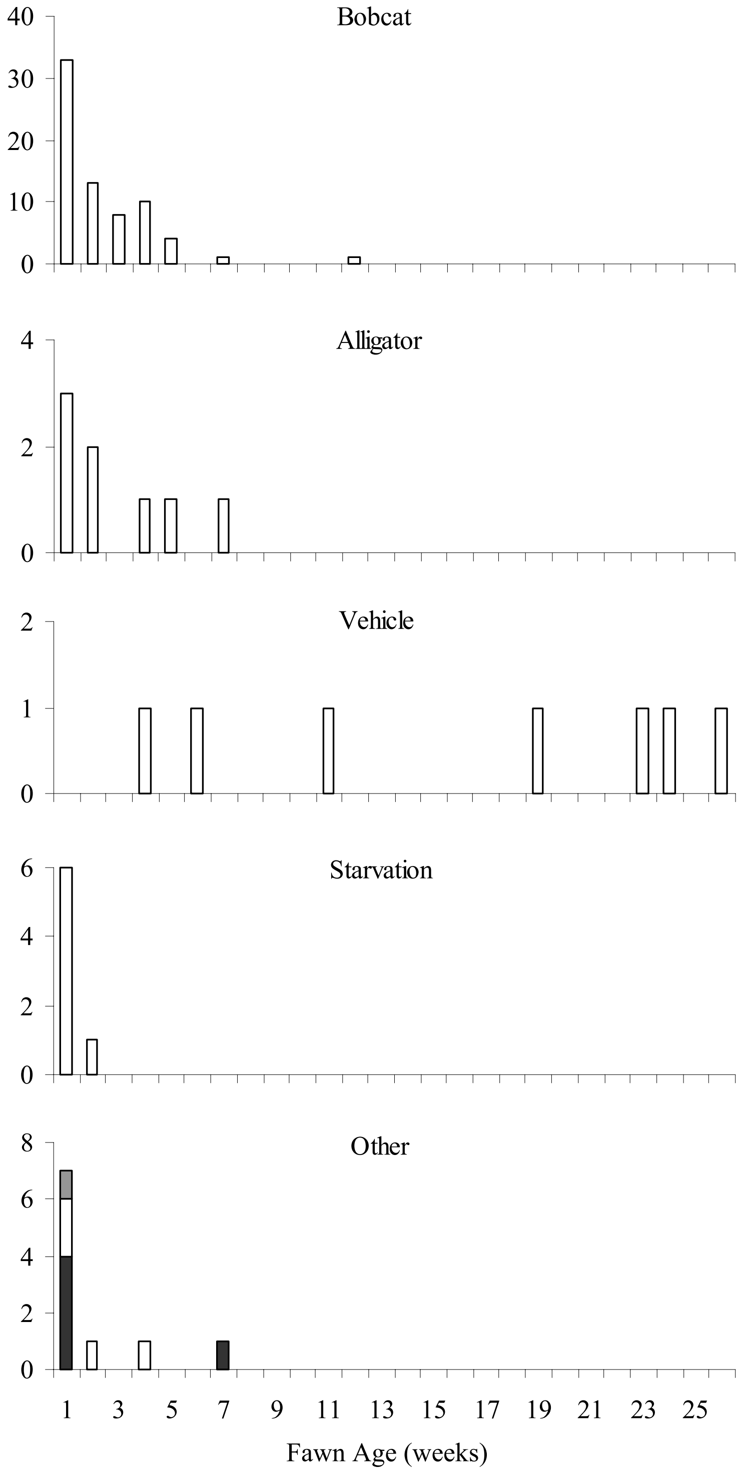

Figure 2.1. Frequency of white-tailed deer fawn mortalities, by age and mortality source, within 26 weeks of capture on Kiawah Island, South Carolina, USA during 2002−2005. “Other” includes drowning (black), unknown cause (white), and unknown predation (gray).

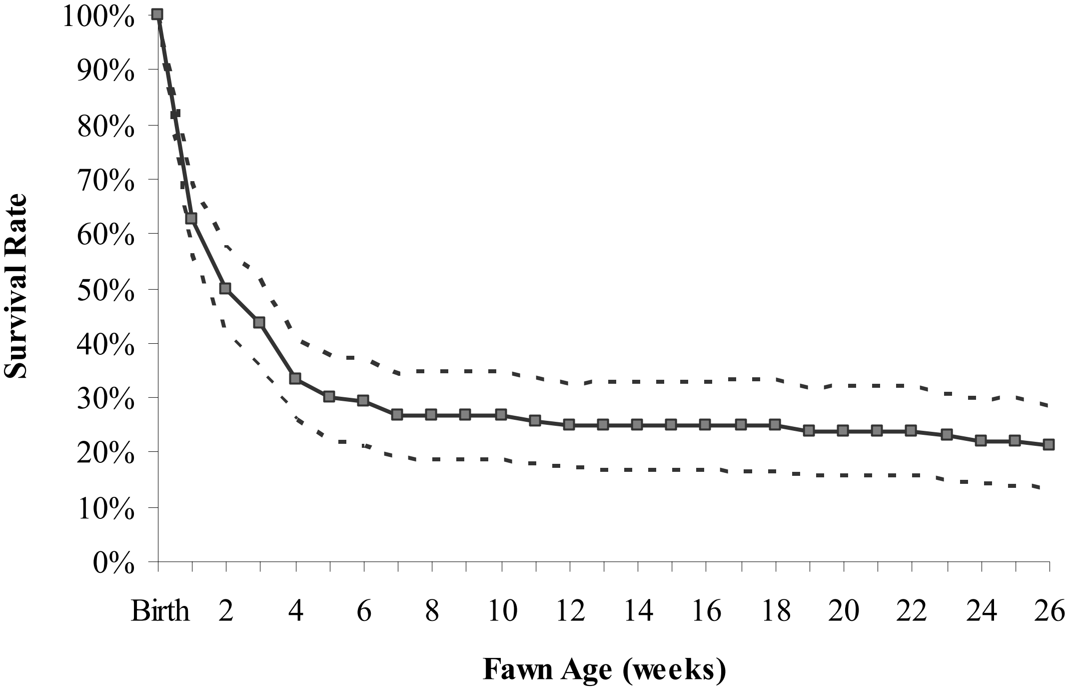

Figure 2.2. Pooled 26-week survival function (dashed line = 95% CI) of white-tailed deer fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

Table 2.2. Year-specific annual (capture through 30 March) and 26-week overall survival rates, and 2-week and 5-week survival rates from bobcat predation, (95% CI) of 134 white-tailed deer fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

		Overall survival	
Period	Year	Survival rate	95% CI
Annual	2002	13.0%	0.0 – 26.6%
	2003	23.1%	8.1 – 38.1%
	2004	9.7%	0.0 – 22.4%
	2005	26.1%	9.5 – 42.7%
26-week	2002	13.0%	0.0 – 26.6%
	2003	29.7%	14.3 – 45.1%
	2004	9.7%	0.0 – 22.4%
	2005	29.8%	12.5 – 47.2%

		Survival from bobcat predation	
Period	Year	Survival rate	95% CI
5-week	2002	39.5%	19.4 – 59.6%
	2003	54.5%	35.9 – 73.1%
	2004	17.7%	4.9 – 30.6%
	2005	50.3%	29.3 – 71.2%
2-week	2002	53.3%	34.9 – 71.8%
	2003	86.5%	75.1 – 97.9%
	2004	44.4%	28.1 – 60.6%
	2005	63.6%	47.6 – 79.7%

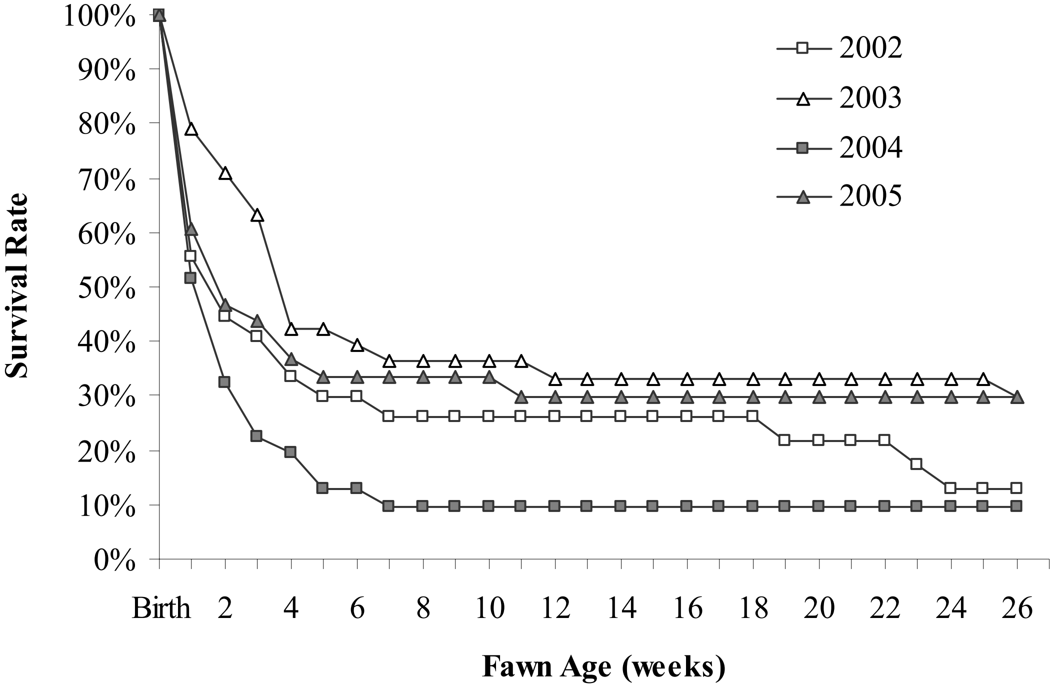

Figure 2.3. Yearly 26-week survival functions of white-tailed deer fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

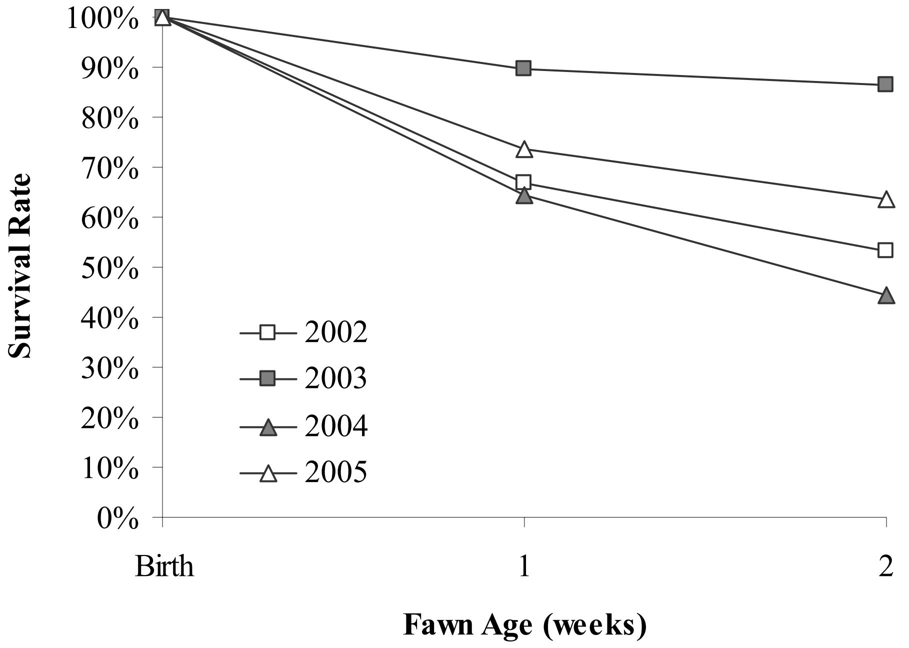

Figure 2.4. Yearly 2-week survival functions of white-tailed deer fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

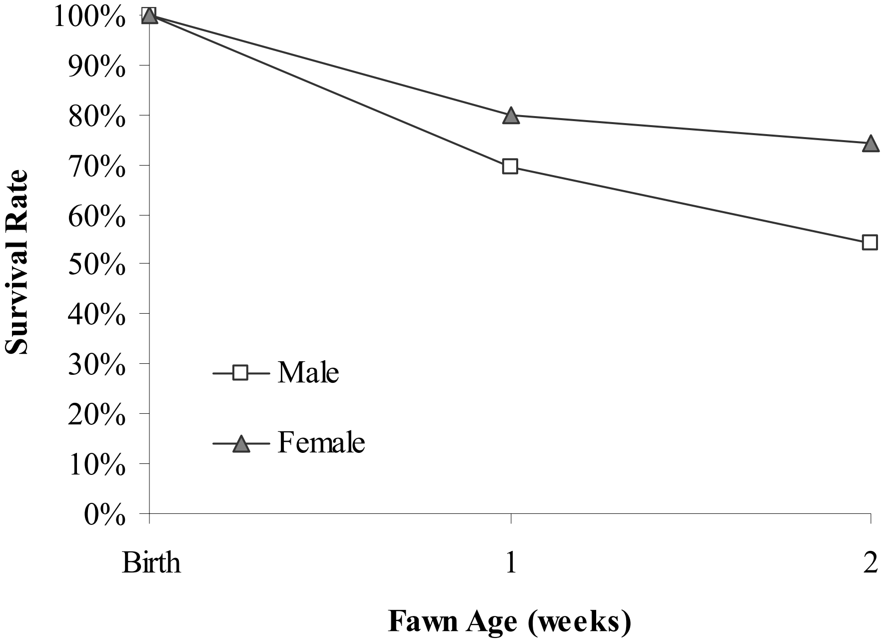

Figure 2.5. Two-week survival functions of male and female white-tailed deer fawns monitored on Kiawah Island, South Carolina, USA, 2002−2005.

Table 2.3. Estimates of fixed and random effects, with associated median odds ratios (MOR) and 80% interval odds ratios (IOR), from best-fitting ($\Delta AIC_c = 0$) logistic regression model of white-tailed deer fawn mortality from bobcat predation within 2 weeks of birth on Kiawah Island, South Carolina, USA, 2002−2005.

							80% IOR	
Fixed effect	**Estimate**	**SE**	**DF**	**t**	***P***	**MOR**	**lower**	**upper**
Intercept	−1.746	0.716	7	−2.44	0.045			
SEX	1.538	0.640	7	2.40	0.047	4.632	0.565	38.484
SDI	1.474	0.542	7	2.72	0.030	4.341	0.529	36.069
Random effect	**Variance component**	**SE**	**DF**	**t**	***P***	**MOR**		
Intercept	1.355	0.530	7	2.56	0.038	3.019		

Note: IOR does not represent a confidence interval.

Table 2.4. Mean annual and seasonal 95% minimum convex polygon (MCP) home ranges (SE) of collared does (*n* = 29) on Kiawah Island, South Carolina, USA, 2002−2003. All estimates are in hectares. Superscript letters represent significant differences (Tukey's HSD) between seasons.

Period	Locations / doe	95% MCP
Annual[a]	159 (6.7)	35.5 (3.2)
Spring (Apr – Jun)	53 (3.8)	23.4 (2.5) ^{A}
Summer (Jul – Sept)	51 (2.7)	17.3 (1.6) ^{B}
Fall[b] (Oct – Dec)	34 (0.1)	26.5 (2.6) ^{A}

[a] Annual home ranges include all collected locations, including locations collected during January – March, 2003 ($n < 30$) that were not used to calculate a seasonal home range

[b] $n = 28$ does (1 doe died at the start of this season)

Table 2.5. Mean annual and seasonal 95% minimum convex polygon home ranges (SE) of collared fawns with ≥ 30 locations in at least 1 season on Kiawah Island, South Carolina, USA, 2002−2003. All estimates are in hectares.

Period	Locations / fawn	95% MCP
Fawns with ≥30 locations in all seasons (*n* = 3)		
Annual[a]	191 (14.9)	35.3 (10.8)
Spring (Apr – Jun)	54 (11.6)	13.5 (10.4)
Summer (Jul – Sept)	77 (0.3)	20.7 (9.4)
Fall (Oct – Dec)	34 (0.0)	28.5 (1.3)
Fawns with ≥30 locations in specific seasons[b]		
Period	Locations / fawn	95% MCP
Spring[c] (Apr – Jun)	59 (6.0)	11.2 (4.0)
Summer[d] (Jul – Sept)	74 (2.2)	14.6 (4.6)

[a] Annual home ranges included all collected locations, including locations collected during January – March, 2003 that were not used to calculate a seasonal home range ($n < 30$)

[b] Includes home ranges for 3 fawns with ≥ 30 locations in all seasons

[c] $n = 8$ fawns

[d] $n = 7$ fawns

Table 2.6. Comparison of annual and seasonal home ranges between data collected on Kiawah Island, South Carolina, USA during 2002 and other studies of suburban-urban white-tailed does.

			Mean home range estimates			
Study	**State**	**Method**	**Annual**	**Spring**	**Summer**	**Fall**
This study	S.C.	95% MCP	36	23	17	27
Swihart et al. (1995)	Conn.	MCP	67 / 158[a]	–	–	–
Cornicelli et al. (1996)	Ill.	MMA[b]	51	40	17	17
Henderson et al. (2000)	S.C.	95% MCP	–	31 / 40[a]	–	–
Kilpatrick & Spohr (2000)	Conn.	95% AK[c]	43	–	–	19 / 43[d]
Picollo et al. (2000)	Ill.	95% MCP	61 / 26[e]	–	–	–
Waddell (2000)	Minn.	90% AK	–	30	–	–
Etter et al. (2002)	Ill.	95% MCP	62	51	26	32
Grund et al. (2002)	Minn.	90% AK	–	144	50	93
Porter et al. (2004)	N.Y.	90% MCP	–	–	21	–

Note: Dates used to delineate seasons in comparison studies did not always align with dates we used to delineate seasons.

[a] Home range in higher-density / lower-density deer herd.

[b] Modified minimum area method (Harvey and Barbour 1965).

[c] Adaptive kernel method (Worton 1989).

[d] Home range from locations collected during daylight / night hours.

[e] Suburban forest preserve study site with higher / lower human influence.

CHAPTER 3

MOVEMENTS, INTERACTIONS, AND HABITAT USE OF BOBCATS ON A DEVELOPED SOUTH CAROLINA BARRIER ISLAND[1]

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Abstract: Kiawah Island, South Carolina supports a relatively dense bobcat (*Lynx rufus*) population within a matrix of residential and resort development and small undeveloped patches of native vegetation. Our objective was to examine movements, interactions, and habitat use of bobcats in this development. We radio-collared the majority of resident bobcats on the island and investigated their home range size, social organization, diel movements, survival, reproduction, and habitat use through regular telemetry monitoring. Home ranges were relatively small compared to undeveloped areas of the southeastern U.S. and home range size did not differ between the sexes. Variation in home range overlap was high, likely in response to population density, prey availability, or patchy distribution of important habitat resources. Survival was high and reproduction was adequate to replace losses. Bobcats increased nocturnal movements and moved little during daylight hours, presumably to avoid interactions with humans. Bobcats selected shrub habitats over all other habitats during diurnal and nocturnal time periods. They also selected developed areas during nocturnal time periods, potentially to exploit prey items around development. We observed an inverse linear relationship between home and core range size and the percentage of the range in shrub habitat. These results suggest the availability of shrub habitats for food production and daytime refugia is critical to maintaining an abundant bobcat population on the island. Our results suggest bobcats are fairly adaptable to human-altered landscapes when adequate food resources and daytime cover are available.

Key Words: bobcat, development, habitat use, home range, interactions, *Lynx rufus*, reproduction, South Carolina, suburban, survival

Introduction

Bobcats are one of a suite of species that have traditionally been associated with rural and "wild" landscapes, but are being forced to interact with humans at an ever-increasing rate (Ditchkoff et al. 2006). However, few studies have specifically examined bobcat presence and ecology in human-altered habitats (Harrison 1998, Nielsen and Woolf 2001*a*, Crooks 2002, Tigas et al. 2002, Riley et al. 2003, George and Crooks 2006, Riley 2006), only 1 of which was conducted outside the southwestern U.S. As human population growth and associated urban sprawl converts more rural and natural areas to wildland-urban interfaces, it is important that we understand the sensitivity of species to habitat fragmentation and human disturbance in all ecosystems threatened by development so that appropriate mitigation measures can be developed and implemented.

In the first investigation of urban-associated bobcats, Harrison (1998) used a mail survey to examine the spatial arrangement of bobcat sightings in residential areas of New Mexico. He found that bobcats used these areas and were frequently observed in close proximity (<25 m) to houses. However, Nielsen and Woolf (2001*a*) examined bobcat use of habitats surrounding residential structures in Illinois and found that they generally avoided homes and selected core ranges that included less human disturbance. Crooks (2002) used track surveys in habitat fragments of varying size and isolation to examine the relative sensitivity of a variety of carnivores to urbanization. He found that bobcats were moderately sensitive to fragmentation and concluded that bobcats can only persist in suburban areas that provide adequate connectivity between natural patches. He suggested the bobcat may serve as a useful indicator of the ecological functionality of a landscape. George and Crooks (2006) used infrared cameras to monitor activity patterns of bobcats, and other species, as they related to human activity in a

California nature reserve. Bobcats were detected less frequently, and shifted their activity patterns to a more nocturnal schedule, in areas of high human use. A series of studies examined the ecology of urban-associated bobcats in California as it compared to other species (coyotes [*Canis latrans*], gray foxes [*Urocyon cinereoargenteus*]) inhabiting these landscapes and bobcats in natural areas (Tigas et al. 2002, Riley et al. 2003, Riley 2006). Each of these studies documented some level of suburban avoidance by bobcats and alterations in behavior to minimize interactions with humans.

Kiawah Island, South Carolina is a resort-style development that supports a fairly abundant population of bobcats. Griffin (2001) noted that bobcats inhabiting a more-developed portion of the island had larger home ranges than those in a less-developed portion and surmised that differences in human activity or prey availability between the areas were likely responsible. However, research on white-tailed deer (*Odocoileus virginianus*) fawn mortality showed that bobcat predation was the major factor limiting growth of Kiawah Island's deer population (Chapter 2), suggesting bobcats were thriving in this human-altered environment. This situation provided a unique opportunity to replicate and expand on the research of Griffin (2001) to examine potential changes in bobcat ecology with continued residential and resort development between 2000 and 2004 and investigate how bobcats interact and use habitat within this suburban landscape. Our specific objectives were to examine bobcat home and core range sizes, movement rates, habitat use, social interactions, survival, and reproduction on Kiawah Island through telemetry monitoring of the majority of the island's bobcat population.

Study Area

Kiawah Island is a 3,500-ha coastal barrier island located approximately 25 km south of Charleston. Approximately 1,500 ha of the island was salt marsh (saltmarsh cordgrass [*Spartina* *alternifora*]) or brackish marsh (saltmeadow cordgrass [*Spartina patens*], salt grass [*Distichlis spicata*], seaside oxeye [*Borrichia frutescens*], black needlerush [*Juncus roemerianus*]). The remaining acreage was a mosaic of maritime forest (live oak [*Quercus virginiana*], slash pine [*Pinus elliottii*], and cabbage palmetto [*Sabal palmetto*]), maritime shrub thickets (sand live oak [*Q. geminate*], yaupon [*Ilex vomitoria*], wax myrtle [*Myrica cerifera*]), salt shrub thickets (seaside oxeye, marsh elder [*Iva frutescens*], wax myrtle, black needlerush), brackish and freshwater ponds, golf course, residential and resort development, and barren sand (Aulbach-Smith 1998). Kiawah Island is separated from other land masses to the north and west by the Kiawah River and to the east by the Stono River. A 2-lane road connected Kiawah Island to Seabrook Island at the narrowest point of the Kiawah River (~50m at low tide), crossing approximately 550m of salt marsh. From 2002 to 2005, Kiawah Island had a mean temperature of 27.6 ºC in July and 8.5 ºC in January, while precipitation averaged about 114 cm annually (N. Shea, Kiawah Island Community Association, unpublished data).

Residential and resort development began on Kiawah Island in 1974. During 2004−2005, this gated community had more than 1,100 permanent residents and was visited by thousands of tourists each year. Of the approximately 3,000 lots available for single-family homes on the island, about 2,000 were developed. Virtually all resort development (all resort hotels and villas and 4 of 5 18-hole golf courses) and the majority of developed residential lots (89%) were concentrated on the western 1,100 ha of the island. With the possible exception of a cleared walking path for real estate purposes, the vegetation on undeveloped lots was usually unaltered. Lots platted for single-family homes comprised 27% (567 ha) of the island's upland acreage, with a mean lot size of 0.19 ha (SE = 0.01 ha). The development and influx of people have dramatically changed the natural landscape of the island. Much of the maritime forest has been replaced with homes and landscaped yards, but construction regulations designed to bolster aesthetic appeal and green space (Kiawah Island Architectural Review Board 2007) have preserved buffer areas between homes, canopy cover within each lot, and vegetation along marsh and pond edges, resulting in a mosaic of native and landscaped vegetation within developed areas. Additionally, a few larger (2–84 ha) un-platted patches of upland habitat were scattered throughout the island, the largest of which were located at the island's extreme west and east ends.

Bobcat Population

According to standardized scent station surveys conducted during the winters (Jan−Feb) of 1998, 2000, 2001, and 2003−2005 and the bobcat abundance regression equation developed by Diefenbach et al. (1994), Kiawah Island supported a dense, relatively stable population of about 30 (SE = 1.6) bobcats (~1.4 bobcats per upland [non-salt marsh] km^2; J. Jordan, Town of Kiawah Island, unpublished data). However, Diefenbach et al. (1994) showed that scent-station indices are only capable of detecting fairly large changes (≥ 25%) in bobcat abundance when multiple surveys are conducted each year, which was not done on Kiawah Island. Griffin (2001) felt that the scent station technique was overestimating bobcat abundance on Kiawah Island, based on bobcat capture success and relatively complete coverage of the island with the home ranges of 9 radio-monitored adult bobcats.

Methods

Capture and Monitoring

From January−March 2004 we captured bobcats on Kiawah Island with Victor No. 1.75, laminated-jaw foot-hold traps (Woodstream Corporation, Lititz, Penn.) and Tomahawk cage traps (Tomahawk Live Trap Co., Tomahawk, Wisc.). Foot-hold traps were used in conjunction with commercial lures (e.g., Caven's bobcat urine and Fox Hollow bobcat gland lure and GH-II; Minnesota Trapline Products, Pennock, Minn.), road-killed deer carcasses (when available), and visual attractants (e.g., white feathers around set). Tomahawk cage traps were modified by adding a chicken wire compartment to the rear of the trap. A live bantam rooster was placed in the compartment to serve as a lure. Bantam roosters were fed and watered daily. Traps were placed along suspected bobcat travel corridors in undeveloped parcels of land throughout the island, where they were unlikely to be encountered by humans or pets. Captured bobcats were sedated with a 5:1 intramuscular injection of ketamine hydrochloride (10−15 mg/kg of body weight) and xylazine hydrochloride (2−3 mg/kg of body weight), administered by jab-stick or syringe. We fitted each bobcat with a 160g VHF radio-collar, equipped with an 8-hour, motion-sensitive mortality switch (M2220, Advanced Telemetry Systems, Isanti, Minn.). We recorded the sex, age class (juvenile [<1 year] or adult [>1 year]), mass (± 0.03 kg), and various body measurements (total length, tail length, and hind foot length) of each bobcat. Once processing was complete, we placed the sedated bobcat into a cage trap and used an intramuscular injection of yohimbine hydrochloride (0.4–0.5 mg/kg body weight) as an antagonist to xylazine hydrochloride. Each bobcat was allowed to fully recover from sedation in the cage trap (held for a minimum of 4 hours) before being released at the capture site. The University of Georgia Institutional Animal Care and Use Committee approved the project protocol for bobcat capture and handling (IACUC #A2002-10113-M1).

We located bobcats 2−5 times per week from 1 April 2004 to 30 March 2005, using a hand-held, 3-element yagi antenna and a scanning receiver (Advanced Telemetry Systems, Inc., Isanti, Minn.). We progressively shifted the start time of each monitoring session in 2-hour increments, allowing for the collection of locations throughout the diel period. Consecutive locations were spaced at least 12 hours apart to ensure independence between observations. Kiawah Island's 15 km of ocean-front beach and extensive network of public roads, paved bike paths, and boardwalks allowed us to locate bobcats without using triangulation the majority of the time. We estimated most locations (92% of all locations) by homing from landmarks that were identifiable in aerial orthophotography or from a georeferenced property boundary map of the island (e.g., lot boundaries, road intersections). We stayed in these publicly accessible areas while using this homing technique to minimize researcher impact on behavior. Bobcats on the island are routinely exposed to human activity on the beach, roads, bike paths, and boardwalks; therefore, our presence likely created little, if any, disturbance. We recorded a description of each estimated location (e.g., 30 m south and 15 m east of Kiawah Island Parkway x Governor's Drive intersection). We used a Geographic Information System (GIS) to estimate Universal Transverse Mercator (UTM) coordinates from these location descriptions. We used the measurement tool in ArcView 3.2 (Environmental Systems Research Institute, Inc., Redlands, Calif.) with a georeferenced property boundary map and digital orthophotography (1-m spatial resolution) of Kiawah Island to estimate locations.

We tested the accuracy of this homing technique by having a colleague place 20 test collars at randomly selected locations throughout the island. Each observer estimated the location of each test collar and we obtained the UTM coordinates of the estimated locations using the technique described above. We determined the exact coordinates (± 3 m) of each test collar using a Trimble Pro XR global positioning system (GPS; Trimble, Sunnyvale, Calif.) and base station for differential correction. The distance (m) between the known and estimated locations was calculated as the telemetry error for that test collar. Error estimates from each test collar and observer were averaged to create an overall telemetry error rate. Using this methodology, the overall telemetry error rate included the error associated with the estimated location's description and the error associated with estimating the actual UTM coordinates in the GIS.

When a bobcat was in an area that prevented us from getting within 150 m by publicly accessible means, we estimated the bobcat's location from compass bearings obtained at 2 telemetry stations (8% of all locations). Since the large undeveloped tracts of land, where triangulation was required to locate a bobcat, were located at the extreme western and eastern tips of Kiawah Island, we were typically unable to obtain a third telemetry bearing (e.g., to get an acceptable angle [60°−120°]; the third station would have been in the ocean, salt marsh, or a river). This precluded us from estimating telemetry error for these locations. However, we attempted to get as close as possible (always ≤ 1 km), take bearings that were as close to perpendicular (90°) as possible, and minimized elapsed time between successive bearings (<15 minutes) to increase accuracy (Withey et al. 2001). Exact coordinates (± 3 m) of the telemetry stations were determined using the GPS and base station data. We used LOCATE II (Nams 2000) to convert compass bearings to an estimated X-Y UTM coordinate.

Home Range Stability

We divided the study period into 4, 3-month seasons to examine seasonal changes in home range size and movement patterns and to assess annual home range stability. Although somewhat arbitrary, these seasons roughly coincided with events that likely affect bobcat behavior (particularly females) on Kiawah Island: spring (April−June) corresponded to denning, summer (July−September) to kitten-rearing, fall (October−December) to increased juvenile independence, and winter (January−March) to breeding/gestation and juvenile dispersal (Griffin 2001). We examined telemetry locations to identify dispersal events and to assess residency status of individual bobcats. Bobcats that exhibited erratic space-use patterns without a well-defined home range (dispersing juveniles, adults with large changes in central tendency and location pattern between seasons) were considered transients (Litvaitis et al. 1987, Benson et al. 2004).

Dispersing juveniles were not included in statistical analyses of home range size, home range overlap, or habitat use. We used shifts in central tendency (mean X-Y location) and maps of periodic telemetry locations to quantify and describe juvenile dispersal patterns and adult extraterritorial movements (Appendix IV). The treatment of adult bobcats exhibiting both transient and resident behavior during the study is specifically addressed for each analysis.

Home Range Size

For bobcats that exhibited resident movements throughout the study period and were monitored for the majority of all seasons, we used an index of location dispersion (average Euclidean distance [i.e., straight-line distance] between all possible pairs of locations) to compare home range size between seasons and between sexes within season (Koeppl et al. 1977, Conner and Leopold 2001). Conner and Leopold (2001) showed that this index of dispersion was a more precise and less biased estimator of home range size than adaptive kernel home ranges when sample sizes were <50. We used a repeated-measures analysis of variance (ANOVA; PROC ANOVA, REPEATED statement, SAS v. 9.1, Statistical Analysis System, Cary, N.C.), with sex as a group effect, to test for seasonal differences in dispersion.

We used Home Range Tools (Rodgers et al. 2005) for ArcGIS 9 (Environmental Systems Research Institute, Inc., Redlands, Calif.) to calculate 95% fixed kernel (FK, Worton 1989) home ranges and 50% FK core ranges for bobcats that exhibited resident behavior for ≥ 6 consecutive months and had ≥ 50 locations (Seaman et al. 1999). We initially calculated FK ranges using both least squares cross-validation (LSCVh) and likelihood cross-validation (LCVh) to select the kernel smoothing factor (Silverman 1986). LSCVh is currently the recommended method for selecting the smoothing factor (Seaman et al. 1999), although Horne and Garton (2006*a*) showed that LCVh generally performed better than LSCVh (i.e., less variability) during simulations. We used the least-squares cross-validation option within Home Range Tools to estimate LSCVh and Animal Space Use 1.0 (Horne and Garton 2006*b*) to estimate LCVh. We then manually inserted LCVh estimates into Home Range Tools to calculate FK estimates. When we calculated FK ranges with LSCVh, the 95% and 50% volume contours were severely undersmoothed. These undersmoothed ranges were represented as numerous small, disjunct contours around individual locations or small groups of locations. Kernohan et al. (2001) state that when LSCVh produces an estimated utilization distribution (UD) that is severely undersmoothed, its accuracy in representing the actual UD is questionable. We felt FK ranges produced with LSCVh were biologically unrealistic, and therefore we only present and discuss 95% and 50% FK ranges calculated with a LCVh-selected smoothing factor.

We also calculated 95% minimum convex polygon (MCP; Mohr 1947) home ranges for bobcats exhibiting resident behavior for ≥ 6 consecutive months, where 5% of the outlying locations (i.e., farthest from the mean center) were eliminated prior to estimation, to facilitate habitat use analyses (see Habitat Use section). We used the Animal Movements Extension 2.1 (Hooge and Eichenlaub 2000) in ArcView 3.2 to calculate 100 bootstrap estimates of MCP home ranges, using varying numbers of randomly-selected locations (5 – all locations), for 5 randomly selected bobcats. We plotted mean bootstrap results (MCP home range area by number of locations used) and used the point on the curve where MCP area increased by <1% with the inclusion of additional locations as the minimum number of points needed to accurately estimate a 95% MCP home range (Odum and Kuenzler 1955). Bootstrap estimates suggested 24–38 locations were needed to accurately estimate 95% MCP home ranges.

Because FK home ranges are based on probability of use and typically include areas outside telemetry locations and MCP home ranges connect the outermost points with straight lines, both estimators can include un-useable areas (e.g., open water) within a home range boundary. Kiawah Island is bordered on all sides by open water and has large expanses of frequently flooded salt marsh. Twice-daily flooding, and associated "pluff mud", likely made the majority of salt marsh inaccessible to bobcats. During telemetry monitoring, we never documented a bobcat traveling in the salt marsh >150 m from upland habitats. Therefore, we used ArcGIS to create a layer including all salt marsh >150 m from upland habitats, the Stono and Kiawah Rivers, and the Atlantic Ocean. We used this layer to clip all home range estimates in ArcGIS (i.e., remove portions of home ranges that fell within these un-useable habitats), creating more biologically realistic estimates of home range size (hereafter referred to as "modified" ranges). All statistical tests of home range size were conducted on modified FK ranges. We also present the original, un-modified home range estimates to facilitate comparisons to other studies. Home range estimates were square-root transformed prior to statistical analyses to meet normality assumptions. We used t-tests to test for differences in 95% and 50% FK ranges between sexes, between juveniles and adults, and between the more-developed, western end and less-developed, eastern end study areas described by Griffin (2001; Figure 3.1).

Home Range Overlap

We calculated the percent overlap of modified 95% FK home ranges for all bobcats with intersecting home ranges. We categorized these interactions as male-male, female-female, male-female (portion of female home range overlapped by male), or female-male (portion of male home range overlapped by female). For pairs that interacted at the home range-level, we also calculated the percent overlap of 50% FK core ranges, categorized in the same manner. When an overlap included a bobcat that died during monitoring, we estimated overlap using FK ranges calculated from locations collected prior to the mortality ($n > 50$), ensuring exploratory movements into vacated home ranges were not evaluated as interactions between live individuals. Only FK ranges estimated from resident movements were used to calculate overlap. Both 95% and 50% FK overlap data were non-normally distributed and could not be successfully transformed; therefore, we used a one-way Kruskal-Wallis test (PROC NPAR1WAY, SAS) to test for differences in percentage overlap between groups.

Reproduction and Survival

During the spring and summer seasons of 2004 and 2005, we watched successive telemetry locations of female bobcats for evidence of restricted or centralized movements. Once we obtained 4−5 successive telemetry locations in the same general area, we conducted a den search. The search involved 1−2 observers equipped with telemetry equipment. We initiated the search by estimating or triangulating the female’s location before approaching. We quietly approached the female’s location by homing and then searched the area where the female was last seen or located. When an active den was found, we handled kittens with latex gloves to minimize human scent at the den site. We recorded the number and sex of kittens found, the GPS location of the den site, and the vegetation structure of the den (e.g., dense shrub thicket, hollow stump). Information was collected as quickly as possible (typically <10 minutes) to minimize human presence at the den site.

Because bobcats were monitored regularly and we never lost contact with any radio-collared bobcat (i.e., no censoring), we simply report the proportion of bobcats surviving the monitoring period as an estimate of annual survival (annual survival rate [%] = number of bobcats surviving the study period / total number of bobcats monitored). We also describe timing and cause of mortalities.

Movement Rates

We conducted a focal telemetry session on all adult bobcats during each season (spring = June 1 and 3, summer = Sept 20 and 22, fall = Dec 20 and 22, winter = Mar 29 and 31) to examine movement rates throughout the diel period. During each focal session, we located adult bobcats every 2 hours throughout a 24-hour period. Each focal session took 2, 24-hour periods to complete (we monitored half of the adult bobcats during each period), since the spatial arrangement of bobcat home ranges made it infeasible to monitor them all every 2 hours. Only 1 randomly selected focal session location was used in home range estimation to ensure independence of locations, although all movements during focal sessions occurred within the respective bobcat's 95% FK home range boundary. For bobcats that exhibited transient movements during a portion of the year, only data from focal sessions during resident movements were included in this analysis. We calculated Euclidean distances (m) between successive locations. We divided distance traveled by elapsed time to calculate a minimum incremental movement rate (m/hr). We divided each focal session into 4 time periods: dawn (2 hours before to 2 hours after sunrise), day (2 hours after sunrise to 2 hours before sunset), dusk (2 hours before to 2 hours after sunset), and night (2 hours after sunset to 2 hours before sunrise). We used sunrise and sunset data collected by the U.S. Naval Observatory (2004) for Charleston, South Carolina to delineate session-specific time periods; therefore, the dawn and dusk time periods were always 4 hours long but the day and night time periods varied by session (sunrise/sunset times; spring = 0610/2030 hrs, summer = 0710/1915 hrs, fall = 0720/1715 hrs, winter = 0610/1840 hrs). Incremental movement rates were categorized in the time period that included the majority of the increment (e.g., if the dawn/day cutoff occurred at 0830 hrs, a movement rate calculated between 0715 hrs and 0915 hrs would be included in the dawn time period). We created an average incremental movement rate for each individual, within each time period, over all sessions. Because we did not have replication for each individual within each season, we did not examine seasonal differences in movement rates. Movement rate data were square-root transformed to meet normality assumptions. We used a 2-way ANOVA (PROC ANOVA, SAS) to examine the effects of sex, time period, and sex × time period interaction on movement rates. We used Tukey's Studentized Range (HSD) test for means separation of significant main effects.

Habitat Use

We used a georeferenced plat map, municipal building permit data, and infrared digital orthophotography (1-m spatial resolution, taken in March of 2005; Town of Kiawah Island, South Carolina), to delineate 8 habitat types (forest [maritime forest; 367.1 ha], shrub [maritime shrub and salt shrub areas; 306.4 ha], dunes [mix of sand and native grasses; 116.4 ha], open-altered [parks and golf courses; 218.1 ha], development [developed residential and resort properties and roads; 577.2 ha], salt marsh [1,509.6 ha; 807.0 ha when areas >150 m from upland habitats were removed], barren sand [234.1 ha], and water [153.7 ha]) in ArcGIS (Figure 3.1). Areas of salt marsh >150 m from upland habitats and open water (ponds, rivers, ocean) were excluded from habitat use analyses. Additionally, areas of barren sand (i.e., ocean-front beach) were considered of little use to bobcats *a priori* and were not included in analyses. Less than

0.5% of locations occurred in barren sand, all of which were within 10 m of other habitat types (i.e., within telemetry error), and a general lack of vegetation precluded these areas from producing substantial prey resources or daytime concealment cover. We felt inclusion of these unused areas would only confuse the analysis since the ocean-front beach was spatially correlated with dune and shrub habitats found between the beach and maritime forest. We manually digitized most habitat types, although we used platted property boundaries (i.e., lot borders and road right-of-ways) to delineate development. We considered all individual lots for which a municipal building permit was issued prior to March 2005 to be developed, even if we could not see a home in the digital orthophotography. We assumed that once a building permit was issued, increased human activity and the probable clearing of native understory vegetation altered the habitat quality of the lot, regardless of the status of residential construction.

We used the Euclidean distance technique described by Conner and Plowman (2001) to examine second-order (i.e., selection of home range habitats within the study area) and third-order (i.e., selection of habitats within the home range) habitat selection of non-dispersing juvenile bobcats and adult bobcats that exhibited resident behavior for ≥ 6 months (Johnson 1980). This technique compares the average distance between telemetry locations and each habitat type to the average distance between random locations and each habitat type using multivariate analysis of variance (MANOVA). As discussed previously, FK home ranges included areas outside the outer boundary of telemetry locations. Because we knew *a priori* that salt marsh was rarely used by bobcats (i.e., few telemetry locations in salt marsh), we felt that using FK home ranges would artificially increase the power of MANOVA to detect significant habitat selection. Allowing random points to be placed in areas of salt marsh that were not likely a part of the bobcat's actual home range (i.e., outside of actual telemetry locations that fell near, or slightly in, the salt marsh), would increase the average distance between those points and non-salt marsh habitat types, resulting in artificially smaller distance ratios (i.e., increased evidence of selection). Because 95% MCP home ranges did not include areas outside the boundary of telemetry locations, they included little salt marsh habitat that wasn't actually used. Therefore, the use of modified 95% MCP home ranges to delineate home range boundaries for habitat use analyses was a more conservative and appropriate approach.

For second-order selection, we used Hawth's Analysis Tools for ArcGIS (Beyer 2004) to generate 2,000 random points throughout the island. We also generated n_i random points (n_i = the number of telemetry locations for individual i) within each bobcat's 95% MCP home range. We measured the Euclidean distance from each random home range point and each random island-wide point to the closest border of each habitat type using the Multiple Minimum Distance Tool for ArcGIS 9 (City of Scottsdale GIS 2007). We calculated the average distance to each habitat type for random locations within each home range, creating a vector of mean distances (r_i). We calculated a vector of mean distances from island-wide random points to each habitat type (w_i) in the same manner. We then created a vector of distance ratios (d_i) by dividing r_i by w_i. If habitat selection was occurring at random, d_i would approach 1. A distance ratio < 1 would generally indicate habitat selection, while a ratio > 1 would indicate avoidance. We used MANOVA (PROC GLM, SAS), with sex and age class (juvenile or adult) as group effects and bobcat as the experimental unit, to test the null hypothesis that d_i did not differ from a vector of 1s (i.e., second-order habitat selection did not differ from random). If a MANOVA was significant, we used univariate t-tests to determine which habitats were selected disproportionately and pairwise t-tests to create a ranking matrix of habitat selection (Conner and Plowman 2001, Conner et al. 2003).

When assessing third-order habitat selection, we measured the Euclidean distance from each telemetry location within the 95% MCP home range to the closest border of each habitat type. We calculated the average distance to each habitat type for each individual bobcat (i), creating a vector of mean distances (u_i). We then created a vector of distance ratios (d_i) by dividing u_i by the vector of average distances from random locations within each home range (r_i). We used MANOVA, with sex and age class as main effects and bobcat as the experimental unit, to test the null hypothesis that habitat selection within home range did not differ from random. We also tested whether time of day influenced third-order bobcat habitat selection by creating separate d_i for diurnal (30 minutes after sunrise to 30 minutes before sunset) and nocturnal (all other times) time periods. We tested the null hypotheses that time period, time period × sex interaction, and time period × age class interaction did not affect third-order habitat selection. As with second-order selection, we used univariate t-tests to determine which habitats were selected disproportionately and pairwise t-tests to create a ranking matrix of habitat selection if MANOVA was significant.

Habitat Composition and Home Range Size

We used ArcGIS 9 to calculate the habitat composition of each bobcat's modified 95% and 50% FK range (i.e., percentage of each habitat type). Based on habitat selection information gained from the habitat use analysis, we used linear regression models (PROC GENMOD, SAS) to examine the relationship between the percentage of the home range or core range in the most-selected habitat (predictor) and range size (response). Male and female bobcat range sizes are generally considered responses to breeding opportunities and habitat quality, respectively (Anderson and Lovallo 2003). In this analysis, we assumed that habitat selection was an indicator of habitat quality. Since habitat quality may significantly influence female range size, but have less of an effect on male ranges (Anderson and Lovallo 2003), we examined male and female bobcats separately. We assessed correlation of predictor variables (PROC CORR, SAS), and created models combining uncorrelated ($P > 0.10$) predictor variables, to avoid problems associated with multicollinearity (Ott and Longnecker 2001:708). We calculated Akaike's Information Criterion corrected for small sample size (AIC_c; Burnham and Anderson 1998) for each candidate model and ranked models according to ΔAIC_c (i.e., difference in AIC_c between the best model [lowest AIC_c] and each other candidate model). We then used ΔAIC_c to calculate the Akaike weight (w) for each model, which can be interpreted as the likelihood of the model, given the data and candidate set of models (Burnham and Anderson 1998). We present model fitting results for all candidate models and parameter estimates with 95% confidence limits (95% CL) from the best fitting model. We assessed goodness of fit of the global model (i.e., model including all predictor variables) by examining residual and normal probability plots. We considered results of all statistical tests significant at $\alpha = 0.10$.

Results

We monitored 16 bobcats (5 adult males, 5 adult females, 3 juvenile males, 3 juvenile females) on Kiawah Island from April 2004−March 2005 (Appendix II). We were able to recapture 3 adult bobcats (1 male, 2 female) that were originally collared in 2000 (Griffin 2001). A general physical examination showed no negative effects of collar wear and we replaced the old radio-collar with a new one. We believe we captured 21 different individuals during trapping (based on body size, sex, and location) although we did not mark juveniles that were released without a radio-collar. Small juveniles (collar >3% of body weight based on visual estimate of mass) and some juveniles captured early in the trapping season were released without a radio-collar since resident adult bobcat ecology was the primary focus of our study.

We took an average of 154 locations (range = 114−162) on each bobcat during routine monitoring, for a total of 2,460 telemetry locations (92% of locations estimated from landmarks). Our assessment of telemetry error showed that bobcat locations estimated from landmarks were fairly accurate ($\bar{x}$ = 12.8 m, SE = 2.2 m; Euclidean distance between estimated and true location of test collars).

Two adult male bobcats exhibited transient movement patterns during the first 6 months of monitoring (April−September) but showed movements resembling resident behavior thereafter. Home and core ranges estimated during resident movements were used in all home range, overlap, and habitat use analyses. All adult and juvenile female bobcats and the remaining adult male bobcats showed no evidence of transient behavior during monitoring. However, we evaluated juvenile and adult females separately in each analysis to examine potential differences.

Home Range Size

Seasonal estimates of home range dispersion did not differ between juvenile and adult females ($F_{1,27} = 0.25$, $P = 0.623$; Table 3.1), so age classes were pooled to conduct the repeated measures analysis. Overall, dispersion was lowest in spring and highest in fall, although the effect of season only approached significance ($F_{3,6} = 3.18$, $P = 0.106$). There was no sex effect ($F_{1,8} = 0.21$, $P = 0.661$) or sex × season interaction ($F_{3,6} = 1.30$, $P = 0.357$).

Juvenile female 95% home ranges and 50% core ranges were larger than those of adult females (home range, $t_6 = -2.11$, $P = 0.080$; core range, $t_6 = -2.98$, $P = 0.025$; Table 3.2). Adult male 50% core ranges were larger than those of adult females ($t_{4.5} = -2.17$, $P = 0.089$), however, the difference in 95% home ranges only approached significance ($t_8 = -1.68$, $P = 0.132$). There was no difference in 50% core range size between adult males and juvenile females ($t_6 = -0.57$,

$P = 0.587$). Like Griffin (2001), we detected a difference in adult female 95% home range ($t_3 = 3.86$, $P = 0.031$) and 50% core range ($t_3 = 3.20$, $P = 0.049$) size between the more-developed, western end and less-developed, eastern end portions of Kiawah Island. On average, adult female 95% home ranges (western end, $\bar{x} = 435.5$ ha, SD = 56.5 ha; eastern end, $\bar{x} = 269.0$ ha, SD = 17.7 ha) and 50% core ranges (western end, $\bar{x} = 98.4$ ha, SD = 15.1 ha; eastern end, $\bar{x} = 62.3$ ha, SD = 1.7 ha) were about 1.6 times larger in the more-developed portion of the island. Western end adult male 95% home ranges were highly variable and we did not detect a difference between areas (western end, $\bar{x} = 712.3$ ha, SD = 331.8 ha; eastern end, $\bar{x} = 390.0$ ha, SD = 14.5 ha; $t_2 = 1.89$, $P = 0.198$), although there was a difference in 50% core range size (western end, $\bar{x} = 235.5$ ha, SD = 68.8 ha; eastern end, $\bar{x} = 90.5$ ha, SD = 19.4 ha; $t_2 = 2.77$, $P = 0.069$).

Home Range Overlap

On average, males interacted with 1.6 (SD = 0.5) other males and 3.8 (SD = 1.8) females at the home range level and with no other males and 2.2 (SD = 1.6) females at the core range level. Females interacted with 3.3 (SD = 1.6) other females and 2.4 (SD = 0.7) males at the home range level and 1.0 (SD = 0.8) other female and 1.4 (SD = 0.7) males at the core range level. With the exception of male-male 50% core range overlap, intrasexual and intersexual overlap was highly variable for both home and core ranges (Table 3.3). Home range overlap differed between groupings (Kruskal-Wallis test, $\chi^2 = 12.19$, df = 3, $P = 0.007$), with 2.6−3.3 times less intrasexual overlap than male-female overlap. The same was true at the 50% core range level (Kruskal-Wallis test, $\chi^2 = 12.11$, df = 3, $P = 0.007$), with approximately 3.8 times less female-female overlap than male-female overlap and no male-male overlap. Of the female-

female core range overlaps, only 1 was >15%. Adult females #492 and #754 overlapped >58% of their core ranges. These females also overlapped >74% of their 95% FK home ranges.

Reproduction and Survival

We were able to locate 2 dens in 2004 and 4 dens in 2005 (Appendix III). Five females denned during late April and early May, while the other denned in late June. We found an average of 1.8 kittens per den (SD = 0.8, range = 1−3 kittens). All dens were located in forest or shrub habitats in patches of thick understory vegetation or dead trees (i.e., hollow stump or dead fall). As expected, none of the juvenile females exhibited denning behavior during 2004, although 2 of 3 denned in 2005. The movement patterns of 3 additional adult females (2 in 2004, 1 in 2005) suggested denning activity, although we were unable to locate den sites. We observed 1 of these females (#492) on 26 January 2005 with a kitten from the previous denning season. Adult female #492 concentrated her movements in an area of south-central Kiawah Island in late April of 2004. This was the same location where we successfully located her den the following year. We were able to locate the den of adult female #754 in both years and the den sites were in the same general area, approximately 230 m apart. Interestingly, adult females #754 and #492 denned approximately 85 m from each other in 2005 during the same time period (dens found on the same day and kittens appeared to be approximately the same age, based on size and closed eyes). Assuming female #492 denned in the area of her concentrated movements during 2004, the 2 dens would have been approximately 160 m apart.

Annual overall survival was 87.5% (14 of 16 bobcats) between April 2004 and March 2005. Overall male survival was 75% (6 of 8) and adult male survival was 60% (3 of 5). No females or juvenile males died during monitoring. Two adult males died during monitoring, both of which inhabited the western section of the island. Adult male bobcat #795 drowned in a water-treatment facility pond. The pond had steep banks lined with a slick, hard plastic that apparently prevented escape once the bobcat had fallen in. A necropsy of adult male #460 revealed trauma to the hindquarters, likely resulting from a bobcat-vehicle collision.

Movement Rates

Both sex ($F_{1,32} = 3.49$, $P = 0.071$) and time period ($F_{3,32} = 12.17$, $P < 0.001$) influenced average bobcat movement rates, however there was no interaction between factors ($F_{3,32} = 0.92$, $P = 0.443$). Males generally moved more than females (males, $\bar{x}$ = 186.1 m/hr, SD = 132.4 m/hr; females, $\bar{x}$ = 127.4 m/hr, SD = 127.4 m/hr). All bobcats moved significantly less during the day time period than during other time periods (Tukey's HSD; Figure 3.2).

Habitat Use

All bobcats exhibiting resident movement for ≥ 6 months had sufficient locations ($n \geq 74$ locations) to estimate accurate 95% MCP home ranges. Eleven of 13 bobcats used in habitat use analyses incorporated all habitat types within their 95% MCP home range. Two female bobcats inhabiting the northeastern section of the island did not incorporate dune habitat in their home range. However, this did not create a problem for analysis of third-order selection with Euclidean distance since the distance ratio between telemetry and random locations for habitats that are unavailable at the home range level simply approaches 1 (i.e., not selected or avoided; Conner and Plowman 2001).

Bobcats did not select habitats within the study area when establishing a home range ($F_{6,7} = 1.49$, $P = 0.305$) and we were unable to detect any effect of sex ($F_{6,6} = 0.76$, $P = 0.625$) or age class ($F_{6,6} = 0.13$, $P = 0.987$) on second-order habitat selection. Bobcats selected habitats within their home range ($F_{6,7} = 9.03$, $P = 0.005$), however we did not detect any effect of sex ($F_{6,6} = 0.83$, $P = 0.588$) or age class ($F_{6,6} = 0.38$, $P = 0.871$) on third-order habitat selection.

Additionally, bobcats selected habitats within their home range differently during the diurnal and nocturnal time periods ($F_{6,19} = 3.54$, $P = 0.016$); therefore, we examined habitat preferences by time period only. We failed to detect a sex × time period interaction ($F_{6,19} = 0.58$, $P = 0.743$) or an age class × time period interaction ($F_{6,19} = 0.76$, $P = 0.607$).

During diurnal periods, bobcats selected shrubs and dunes and avoided salt marsh and open-altered habitats (Table 3.4). Shrubs were selected over all other habitats and dunes were selected over all habitats except shrub (Table 3.5). There was no difference between avoided habitats. During nocturnal periods, bobcats selected shrubs, development, and dunes while avoiding salt marsh. Shrubs were selected over all other habitats, while development and dunes were selected over open-altered and salt marsh. There was no difference in selection between development and dunes.

Habitat Composition and Home Range Size

Since shrub was the most preferred habitat type in our habitat use analyses and was identified as the most suitable habitat type in a concurrent examination of bobcat habitat suitability (Chapter 4), it seems logical that the percentage of a bobcat's home and core range comprised of shrub habitat (% Shrub) would be inversely related to range size if range size was a response to habitat quality (Anderson and Lovallo 2003). Since juvenile female home and core ranges were larger on average than those of adult females (see Home Range section), we knew *a priori* that a significant correlation between age class and range size was likely. Therefore, we compared the relationship between % Shrub ([area of range in shrub habitat (m^2) / total area of range] × 100), Age Class (adult = 0, juvenile = 1), and female home and core range size (ha) with 3 linear regression models (predictive models: Age Class, % Shrub, Age Class + % Shrub; response variable: 95% FK home range or 50% FK core range size). Age Class and % Shrub were not significantly correlated ($r = 0.020$, $P = 0.963$). For male bobcats, we simply examined the relationship between % Shrub (predictor) and home and core range size (response), since we did not estimate home range size for dispersing juveniles.

Residual and normal probability plots for the female home and core range global models (Age Class + % Shrub) suggested the data met the assumptions of linear regression. The Age Class + % Shrub model was the best-fitting model for predicting both female home range and core range size ($\Delta AIC_c = 0.00$; Table 3.6). This model was 1.6 and 1.7 times more likely than the next best model (Age Class) for home range and core range, respectively. All models were significant ($F_{2,5} \geq 4.13$, $P < 0.09$), although the best model explained a higher proportion of the variation in home range ($r^2 = 0.85$) and core range ($r^2 = 0.89$) data. Both independent variables were significant contributors to prediction of home and core range size in the best models (Table 3.7). Confidence limits (95%) on parameter estimates suggested juvenile female home ranges were about 79 to 244 ha larger than adults and home range size decreased by about 5 to 17 ha with each 1% increase in shrub habitat. Similarly, juvenile female core ranges were about 27 to 73 ha larger than adults and core range size decreases by about 1 to 3 ha with each 1% increase in shrub habitat.

The original linear regression of % Shrub and male 95% FK home range size showed no relationship ($F_{1,3} = 0.49$, $P = 0.536$), but a residual plot suggested male bobcat #445 was an outlier (standardized residual for #445 [1.73] was 4.3 times larger than the median residual [0.40]). When this male was removed from the analysis, there was a significant ($F_{1,2} = 65.89$, $P = 0.015$) inverse relationship between % Shrub and 95% FK home range size (regression equation: $y = 590.63 - [9.91 \times \% \text{ Shrub}]$). The original linear regression of % Shrub and male 50% FK home range size approached significance ($F_{1,3} = 4.34$, $P = 0.129$), but a residual plot suggested non-constant variance (i.e., heteroscedasticity) and a possible outlier. We transformed the predictor and response variables by taking the natural logarithm to decrease heteroscedasticity (Ott and Longnecker 2001:537). A residual plot of transformed data showed no evidence of heteroscedasticity, but data for bobcat #445 appeared to be an outlier (standardized residual for #445 [1.68] was 3.9 times larger than the median residual [0.43]). When bobcat #445 was removed from the analysis, there was a significant ($F_{1,2} = 57.96$, $P = 0.017$) inverse relationship between % Shrub and 95% FK home range size (regression equation: $\ln[y] = 6.60 - [0.64 \times \ln(\% \text{ Shrub})]$).

Discussion

Because the bobcat is a territorial species whose movements, home range, and habitat use are potentially influenced by neighboring individuals, accurate assessments of social interactions and movement ecology should be based on studies that monitor a high portion of the local population (Anderson and Lovallo 2003). We agree with Griffin (2001) that past scent-station indices likely overestimated bobcat abundance on Kiawah Island, at least to some degree, although scent-stations are estimating the abundance of all bobcats, not just resident adults. Based on the density formula used by Nielsen and Woolf (2001*b*), which estimates bobcat density from average core range size and overlap (modified 50% FK), resident bobcat density on Kiawah Island was approximately 0.84 bobcats/km^2 (approximately 17 bobcats on 20 upland km^2) during 2004−2005. The large amount of variation we observed in intrasexual home range overlap and male home range size makes this density estimate tenuous, however, it is likely a more accurate representation of the resident bobcat population than scent station indices. Based on our intensive trapping effort, infrequent observations of un-collared bobcats during the study period (most of which appeared to be juveniles), and the relatively complete coverage of the island with overlapping, same-sex resident bobcat home ranges, we believe that we were monitoring most, if not all, of the resident bobcats on Kiawah Island during 2004−2005. Therefore, we contend that our sample size provides an adequate representation of resident bobcat ecology in this suburban setting.

We believe it is important to describe some differences in terminology and scale between our study and projects that examined bobcat ecology in and around human developments in California (Tigas et al. 2002, Riley et al. 2003, Riley 2006), prior to making comparisons. Based on our interpretation of their study area descriptions, study area maps, and bobcat home range maps, most urban-associated bobcats in these studies centered their home ranges in relatively large tracts of mostly undeveloped or park-like land adjacent to, or surrounded by, residential and commercial development. With the exception of 1 adult male and 1 juvenile female that inhabited undeveloped areas at the extreme eastern end of Kiawah Island, the home ranges and daily movements of all bobcats in our study included residential and resort development. Additionally, we differentiated between development and undeveloped natural vegetation at the individual lot-level (Figure 3.1), whereas entire neighborhoods or cities were considered "developed" in these studies (e.g., Figure 1, Riley et al. 2003; Figure 1, Riley 2006). We believe these are important differences because almost all of Kiawah Island, with the exception of the larger tracts of undeveloped land at the extreme eastern and western ends of the island, and most of the bobcat home ranges would likely fall within "developed" under the land cover classification schemes used in these studies.

Home Range Size and Overlap

It is generally accepted that the social organization of bobcats is based on a land tenure system, where relatively exclusive home and core ranges are indirectly defended from same-sex conspecifics through scat and urine scent markings and are only transferred after the death of a resident (Bailey 1974, Litvaitis et al. 1987, Anderson 1988, Lovallo and Anderson 1995). Although most research examining the social interactions of bobcats supports the land tenure theory to some extent, bobcats may exhibit a more complex social system in which not all home ranges are held for life, bobcats may contest the prior rights of a same-sex resident, and territoriality may be less pronounced at the home range level than at the core range level (Chamberlain and Leopold 2001, Benson et al. 2004). Additional research suggests high population density, low or high prey abundance, inclement weather, time-in-residence, and the patchy distribution of important resources (e.g., habitat features) can lead to changes in home and core range size and overlap, resulting in violations of a strict land tenure system (Bailey 1974, Conner et al. 1999, Nielsen and Woolf 2001*b*, Benson et al. 2006, Diefenbach et al. 2006). In addition to these ecological factors, we believe the geographic boundaries of Kiawah Island may have played a role in bobcat home range size and organization. Kiawah Island has large expanses of uninhabitable salt marsh that do not restrict movements on or off the island, as evidenced by juvenile male dispersal movements (Appendix IV), but undoubtedly restrict resident movements to some extent. In a geographically restricted, dense population of territorial animals, home ranges must be relatively small or a strict land tenure system must be compromised (e.g., increased sharing of space). We observed some evidence of both during our project.

Kiawah Island bobcat home ranges were among the smallest documented in the southeastern U.S. Male bobcat home ranges in undeveloped areas of the Southeast range from approximately 260 ha (Miller and Speake 1979) to over 4,200 ha (Kitchings and Story 1979), while home ranges of females can be from 100 ha (Hall and Newsom 1976) to over 2,200 ha

(Lancia et al. 1986). Home ranges (95% MCP) of male and female Kiawah Island bobcats were larger during 2000 (males, $\bar{x}$ = 830 ha, SD = 136; females, $\bar{x}$ = 567 ha, SD = 305; Griffin 2001) than during our study. Male and female bobcat home range sizes are generally considered responses to breeding opportunities and habitat quality, respectively (Anderson and Lovallo 2003), and areas of high prey availability are generally considered high quality bobcat habitat (Lancia et al. 1982, Boyle and Fendley 1987).

Bobcat diet analyses conducted on Kiawah Island showed that rodents (mostly cotton rats [*Sigmodon hispidus*], but also black rats [*Rattus rattus*] and eastern gray squirrels [*Sciurus carolinensis*] among others) comprised >40% of year-round diets, while the remainder was comprised of eastern cottontails (*Sylvilagus floridanus*), a variety of birds, white-tailed deer, raccoons (*Procyon lotor*), and opossums (*Didelphis virginiana*; Jordan 1998; Griffin 2001; K. Holcomb, University of Georgia, unpublished data). A concurrent study of deer fawn mortality showed that bobcats were heavily utilizing deer fawns during the spring and early summers of 2002−2005 (Chapter 2). Although we did not assess site-specific prey density during this project, a small-scale rodent trapping effort conducted throughout the island during the summers of 2003−2005 showed that cotton rats were fairly abundant, and were more abundant in preferred shrub habitats than in forest or dune habitats (Chapter 4). Island-wide deer density estimates from standardized spotlight surveys averaged 14.8 deer/km^2 (SE = 1.8) during the study period and raccoons and opossums were quite abundant based on frequent captures during our bobcat trapping efforts and increasing trends in annual scent-station surveys (J. Jordan, Town of Kiawah Island, unpublished data). We believe overall prey availability was quite high during the project and likely had a large influence on the size and organization of bobcat home ranges and associated population density.

Although population density estimates remained relatively stable since 1997 (Jordan 1998, Griffin 2001, J. Jordan, Town of Kiawah Island, unpublished data), it is possible that bobcat density differed between our study and Griffin (2001) due to the insensitivity of scent-station indices to small (<25% of population) changes in density (Diefenbach et al. 1994). Griffin (2001) felt that he had the majority of resident bobcats collared during the 2000 research ($n = 9$). It also is possible that prey availability differed between studies, although no rodent abundance data were collected during 2000 for comparison.

Resident bobcats maintained fairly consistent home range boundaries throughout the year, with average intrasexual home and core range overlaps similar to some studies (Chamberlain and Leopold 2001, Cochrane et al. 2006) and less than others (Nielsen and Woolf 2001*b*, Diefenbach et al. 2006). We observed a higher degree of intersexual overlap than intrasexual overlap at both the home and core range levels, which is fairly consistent with most studies (Fendley and Buie 1986, Chamberlain and Leopold 2001, Nielsen and Woolf 2001*b*, Cochrane et al. 2006). However, intrasexual overlap was quite variable and we documented 2 pairs of females with extensively overlapping home ranges. One overlap was between an adult and juvenile female, and may have been the result of the juvenile establishing a home range adjacent to its natal range (Chamberlain and Leopold 2001). Cochrane et al. (2006) suggested that highly abundant prey resources may lead to a relaxation of strict land tenure, similar to what Knick (1990) observed when prey abundance was extremely low. Conner et al. (1999) and Chamberlain and Leopold (2001) suggested resident female age can also affect home range size and the amount of overlap they tolerate from adjacent females, since older animals are more familiar with their territory and can more efficiently obtain resources from it. Because the adult female involved in this situation was originally collared as an adult in 2000 (Griffin 2001), and was therefore ≥ 6 years old during monitoring in 2004−2005, the occasional presence of another female may not have negatively impacted her acquisition of resources. The other large overlap occurred between the 2 adult females that we believe denned at the same time and in the same area during 2004 and 2005. These females incorporated, and denned in, the 2 largest undeveloped patches (>2 ha) of forest and shrub habitat in the central portion of the island, suggesting the availability of adequate denning habitat, and potentially the prey resources in these patches, may have contributed to their extensive sharing of space. Bailey (1974) observed multiple bobcats bedding together in a rock pile during inclement weather, suggesting individuals may tolerate territory violations when important resources or habitat features are rare.

In 2000, Griffin (2001) estimated the home range of adult male #460 (then identified as #933) at >900 ha (95% MCP) and it encompassed most of his west-end 2004−2005 home range (504 ha) and the adjacent range of adult male #795 (538 ha) to the east. Although we do not have data on the home range dynamics that occurred between 2000 and 2004, this suggests that #795 may have contested the prior rights of #460 between studies and claimed a portion of #460's former territory. After #795 died in December of 2004, adjacent adult males to the east (#445) and west (#460) were located infrequently within the vacated home range (3 and 7 times, respectively), although we did not detect any permanent shifts by these residents to incorporate the vacant area. These "exploratory" movements by males #460 and #445 occurred 9 and 14 days after the death of #795, respectively. However, an adjacent juvenile male significantly shifted its movements into the vacated range (Appendix IV). We did not detect any changes in movement pattern for adjacent females after the home range was vacated.

Although male home ranges were generally larger than females, we detected no significant difference in home range size between the sexes. Male bobcat home ranges were relatively small, but they interacted with an average of almost 4 females within these small ranges. We believe that high population density and prey availability, coupled with the geographical constraints of the island, led to small annual female home ranges and minimal seasonal variation in home range size. These small female home ranges in turn led to small male home ranges, and no significant increase in male home range size during the breeding season, because males did not have to travel far to encounter multiple females (Nielsen and Woolf 2001*b*).

Reproduction and Survival

During 2000−2001, Griffin (2001) located 8 active bobcat dens out of 11 potential opportunities (73% denned; 6 adult females monitored during spring of 2000, 5 in 2001) on Kiawah Island, containing an average of 2.0 kittens (SD = 0.8, range = 1−3 kittens). We observed a similar average litter size ($\bar{x}$ = 1.8 kittens, SD = 0.8, range = 1−3) in 2004−2005, although we only documented 6 active dens out of 13 potential opportunities (46% denned; 5 adult females monitored in 2004, 8 in 2005 [juvenile females considered adults in 2005]). However, if we assume we were simply unsuccessful in locating the dens of the 3 additional females that exhibited denning behavior during 2004−2005 (1 was observed the following winter with a kitten), the percentage of denning females would increase to 69%. Evidence suggests female bobcats are capable of reproducing throughout their life span (Crowe 1975), however neither of the adult females that were originally collared in 2000 (Griffin 2001) denned during 2004−2005. Both of these females were identified as adults (>1 year old at capture) in winter of 2000 and would have been ≥ 6 years old during spring of 2004. Dens were located for both of these females in 2002−2003 (J. Jordan, Town of Kiawah Island, unpublished data). Lembeck and Gould (1979) and Diefenbach et al. (2006) documented declines in reproduction with increased population density, which may explain why studies of less dense bobcat populations have documented higher average litter sizes than we observed (2.8 kittens/den, Bailey 1974; 2.3 kittens/den, Knick 1990). Although we do not have data on kitten survival or immigration, our juvenile trapping success suggests kitten survival is relatively high or juvenile immigration is common. Regardless, there is an apparent abundance of juveniles available to fill territorial vacancies left by resident mortalities.

There have been few examinations of bobcat survival in populations that are impacted by human activities, but not subjected to incidental harvest or trapping (Griffin 2001, Nielsen and Woolf 2002, Riley et al. 2003). Overall annual survival on Kiawah Island was quite high (87.5%), and was higher than survival rates from an unexploited bobcat population in Illinois (80%; Nielsen and Woolf 2002) and from a suburban-associated population in California (76%; Riley et al. 2003). Griffin (2001) reported lower survival (79%, 11 of 14 bobcats survived) on Kiawah Island during 2000, when 1 adult female and 1 juvenile male were killed by cars and 1 juvenile female died of unknown causes. In addition to the bobcat that was killed by a vehicle during our project, 1 adult male drowned in the island's water treatment facility. Hundreds of Hooded Mergansers (*Lophodytes cucullatus*) and Buffleheads (*Bucephala albeola*) were utilizing these water treatment ponds during this time and it is possible the bobcat fell in the pond during an attempted ambush. Since our project ended, fencing around this facility has been improved, although at least 1 other bobcat has drowned in this pond since the fence improvements (J. Jordan, Town of Kiawah Island, personal communication). Annual and sex-specific mortality is likely quite stochastic on the island since the majority of mortalities (4 of 5 between this study and Griffin [2001]) have been the result of bobcat-vehicle collisions. We observed no evidence of disease or heavy parasite load during capture, and body weights and measurements suggest Kiawah Island bobcats are generally healthy (Crowe 1975, McCord and Cardoza 1982).

Movement Rates

Bobcats typically exhibit bimodal activity patterns with peaks in activity coinciding with crepuscular peaks in prey activity and subsequent decreases in diurnal and nocturnal activity (Fendley and Buie 1986, Griffith and Fendley 1986, Lancia et al. 1986, Bradley and Fagre 1988, Chamberlain et al. 1998). This general trend was also evident in 2 studies of urban-associated bobcats in California (Tigas et al. 2002, Riley et al. 2003). However, both Tigas et al. (2002) and Riley et al. (2003) documented some level of modified activity in urban-associated bobcats when compared to those inhabiting natural settings (less diurnal activity in bobcats inhabiting more-fragmented area [Tigas et al. 2002], more nocturnal movements for urban-associated animals [Riley et al. 2003]). George and Crooks (2006) showed that bobcats inhabiting a California nature reserve were less active, and shifted their activity to a more nocturnal pattern, in areas of high human activity. Our results were consistent with these findings as bobcats on Kiawah Island significantly depressed daytime movements, increased movements throughout the crepuscular periods (i.e., dawn and dusk), and maximized movements during the nocturnal period, although crepuscular and nocturnal movements did not differ statistically. Male bobcats generally moved farther than females during our study but there was no interaction between sex and time period, suggesting bobcats of both sexes were depressing daytime movements and taking advantage of darkness to move with less human interaction. It is also possible that increased nocturnal bobcat movements were a response to behavioral modifications by prey species to avoid human interactions.

Habitat Use

Bobcats did not select habitats when establishing a home range on Kiawah Island, potentially due to the relatively high population density, the geographic confines of the island, and an overall abundance of prey. Because there is limited space within the salt marsh confines of the island and virtually all areas are occupied by a resident bobcat, it seems reasonable that bobcats do not choose a home range as much as they take what is available through vacancies.

Within the home range, shrubs were the most preferred habitat during both the diurnal and nocturnal time periods. Shrubs provided abundant prey resources and likely provided the best vertical structure for daytime concealment cover of the habitats available on Kiawah Island (Chapter 4). These results are consistent with a variety of other studies in which bobcats preferred shrubby, or otherwise dense early-succession, habitats (Hall and Newsom 1976, Rolley and Warde 1985, Heller and Fendley 1986, Litvaitis et al. 1986, Anderson 1990, Kolowski and Woolf 2002).

The only significant change in habitat selection between the diurnal and nocturnal time periods occurred with development. Bobcats generally avoided development during the diurnal time period, although this avoidance was not significantly different from random. However, bobcats selected development during the nocturnal time period, suggesting they are well-adapted to this suburban habitat matrix and are likely exploiting food resources around human structures (e.g., black rats, cotton rats in landscaped shrubbery). Conversely, bobcats in California incorporated little development in their home ranges (7.6% of 95% MCP home range on average) during 1 study (Riley et al. 2003) and only incorporated developed areas that occurred within a park in another (Riley 2006). However, Tigas et al. (2002) and Riley et al. (2003) reported increased use of developed areas during nocturnal time periods and noticed that males were more likely to use development than females. Although no bobcats were located outside a park setting during the study, Riley (2006) also noticed the home ranges of male bobcats were closer to development than females. We detected no difference in habitat selection between the sexes during either time period, suggesting both males and females were using developed areas.

Open-altered and salt marsh habitat were avoided during diurnal periods and salt marsh was avoided during nocturnal periods. These results are fairly unsurprising since neither habitat type provides adequate habitat for their main prey species (cotton rats) or provides adequate concealment cover. Open-altered was not significantly avoided during nocturnal periods, probably as a result of its spatial correlation with development (i.e., golf courses typically ran between rows of homes; Conner et al. 2005). The same is probably true for the apparent selection of dune habitats during the diurnal and nocturnal periods. Dunes were almost always spatially correlated with highly-selected shrub habitats (e.g., ocean-to-inland transition of oceanfront beach to dunes to shrubs) and, therefore, bobcats located in shrub habitats would be closer than expected to dune habitats, indicating a preference for dunes. The native grasses of dune habitats undoubtedly provided some food resources for bobcats during the nocturnal time period; however, the lack of vertical structure and proximity to human activity on the beach does not provide for adequate daytime concealment cover. Therefore, it is unlikely these areas were actually preferred during diurnal periods.

Habitat Composition and Home Range Size

Like Griffin (2001), we detected a significant difference in female home and core range size between the more-developed, western end and less-developed, eastern end portions of Kiawah Island. Griffin (2001) suggested these differences were due to differences in human disturbance or prey availability between areas. Our examination of the relationship between the percentage of home or core ranges in shrub habitat and range size supports the latter. The mosaic of upland and salt marsh, and extensive shrub-covered dunes, in the eastern end portion of the island results in a higher portion of upland habitats in preferred salt shrub (i.e., upland-salt marsh interface) and maritime shrub habitats (>25%) when compared to the western end portion (<7%). Although there was a significant correlation between the percentage of a home range in development and the percentage in shrub habitat (Pearson Correlation; $r = -0.897$, $P < 0.001$), the majority of development to date has been focused in areas that had less shrub habitat to begin with (i.e., the western end) and this residential and resort construction has mainly removed patches of maritime forest with little removal of shrubs. Therefore, the difference between areas was likely a response to differences in natural vegetation composition rather than a relationship between development and shrub loss.

Our results are consistent with other studies that have documented a significant relationship between bobcat home range size and habitat quality or prey abundance, particularly for females (Litvaitis et al. 1986, Knick 1990, Lovallo et al. 2001, Benson et al. 2006). Our results also indicate that the difference in home and core range size between juvenile and adult females was due not only to age but also to differences in range habitat composition between age classes. The former is consistent with Conner et al. (1999) who observed a general decrease in home range size as bobcats aged and became more familiar with, and efficient in, their home range. The latter is likely due to population density, social organization, and the confines of the island, where a juvenile female attempting to establish a home range is forced to choose from available areas, which are probably of lower habitat quality (i.e., fewer shrubs) than occupied areas.

Although we detected a significant relationship between male home and core range size and percent shrub habitat, we treated 1 adult male as an outlier, and therefore these results should be considered with caution. The movements and home range of the adult male treated as an outlier could have been influenced by a number of dynamic social interactions that occurred in and around his home range during the study (e.g., the death of an adjacent male, the dispersal movements of a juvenile male into an adjacent area). Based on these potential interactions, we felt justified in excluding his movements from the analysis, and we believe the importance of shrub habitats for daytime concealment cover and food resources realistically influences male home and core range size on Kiawah Island as well.

Management Implications

Our research suggests that bobcats are potentially more adaptable to human-altered landscapes than past research has shown. Kiawah Island supports a relatively dense bobcat population, with fairly high survival and adequate reproduction, although there is some evidence of behavioral modifications to avoid interactions with humans: increased nocturnal movements and selection of thick daytime concealment cover with little diurnal movement. However, habitat use data suggest bobcats are selecting developed areas during nocturnal time periods, potentially to exploit additional prey resources. Additionally, data collected during concurrent research on white-tailed deer fawn mortality (Chapter 2) suggest Kiawah Island's bobcat population is the major factor limiting deer population growth.

Continued residential and resort development between 2000 and 2004 has had little measurable negative impact on bobcat ecology. Strict construction regulations designed to bolster aesthetic appeal and maintain green space have preserved buffer areas and canopy cover within developed areas and vegetation along marsh and pond edges, likely facilitating the success of bobcats in this suburban setting by providing abundant prey, movement corridors, and daytime refugia. Additionally, bobcats are generally accepted by the residents of Kiawah Island and a local conservation organization has successfully preserved patches of natural habitat throughout the island, using the bobcat as an icon for its habitat preservation efforts (Chapter 5). However, development activities to date have not severely impacted highly selected shrub habitats and relatively large patches of these important habitats are intact throughout portions of the island. The probable future development of these areas may have wide-ranging negative effects on reproductive habitat suitability, prey availability, and daytime concealment cover.

Nielsen and Woolf (2001*a*) suggested that wildlife managers focus conservation efforts on public lands and other natural areas to maintain refugia for bobcats. While we certainly do not disagree with this statement, our results suggest the combination of a proactive development strategy and community-based habitat preservation efforts may be an additional conservation option in developing environments where native predators are accepted and valued.

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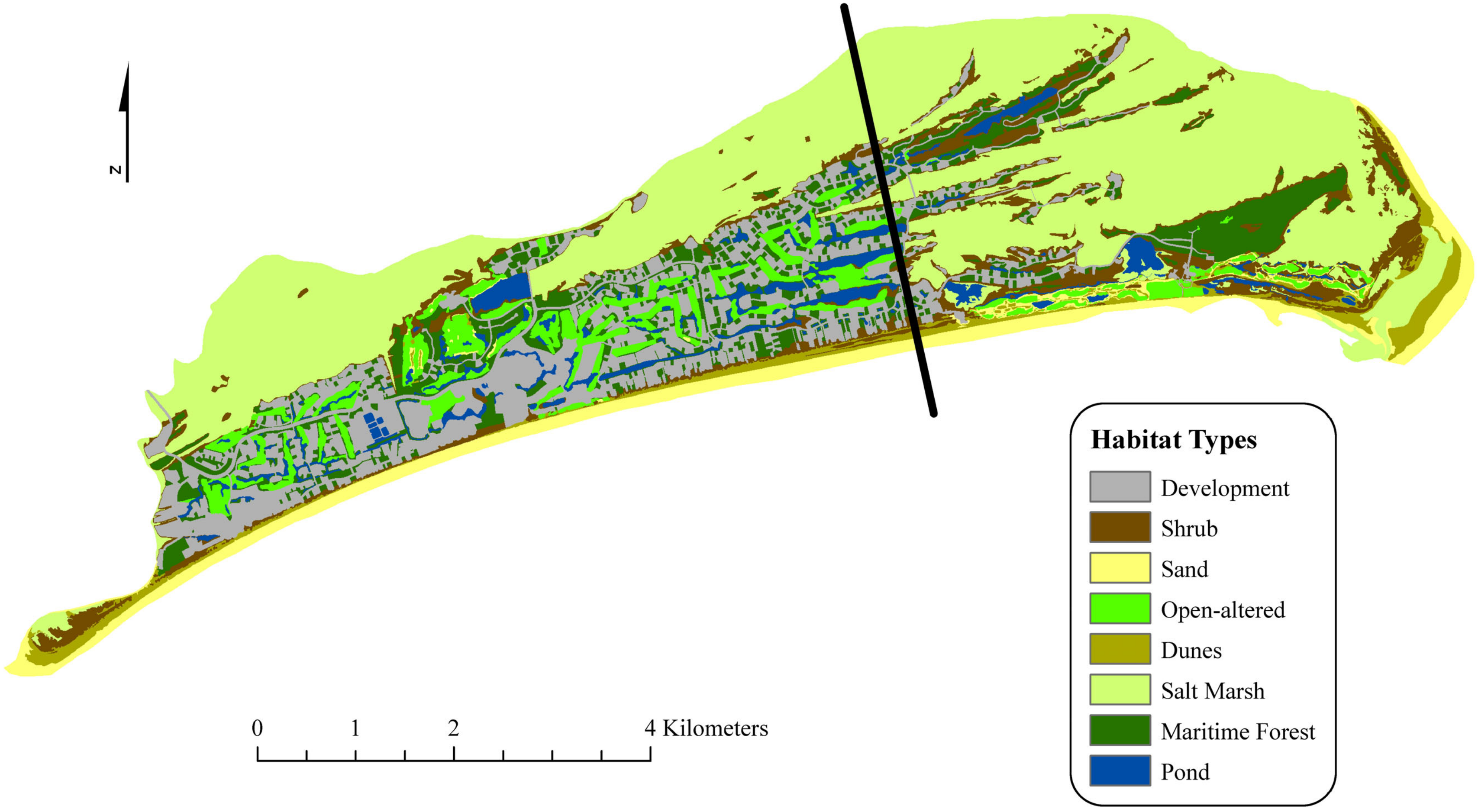

Figure 3.1. Habitat types and boundary dividing the more-developed (west end) and less-developed (east end) study areas of Griffin (2001) on Kiawah Island, South Carolina, April 2004−March 2005.

Table 3.1. Mean dispersion[a] estimates (m) of seasonal home range size and standard deviation (in parentheses) for year-round resident bobcats that were monitored each season on Kiawah Island, South Carolina, USA, April 2004−March 2005.

	n	**Spring (Apr-Jun)**	**Summer (Jul-Sept)**	**Fall (Oct-Dec)**	**Winter (Dec-Mar)**
Males					
Adult	2[b]	1151.6 (136.7)	994.6 (116.4)	1253.4 (332.6)	1446.2 (763.1)
Females					
Adult	5	1043.8 (220.4)	1191.1 (151.1)	1322.8 (216.2)	1113.2 (272.5)
Juvenile	3	1090.9 (220.1)	1208.9 (213.9)	1156.8 (124.3)	1070.0 (112.5)

[a] Average distance between all pairs of locations for each individual in each season.

[b] n = 2 due to 1 winter season mortality and the transient behavior of 2 males during the spring and summer seasons.

Table 3.2. Mean 95% fixed kernel (FK) and minimum convex polygon (MCP) home range and 50% FK core range size estimates (ha) for bobcats monitored on Kiawah Island, South Carolina, USA, April 2004−March 2005.

		95% FK (SD)		**95% MCP (SD)**		**50% FK (SD)**	
	n	**Original**	**Modified**[a]	**Original**	**Modified**	**Original**	**Modified**
Males[b]							
Adult	5	793 (454)	583 (294)	456 (288)	435 (286)	184 (100)	177 (94)
Females							
Adult	5	404 (124)	369 (100)	325 (84)	310 (92)	87 (29)	84 (22)
Juvenile	3	565 (121)	527 (109)	408 (139)	399 (127)	145 (35)	144 (36)

[a] Portions of range falling in salt marsh >150 m from upland habitats, the Kiawah or Stono Rivers, or the Atlantic Ocean were removed.

[b] 6-month ranges (Oct−Mar) used for 2 adult male bobcats that showed transient movements during Apr−Sept, remainder annual (Apr−Mar) ranges.

Table 3.3. Mean 95% fixed kernel (FK) home range[a,b] and 50% FK core range overlap for bobcats on Kiawah Island, South Carolina, USA, April 2004−March 2005.

	95% FK home range overlap (%)			
	No. of overlaps	$\bar{x}$	**SD**	**Range**
Male-Male	8	14.4	8.3	5.7 – 27.1
Female-Female	26	18.2	25.1	0.2 – 90.2
Male-Female	19	47.7	38.4	3.7 – 100.0
Female-Male	19	33.0	29.7	3.9 – 96.9
	50% FK core range overlap (%)[c]			
	No. of overlaps	$\bar{x}$	**SD**	**Range**
Male-Male	8	0.0	0.0	0.0
Female-Female	26	6.2	17.0	0.0 – 66.5
Male-Female	19	23.3	28.4	0.0 – 72.2
Female-Male	19	13.2	18.9	0.0 – 67.8

[a] Modified home ranges (salt marsh >150 m from upland habitats, rivers, oceans removed) used to calculate percent overlap.

[b] 6-month 95% FK home ranges and 50% FK core ranges (Oct−Mar) used in percent overlap calculations for 2 adult males that showed transient behavior from Apr−Sept.

[c] 50% FK overlap calculated for all individuals with overlapping 95% FK home ranges.

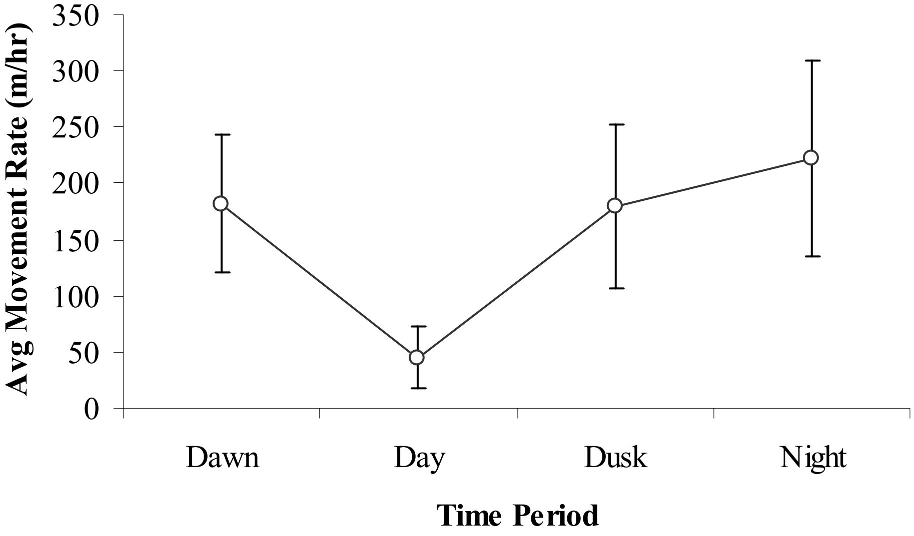

Figure 3.2. Average bobcat movement rates (m/hr), with 95% confidence limits, during 4 time periods (dawn = 2 hours before and after sunrise, day = 2 hours after sunrise to 2 hours before sunset, dusk = 2 hours before and after sunset, night = 2 hours after sunset to 2 hours before sunrise) on Kiawah Island, South Carolina, USA, April 2004−March 2005.

Table 3.4. Third-order[a] (Johnson 1980) diurnal and nocturnal habitat selection rankings from a Euclidean distance assessment of bobcat habitat use on Kiawah Island, South Carolina, USA, 2004−2005.

	Habitat ranking[b,c]					
Time period[d]	**Selected**	→				**Avoided**
Diurnal	**Shrub** **(0.44)**	**Dune** **(0.85)**	Forest (0.97)	Devel (1.30)	**Marsh** **(1.31)**	**Alter** **(1.44)**
Nocturnal	**Shrub** **(0.64)**	**Devel** **(0.82)**	**Dune** **(0.88)**	Forest (0.89)	Alter (1.13)	**Marsh** **(1.18)**

[a] Third-order = habitat selection within home range.

[b] Forest = maritime forest, Alter = open-altered, Marsh = salt marsh, Devel = Developed.

[c] Distance ratios < 1.0 indicate habitat selection while distance ratios > 1.0 indicate habitat avoidance. Bold habitat types had a distance ratio (in parentheses) that significantly differed (t-test, *P* < 0.10) from 1.0.

[d] Diurnal = 30 minutes after sunrise to 30 minutes before sunset, nocturnal = all other times.

Table 3.5. Ranking matrix[a] of *P*-values from pairwise univariate t-tests between habitat[b] distance ratios used to examine third-order[c] habitat selection of bobcats, during diurnal and nocturnal time periods, on Kiawah Island, South Carolina, USA, 2004−2005.

Diurnal[d]

	Dune	Forest	Devel	Marsh	Alter
Shrub	<0.001	0.010	0.001	<0.001	<0.001
Dune		0.549	0.055	0.004	0.019
Forest			0.003	0.220	0.028
Devel				0.993	0.350
Marsh					0.550

Nocturnal

	Devel	Dune	Forest	Alter	Marsh
Shrub	0.037	0.001	0.054	0.001	0.001
Devel		0.590	0.324	0.023	0.043
Dune			0.936	0.064	0.010
Forest				0.162	0.127
Alter					0.741

[a] Significant *P*-value ($P < 0.10$) indicates preference of row habitat over column habitat.

[b] Forest = maritime forest, Alter = open-altered, Marsh = salt marsh, Devel = developed.

[c] Habitat selection within home range.

[d] Diurnal = 30 minutes before sunset to 30 minutes after sunrise, nocturnal = all other times.

Table 3.6. Model selection results for candidate linear regression models predicting 95% FK home range and 50% core range size (ha) of female bobcats on Kiawah Island, South Carolina, USA, April 2004−March 2005.

Range	**Model**	**$\Delta \mathrm{AIC_c}$**[a]	***w***[b]	**r^2**	***P***
95% FK	Age Class[c] + % Shrub[d]	0.00	0.459	0.85	0.009
	Age Class	0.94	0.287	0.43	0.080
	% Shrub	1.18	0.254	0.41	0.089
50% FK	Age Class + % Shrub	0.00	0.538	0.89	0.004
	Age Class	1.08	0.313	0.59	0.027
	% Shrub	2.57	0.149	0.50	0.049

[a] Difference in $\mathrm{AIC_c}$ compared to the best model (i.e., lowest $\mathrm{AIC_c}$).

[b] Akaike weight (likelihood of model given the data and candidate set of models).

[c] Age Class = adult (0) or juvenile (1).

[d] Percentage of the FK range in shrub habitat (shrub area [m^2]/total area] × 100).

Table 3.7. Parameter estimates and 95% confidence limits (95% CL) for best-fitting[a] linear regression models predicting 95% FK home range and 50% core range size (ha) of female bobcats on Kiawah Island, South Carolina, USA, April 2004−March 2005.

				95% CL			
Range	**Parameter**	**Estimate**	**SE**	**lower**	**upper**	***t***	***P***
95% FK	Intercept	524.46	48.77				
	Age Class[b]	161.48	42.11	78.94	244.05	3.83	0.012
	% Shrub[c]	−10.99	2.93	−16.73	−5.25	−3.76	0.013
50% FK	Intercept	127.50	13.26				
	Age Class	50.17	11.68	27.28	73.06	4.29	0.008
	% Shrub	−1.73	0.45	−2.61	−0.85	−3.80	0.013

[a] Best model determined by model selection with Akaike's Information Criterion corrected for small sample size ($\Delta AIC_c = 0.00$; see Table 3.6)

[b] Age Class = Adult (0) or Juvenile (1).

[c] Percentage of the FK range in shrub habitat (shrub area [m^2]/total area] × 100).

CHAPTER 4

USING BOBCAT HABITAT SUITABILITY TO PRIORITIZE HABITAT PRESERVATION EFFORTS ON A DEVELOPING SOUTH CAROLINA BARRIER ISLAND[1]

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[1] Roberts, S. B., J. D. Jordan, P. Bettinger, and R. J. Warren. To be submitted to *Conservation Biology*.

Abstract: Residential and resort development on Kiawah Island, South Carolina has significantly altered this barrier island's natural landscape. The Kiawah Island Natural Habitat Conservancy (KINHC), a local non-profit, land-trust organization, is attempting to preserve wildlife habitat in the face of ever-increasing property values and development pressure. Kiawah Island supports a dense bobcat (*Lynx rufus*) population (~1.4 bobcats/upland km^2) that is crucial to natural control of the island's white-tailed deer (*Odocoileus virginianus*) herd. Using the bobcat as a focal species, we modified an existing bobcat habitat suitability index model (Boyle and Fendley 1987), which focuses on the food suitability of habitats, by including components for concealment cover and reproductive habitat. The reproduction component of our modified habitat suitability index (MHSI) is dependent on patch size and the habitat composition of adjacent areas. We developed a windows-based computer program that calculates and outputs MHSI values that can easily be imported into a GIS for display in map form, allowing for frequent re-evaluation of site-specific habitat suitability as land-use patterns change. We used locations collected from radio-collared bobcats to assess validity of the MHSI. Bobcats used areas identified as highly suitable more than expected and areas of low suitability less than expected. We evaluated bobcat habitat suitability with MHSI at the home range- and lot-level. The multi-scaled approach will allow KINHC to identify sections of the island where current habitat preservation efforts should be focused, and then identify lots within those sections that will likely provide the greatest ecological benefit to bobcats and their associated wildlife community.

Key Words: bobcat, development, habitat suitability, habitat preservation, land trust, *Lynx rufus*, South Carolina

Introduction

As the human population continues to grow, and associated urban sprawl continues to alter natural landscapes, wildlife populations are being forced to survive in fragmented suburban habitats at an ever-increasing rate. Although most people live in urban or suburban areas, the interest in attracting and viewing wildlife is strong, and many developers are incorporating green space and the presence of wildlife into their development and advertising strategies (Adams et al. 2006). Additionally, the number of local and regional organizations focused on preserving natural areas within this suburban matrix is also increasing (Land Trust Alliance 2006). As property values are typically high and development patterns are often dynamic and fast-paced in these desirable real estate locales, preservation organizations must attempt to maximize the influence of funding available for land preservation while adapting their preservation priorities to changing development patterns and rates. This paper describes how we modified an existing habitat suitability index for the bobcat (*Lynx rufus*) to help the Kiawah Island Natural Habitat Conservancy (KINHC), a local land-trust organization, prioritize and periodically reassess its land preservation priorities on Kiawah Island, South Carolina, a resort-style developing barrier island.

According to standardized scent station surveys (Diefenbach et al. 1994) conducted between 1998 and 2005, Kiawah Island supported a dense, relatively stable population of approximately 30 bobcats (SE = 1.6, ~1.4 bobcats per upland [non-salt marsh] km^2; J. Jordan, Town of Kiawah Island, unpublished data). This is notable, as a number of research projects have shown that bobcats generally avoid human developments (Lovallo & Anderson 1996; Nielsen & Woolf 2001; Tigas et al. 2002; Riley et al. 2003; Riley 2006). Research conducted on Kiawah Island during 2000−2001 showed that bobcats in the more-developed western portion of the island had larger home ranges than those in the less-developed eastern portion of the island (Griffin 2001). Griffin (2001) hypothesized these differences could be due to differences in habitat suitability between the areas. Subsequent research we conducted on Kiawah Island has shown that bobcat predation on white-tailed deer (*Odocoileus virginianus*) fawns is the major factor limiting deer population growth (Chapter 2). Without some form of control, suburban deer populations often grow to levels that can be ecologically damaging and socially unacceptable (see McAninch 1995; McShea et al. 1997; Warren 1997).

Due to the significant influence bobcats have on deer population regulation, and the apparent negative effect of human disturbance on Kiawah Island bobcat ecology, the preservation of bobcat habitat has become a primary focus of KINHC. Our objectives were to develop a simple, easily applied index to bobcat habitat suitability on Kiawah Island, assess validity of the index with data collected from radio-monitored bobcats, and show how the index could be used to prioritize habitat preservation efforts at multiple spatial scales.

Methods

Study Area

Kiawah Island, South Carolina is a 3,500-ha coastal barrier island located approximately 25 km south of Charleston. Approximately 1,500 ha of the island was salt marsh (saltmarsh cordgrass [*Spartina alternifora*]) or brackish marsh (saltmeadow cordgrass [*Spartina patens*], salt grass [*Distichlis spicata*], seaside oxeye [*Borrichia frutescens*], black needlerush [*Juncus roemerianus*]). The remaining acreage was a mosaic of maritime forest (live oak [*Quercus virginiana*], slash pine [*Pinus elliottii*], and cabbage palmetto [*Sabal palmetto*]), maritime shrub thickets (sand live oak [*Q. geminate*], yaupon [*Ilex vomitoria*], wax myrtle [*Myrica cerifera*]), salt shrub thickets (seaside oxeye, marsh elder [*Iva frutescens*], wax myrtle, black needlerush), brackish and freshwater ponds, golf course, residential and resort development, and barren sand (Aulbach-Smith 1998). Kiawah Island is separated from other land masses to the north and west by the Kiawah River and to the east by the Stono River. A 2-lane road connects Kiawah Island to Seabrook Island at the narrowest point of the Kiawah River (~50 m at low tide), crossing approximately 550 m of salt marsh. During 2004−2005, Kiawah Island had a mean temperature of 27.6 ºC in July and 8.5 ºC in January, while precipitation averaged 114 cm annually (N. Shea, Kiawah Island Community Association, unpublished data).

Residential and resort development began on Kiawah Island in 1974. About 72 new homes were constructed on the island each year between 2000 and 2005 (Town of Kiawah Island, unpublished data). During 2004−2005, this gated community had more than 1,100 permanent residents and was visited by thousands of tourists each year. Of the approximately 3,000 lots available for single-family homes on the island, about 2,000 were developed. Virtually all resort development (all resort hotels and villas and 4 of 5 18-hole golf courses) and the majority of developed residential lots (89%) were concentrated on the western 1,100 ha of the island. With the possible exception of a cleared walking path for real estate purposes, the vegetation on undeveloped lots was usually unaltered. Lots platted for single-family homes comprised 28% (567 ha) of the island's upland acreage, with a mean lot size of 0.19 ha (SE = 0.01 ha). The development and influx of people have dramatically changed the natural landscape of the island. Much of the maritime forest has been replaced with homes and landscaped yards, but construction regulations designed to bolster aesthetic appeal and maintain green space (Kiawah Island Architectural Review Board 2007) have preserved buffer areas between homes, canopy cover within each lot, and vegetation along marsh and pond edges, resulting in a mosaic of native and landscaped vegetation within developed areas. Additionally, a few relatively large

(2–84 ha) un-platted patches of upland habitat were scattered throughout the island, the largest of which were located at the island's extreme west and east ends.

In 1997, a group of residents founded KINHC based on concerns that the continued development of Kiawah Island would diminish the island's natural beauty and ability to sustain viable wildlife populations. KINHC, a 501(c)(3) non-profit, land-trust organization, was designed to (1) educate visitors and residents about wildlife ecology and backyard habitat and (2) facilitate the preservation of wildlife habitat by purchasing properties with tax-deductible donations and by protecting the habitat on properties of willing participants with conservation easements.

Habitat Mapping

We used a georeferenced plat map, municipal building permit data (Town of Kiawah Island, Kiawah Island, South Carolina), and infrared digital orthophotography (1-m spatial resolution, taken in March of 2005), to delineate 10 habitat types (forest, shrub [maritime shrub and salt shrub areas], open dunes [mix of sand and native grasses], salt marsh, sand, open-altered [e.g., parks], golf course, developed areas [developed residential and resort properties], roads, and water) in ArcGIS 9.1 (Environmental Systems Research Institute, Inc., Redlands, CA; Figure 4.1). We manually digitized most habitat types, although we used platted property boundaries to delineate developed areas and road right-of-ways. We considered all individual lots for which a municipal building permit was issued prior to March 2005 to be developed, even if we could not see a home in the digital orthophotography. We assumed that once a building permit was issued, increased human activity and the probable clearing of native vegetation altered the habitat suitability of the lot, regardless of the status of residential construction. We assumed areas of salt marsh that were >150 m from upland habitats were inaccessible, due to flooding frequency and associated “pluff mud”, and removed them from all analyses. We converted digitized habitat polygons to a 5-m raster grid in ArcGIS 9.1 to facilitate analyses.

Habitat Suitability Index Components

We used the bobcat habitat suitability index model developed by Boyle and Fendley (1987) as the foundation for our index of habitat suitability. The model uses an index of food suitability (FSI) as a measure of overall habitat suitability, as it assumes the other general life requisites of a bobcat (water, cover, and reproduction) can be met in undeveloped areas of the southeastern U.S or within areas of adequate food suitability. The calculation of FSI in this model requires the estimation of 2 suitability index variables (SIV1 and SIV2). SIV1 relates to the percentage of the sample area covered by grasses, forbs, or shrubs and SIV2 relates to the percentage of the grass, forb, or shrub vegetation that is grasses or forbs (see Boyle & Fendley [1987] for full FSI model details). In their model, optimal bobcat habitat is an area of ≥ 90% grass, forb, or shrub ground cover with 50−70% of this vegetation in grasses or forbs. This interspersion of vegetation provides optimal habitat for rodents (primarily cotton rats [*Sigmodon hispidus*]) and eastern cottontails (*Sylvilagus floridanus*), which are usually the main components of bobcat diets in the southeastern U.S., by providing adequate food resources and accessible escape cover from avian predators (Boyle & Fendley 1987). Bobcat diet analysis conducted on Kiawah Island from 2002−2005 showed that rodents (mostly cotton rats) comprised about 50% of year-round bobcat diets, while rabbits comprised about 7% of diets (K. Holcomb, University of Georgia, unpublished data), supporting the use of a model that considered habitat for these species. Although cotton rats were the most frequently encountered rodent in bobcat scats, black rat (*Rattus rattus*) and eastern gray squirrel (*Sciurus carolinensis*) remains were also frequently found. The majority of the remaining diet consisted of a variety of birds, white-tailed deer, raccoons (*Procyon lotor*), and opossums (*Didelphis virginiana*). Because many of these species thrive in human-altered areas, estimates of food suitability within the developed and open-altered land cover types are likely conservative.

Like Boyle and Fendley (1987), we considered water to be readily available to bobcats on Kiawah Island and did not consider it in our analysis of habitat suitability. However, habitat fragmentation in suburban areas undoubtedly limits the availability, and increases the importance, of daytime concealment cover and quality den sites, when compared to undeveloped landscapes. Although we agree that prey availability is the most important factor in bobcat ecology, a lack of suitable cover may decrease accessibility to these prey items. Cover requirements of bobcats in the southeastern U.S. are fairly general, and the importance of cover is often expressed within the context of food suitability (Lancia et al. 1982; Boyle & Fendley 1987). However in a suburban setting, the general presence of concealment cover, regardless of its food production value, likely facilitates corridor movements and provides daytime resting cover for this reclusive, primarily nocturnal carnivore (Tigas et al. 2002; Riley et al. 2003). Female bobcats in the southeastern U.S. typically den in hollow stumps, uprooted trees, and areas of thick understory vegetation (Lancia et al. 1982; Boyle & Fendley 1987). Bobcats on Kiawah Island seem to follow this trend, as dens have been located under uprooted trees, downed logs, and in thick shrub patches (Griffin 2001; Appendix III). Additionally, patch size seems to be important to bobcat reproduction on Kiawah Island, as all bobcat dens have been located in contiguous forest or shrub habitats ≥ 2 ha in size. Although published literature is lacking, it seems intuitive that a scarcity of adequate reproduction habitat could negatively affect a female bobcat's reproductive effort. Riley et al. (2003) hypothesized that areas of high human influence may be perceived by female bobcats as "unsafe" for raising young. It also seems intuitive that poor quality den locations could negatively affect kitten survival by placing kittens in closer proximity to anthropogenic disturbances (i.e., roads) or in areas with suboptimal cover (i.e., increased vulnerability to predators). Therefore, we added a reproduction component, which took into account habitat type and patch size, and a cover component to Boyle and Fendley's (1987) FSI to create our modified bobcat habitat suitability index (MHSI).

Vegetation Sampling and Component Index Estimation

To estimate FSI within each habitat type on Kiawah Island we generated 1,000 random locations throughout the island using Hawth's Analysis Tools (Beyer 2004) in ArcGIS 9.1. In June of 2006, we visually estimated vegetation composition within a 10-m^2 circle, to calculate SIV1 and SIV2, at random locations that fell within forest, shrub, or open dune habitats (Boyle & Fendley 1987). For randomly selected, developed lots, we estimated the portion of the lot that was visible from the road, the area (m^2) of the portion that was covered in native grass, forb, or shrub vegetation, and the portion of this vegetation that was native grasses or forbs. We used these estimates and the total area (m^2) of the lot to calculate FSI for the entire lot. Open-altered areas (e.g., parks) were typically comprised of non-native, manicured grass and small forested patches. We estimated the portion of the open-altered parcel covered in forest using digital orthophotography; then we used the total area of the parcel, coupled with the average SIV1 and SIV2 values for forest habitats collected at the random vegetation sampling locations, to estimate FSI within the parcel. We use the right-of-way boundaries from the georeferenced plat map to delineate the road land cover type. Therefore, roads included not only pavement, but roadside buffers of forest habitat and roadside manicured grass that fell within the right-of-way. At randomly selected locations along the roadway, we measured the portion of the right-of-way width covered by forest using the measurement tool in ArcGIS. We used these measurements, coupled with the average SIV1 and SIV2 values from sampled forest habitats, to estimate average food suitability along the roadway corridors. We assumed areas comprised entirely of manicured grass (e.g., golf courses) or salt marsh (≤ 150 m from upland areas) had minimal food production value and subjectively assigned the lowest food suitability value possible (FSI = 0.05).

We calculated a cover suitability index (CSI) for each land cover type as the portion of the cover type comprised of forest or shrub habitats (e.g., a park comprised of 10% forest and 90% landscaped grass would receive a CSI rating of 0.10). We assumed concealment cover was adequate within these 2 habitat types. We assumed forested areas within road right-of-ways did not provide adequate concealment cover due to traffic noise, and subjectively assigned a CSI value of 0.0 to these areas. We chose not to subjectively alter CSI values within the developed land cover type because a large number of residential properties on Kiawah Island are infrequently occupied (i.e., vacation homes). The shrubby vegetation, natural or landscaped, around these mostly-vacant structures likely provides adequate cover during a portion of the year. Therefore, we used the estimates of shrub cover within each sampled lot to calculate CSI for developed areas.

We also calculated a reproduction suitability index (RSI) based on characteristics of documented bobcat den sites on Kiawah Island (Griffin 2001, Chapter 3). Due to their exclusive use in the past, we assumed forest and shrub habitats provided the vegetation structure necessary for denning (RSI = 1.0), and all other land cover types were unsuitable (RSI = 0.0). We used a moving-window analysis to average RSI values within a 2-ha (i.e., smallest undeveloped patch used for denning) window and assign the average RSI to the center pixel of the window. The moving-window progressed, 1 pixel at a time, through the entire raster grid and saved the averaged RSI values in a new raster grid. In this moving window analysis, the center pixel received an optimal RSI value (RSI = 1.0) when all of the pixels within the window were forest or shrub, while the RSI of small patches (<2 ha) of forest or shrub habitat was negatively influenced by the surrounding, unsuitable land cover types.

If mean component index values did not differ between 2 habitat types (Mann-Whitney U-Test; Sokal & Rohlf 1995), vegetation sampling data were pooled to calculate 1 mean index value for both habitats. We present standard errors (SE) on all suitability indices estimated from vegetation sampling to discuss the potential influence of input variability on our results (Roloff & Kernohan 1999). As open water (e.g., pond) is uninhabitable we considered it unsuitable in all component indices (FSI, CSI, and RSI = 0.0).

Modified Habitat Suitability Index

We created a 5-m raster grid for each of the model inputs (FSI, CSI, and RSI) in ArcGIS by reclassifying each land cover type identifier in the original habitat map with its respective mean suitability index value. We developed a program (copies of the program are available upon request) in Visual Basic 6.0 (Microsoft Corporation, Redmond, WA) that read these 3 grid files, conducted the 2-ha moving-window averaging on the RSI input file, created a moving-window-modified RSI file (RSI_{mw}), and created a MHSI grid file by calculating MHSI from the input FSI and CSI files and the RSI_{mw} file as

$$MHSI = \left(FSI \times \left(\frac{CSI + RSI_{mw}}{2} \right) \right)^{0.5} .$$

This calculation of MHSI emphasizes the importance of reproduction habitat and concealment cover in this suburban landscape by modifying the influence of FSI on overall habitat suitability, while representing the partial suitability of areas that provide reproduction or concealment cover but not both. FSI is essentially supplemented in areas that provide adequate cover and reproduction habitat, while it is penalized in areas providing little cover and reproduction benefit. In areas that provide no cover or reproduction benefit (CSI and $\text{RSI}_{\text{mw}} = 0.0$), the geometric mean provides a limiting effect on habitat suitability (MHSI = 0.0).

Assessment of Index Validity

During January−March 2004, we captured and radio-collared 16 bobcats (5 adult males, 5 adult females, 3 juvenile males, and 3 juvenile females) on Kiawah Island as part of a related study examining suburban bobcat ecology (Chapter 3). We recorded telemetry locations of radio-collared bobcats 2−5 times per week from 1 April 2004–30 March 2005. We incrementally shifted the starting time of telemetry monitoring sessions to allow the collection of locations throughout the diel period. We used Home Range Tools (Rodgers et al. 2005) for ArcGIS 9 to calculate 95% fixed kernel (FK; Worton 1989) home ranges for bobcats that exhibited resident behavior for ≥ 6 consecutive months and had ≥ 50 locations ($n = 13$; Seaman et al. 1999). We used Animal Space Use 1.0 (Horne & Garton 2006*a*) to select the kernel smoothing factor with likelihood cross-validation (Silverman 1986; Horne & Garton 2006*b*). We also attempted to locate all female den sites during the spring of 2004 and 2005.

Because reproduction habitat, which is only seasonally important to female bobcats, was a main component of MHSI, we felt we could not simply compare frequency of bobcat use (i.e., telemetry locations) to the MHSI output to assess index validity (i.e., the frequency of telemetry locations in an area may not effectively convey its importance as reproduction habitat). Additionally, we used observations of radio-collared female bobcat den site selection (e.g., composition and size of habitats around den sites) to construct the RSI portion of the index, making any assessment of RSI_{mw} validity with these same individuals erroneous. Therefore, we chose to evaluate the validity of the input FSI and CSI components of the index separately, using telemetry locations collected during the nocturnal period and cotton rat abundance estimates to evaluate FSI and telemetry locations collected during the diurnal period to evaluate CSI. We present the RSI_{mw} value for each documented den site not as index validation, but to discuss implications for habitat preservation.

Bobcats are generally considered nocturnal predators, although peaks in activity are often associated with crepuscular peaks in prey species activity (Andersen & Lovallo 2003). Therefore, telemetry locations collected during the crepuscular and nocturnal portions of a diel period (hereafter called "nocturnal") should generally represent feeding activity, and we would expect these locations to be associated with high FSI values if the index is accurately reflecting prey availability. We would also expect diurnal telemetry locations to generally represent hiding behavior, which should be associated with high CSI values if the index is accurately reflecting the adequacy of concealment cover. We used the intersect point tool in Hawth's Analysis Tools for ArcGIS 9 to record the FSI value at each nocturnal telemetry location (30 minutes before sunset to 30 minutes after sunrise) and the CSI value at each diurnal location (all other times). We used 2004 sunrise and sunset data for Charleston, South Carolina, collected by the U.S. Naval Observatory (2004), to delineate month-specific diurnal and nocturnal periods. For each bobcat, we compared the frequency of locations within each FSI or CSI category to the expected frequency, based on availability within the 95% FK home range, using log-likelihood G-tests (Sokal & Rohlf 1995). We then summed G statistics and associated degrees of freedom across all bobcats to test overall use versus availability for FSI and CSI (White & Garrott 1990).

We also used data collected from a small-scale rodent trapping effort to evaluate general relationships between cotton rat abundance and mean FSI values in the open dune, shrub, and forest habitat types. If FSI was accurately reflecting the quality of cotton rat habitat, then differences in FSI values between these habitat types should generally correspond to measured differences in cotton rat abundance. During July of 2003−2005, 16 snap-trap transects were placed throughout undeveloped areas of the island. One Victor EasySet mouse trap and 1 Victor Professional Expanded Trigger rat trap (Woodstream Corp, Lititz, PA) were set at each of 10 stations along each transect. Stations were spaced 10 m apart and the rat and mouse traps were spaced approximately 1 m apart at each station. Traps were pre-baited (i.e., trap baited, but trigger not set) with a mixture of peanut butter and rolled oats on the first night and re-baited and set each of the ensuing 3 nights. We checked traps each morning and collected and identified captured rodents to species when possible (scavenging by fire ants [*Solenopsis invicta*] made identification of small rodents impossible in some cases). Since FSI was not designed to assess habitat quality for all rodents, we only report a habitat-specific index of cotton rat abundance (C/E) as the number of cotton rats captured divided by the total trapping effort (trap nights). We assumed the probability of capture was a reflection of abundance and that individuals from different rodent species had an equal probability of capture (i.e., the number of cotton rat captures represented habitat-specific abundance and not differences in habitat-species-specific capture probabilities). As the purpose of this analysis was to compare average cotton rat abundance between habitats, not to examine temporal differences in cotton rat abundance, we pooled habitat-specific capture data between years. Although cotton rat abundance is known to vary between years, we assumed potential differences between habitats would be evident regardless of overall population abundance (Goertz 1964).

Prioritization of Preservation Efforts

Habitat suitability models are typically interpreted at the scale at which the animal fulfills its life requisites. Allometric or minimum documented home range size is often used to define this scale (Roloff & Kernohan 1999). Interpreting habitat suitability on Kiawah Island solely at a home range scale would essentially negate the purpose of our fine-scale analysis (i.e., prioritization of undeveloped lots by their potential ecological benefit to bobcats). However, preservation of habitat in 1 or a few portions of the island or in portions of the island where habitat suitability is unlikely to be substantially impacted by future development, would do little to preserve habitat suitability island-wide and would be a sub-optimal use of land preservation funds. Therefore, we interpreted habitat suitability at the home range- and lot-level to identify sections of the island where current preservation efforts should be focused, and then identify lots within those sections that, if preserved, would likely provide the greatest ecological benefit to bobcats and their associated wildlife community.

To assess lot-level habitat suitability, we used zonal statistics in Hawth's Analysis Tools to calculate the mean MHSI value within each undeveloped lot. The smallest bobcat home range we documented on Kiawah Island during 2004−2005 was approximately 237 ha. Therefore, we used a 237-ha moving-window with the landscape characterization tool in Hawth's Analysis Tools for ArcGIS 9 to create a home range-averaged MHSI raster grid (MHSI_{hr}) from the original MHSI output to assess habitat suitability at the island-level. With the exception of the moving window size, this analysis was similar to the moving window analysis of RSI described previously.

The majority of bobcat home ranges on Kiawah Island during 2004−2005 were approximately rectangular with an east-west orientation (Chapter 3), likely in response to the rectangular shape of the island and the associated east-west linear orientation of many undeveloped habitat types (e.g., dune shrubs). We partitioned the island into 20 rectangular sections (100−138 ha), the majority of which had a north-south orientation, to help identify portions of the island where preservation efforts should be initially focused and to promote interspersion of preserved areas within bobcat home ranges and throughout the island. The irregular shape of upland habitats in the eastern portion of the island made a north-south orientation unrealistic in many sections; however, this arrangement ensured that all 2004−2005 bobcat home ranges intersected with ≥ 3 different sections. We overlaid these sections on the $MHSI_{hr}$ raster grid and calculated the average $MHSI_{hr}$ within each section with the zonal statistics tool in Hawth's Analysis Tools for ArcGIS 9. We used these section averages to prioritize immediate preservation needs among sections and then used the lot-specific mean suitability values to prioritize lots within each section.

Results

We delineated 367.1 ha of forest, 306.4 ha of shrub, 116.4 ha of open dunes, 1509.6 ha of salt marsh (807.0 ha after areas >150 m from upland habitats were removed), 234.1 ha of sand, 9.3 ha of open-altered, 208.8 ha of golf course, 416.5 ha of residential and resort development, 160.7 ha of roads, and 153.7 ha of water on Kiawah Island (Figure 4.1). We used field estimates at 308 randomly selected locations to estimate mean component index values (FSI and CSI) within the shrub, forest, open dune, and developed habitat types, and we used aerial orthophotography to estimate mean component index values within the 9 open-altered areas and at 47 random locations along Kiawah Island's roadways (Table 4.1). Mean FSI did not differ between forest ($\bar{x}$ FSI = 0.37, SE = 0.02, n = 107) and open dune ($\bar{x}$ FSI = 0.34, SE = 0.03, n = 24) habitats (Mann-Whitney U-Test, $P = 0.601$), therefore FSI data were pooled between these habitats to calculate the mean FSI used in habitat suitability analyses ($\bar{x}$ FSI = 0.36, SE = 0.02, n = 131). All other mean measured component index values (see Table 4.1) were significantly different (Mann-Whitney U-Tests, $P > 0.05$) between habitats. Because the measured component index values we used as inputs to MHSI were significantly different with relatively little variation, our results on the prioritization of important habitats should be fairly robust to potential errors caused by within-habitat variability.

During both the nocturnal (68 ± 5.4 telemetry locations/bobcat) and diurnal periods (85 ± 4.6 telemetry locations/bobcat), bobcats used habitat types disproportionately with respect to availability (nocturnal, $G_{65} = 645.4$, $P < 0.001$; diurnal, $G_{49} = 1205.3$, $P < 0.001$); with low suitability areas used less and highly suitable areas used more than expected during both time periods (Figure 4.2). This suggests the FSI and CSI component indices were adequately reflecting the importance of habitats used by bobcats to fulfill these life requisites (food and cover). Additionally, cotton rats were more than twice as abundant in shrub habitats (C/E = 0.033) than in open dune or forest habitats, which were similar (C/E = 0.012 for both), during summer rodent trapping. Cotton rats comprised 50% of all captures (n = 98) during a total of 2,872 trap nights (662 in shrub, 414 in open dune, and 1,796 in forest), while the next most frequently captured group (*Peromyscus* spp.) accounted for 22% of all captures. This fairly consistent relationship between habitat-specific cotton rat abundance and mean FSI (i.e., shrub habitats approximately twice as important as forest or open dune habitats, which are similar) reinforces the use of FSI as a representation of cotton rat availability in this analysis.

We were able to document the exact location of 6 bobcat dens during 2004−2005. Two dens were found in forested areas with RSI_{mw} values of 0.84 and 1.0, whereas 4 dens were found in shrub habitats with RSI_{mw} values of 0.47, 0.51, 0.81, and 0.81. One of the den sites with an

RSI_{mw} value <0.8 was located on the edge of a large (>2 ha) contiguous patch of suitable habitat while the other was located in a large, narrow patch of suitable habitat surrounded by salt marsh, both of which were perceived as less suitable within the square moving-window. We believe the square moving-window was the best overall choice for this analysis because of the square to rectangular shape of most undeveloped patches on Kiawah Island (e.g., platted lots), although it will not be optimal in identifying reproduction habitats that occur in irregular shapes. Therefore, we recommend using a minimum threshold on MHSI (described below) when identifying habitats that are potentially suitable for all 3 bobcat life requisites is the goal.

Output MHSI values ranged from 0.00 in uninhabitable or low-quality areas (e.g., water, large expanses of golf course, sand, or salt marsh) to 0.83 in highly suitable areas (e.g., large areas of contiguous shrub habitat) throughout the island (Figure 4.3). Bobcat home range-level habitat suitability ($MHSI_{hr}$) averaged 0.20 island-wide (range = 0.07 – 0.36), with marked differences in mean $MHSI_{hr}$ between the 20 sections of the island (Figure 4.4; Table 4.2). Mean MHSI within undeveloped lots ranged from 0.40 to 0.76, with habitat suitability in the majority of undeveloped lots falling between 0.40 and 0.50. As we expected, based on the patch size stipulation of RSI, areas of highest suitability did not fall within platted building lots. Only 5 platted lots had mean MHSI values ≥ 0.7, none of which occurred west of section 11.

Due to the relationship between patch size and suitability of reproduction habitat, the loss of suitable den sites through continued habitat fragmentation is likely the most immediate threat to Kiawah Island's bobcat population. Using MHSI calculated from the lowest documented RSI_{mw} value at a bobcat den site (0.47) and the lowest possible FSI (0.37) and CSI (1.0) values at a suitable den site (forest or shrub habitat) as a minimum threshold of habitat suitability, we believe immediate preservation efforts should be focused on areas with MHSI >0.5 throughout the island. Habitats with MHSI >0.5 in section 1 and portions of sections 2, 5, 6, and 7 should receive highest priority as they likely represent the only remaining suitable reproduction habitat in the western portion of the island. Between this project and the research conducted by Griffin (2001), a total of 6 bobcat dens have been found in the western portion of Kiawah Island, 5 of which were located in section 1 and the other in the northwest portion of section 6. Although section 1 is currently not platted for development, the upland portions of it can be developed based on the 2005 development agreement between the Town of Kiawah Island and Kiawah Resort Associates, the developer of Kiawah Island. The same is true for Cougar Island, the large undeveloped tract of land in section 19. Little Bear Island, which makes up the majority of section 20, is mostly protected from development by a conservation easement held by Ducks Unlimited and KINHC (the easement allows for 2 small residential dwellings). Section 14, which also has fairly high overall habitat suitability, is a relatively new development with numerous undeveloped platted lots of moderate to high suitability (78 lots with MHSI >0.5). The conservation easement on Little Bear Island will ensure that some highly suitable habitat is retained at the eastern tip of Kiawah Island, but without significant preservation efforts the future development of sections 1, 14, and 19 could have wide-ranging negative effects on bobcat reproduction and overall habitat suitability.

Secondary habitat preservation efforts, at least in the immediate future, should be focused in the western sections of Kiawah Island (sections 1−9) in an attempt to retain interspersed patches of habitat for feeding and concealment (using MHSI to prioritize preservation opportunities), particularly in sections with the lowest mean MHSI_{hr} (e.g., sections 3 and 8). Since the development of new neighborhoods on Kiawah Island has followed a general west-to-east progression, and the majority of tourism activity is confined to the western portion of the island, the highest density of development is found in these western sections. Additionally, due to the general shape and arrangement of Kiawah Island's upland habitats, the western sections have fewer important salt and maritime shrub habitats (~7% of land cover in sections 1−9) than the eastern sections (~20% of land cover in sections 10−20). Many of these shrub habitats are at least partially protected from human alteration (e.g., salt marsh-upland interface, secondary dunes) by local or state regulations (see Kiawah Island Architectural Review Board 2007; South Carolina Department of Health and Environmental Control – Office of Coastal Resource Management 2006) or fall outside of property boundaries slated for development. When these factors are considered and based on the data at hand, the preservation of suitable platted lots in the western sections of the island would likely provide a greater net benefit to Kiawah Island's bobcat population than preservation of lots in the eastern sections. However, bobcat habitat suitability and associated preservation priorities will need to be reassessed periodically to account for the effects of continuing development and potentially changing development patterns (e.g., intensification of development in specific sections).

Discussion

Based on our research of bobcat ecology (Chapter 3), KINHC is using the bobcat as a flagship and umbrella species (Caro & O'Doherty 1999) for habitat preservation on Kiawah Island (Chapter 5). The umbrella species approach to habitat conservation (i.e., 1 species representing the habitat requirements of a suite of species or ecological community) has come under some scrutiny in the literature because the habitat needs of the umbrella species do not always encompass all habitat requirements of the suite of species or wildlife community it is meant to represent (Andelman & Fagan 2000; Roberge & Angelstam 2004). We believe the bobcat is a justified umbrella species for habitat preservation efforts on Kiawah Island. If patches of habitat that fulfill all life requisites of the bobcat can be preserved, then at least some portion of virtually all upland habitat types at risk from development (e.g., maritime forest, maritime and salt shrub) on Kiawah Island will be preserved. These preserved habitat patches will undoubtedly benefit a variety of wildlife species on the island; however, this system for habitat prioritization could easily be altered to consider the habitat requirements of multiple species sensitive to anthropogenic disturbance (i.e., the focal species approach; Lambeck 1997) if future research demonstrates that life requisites of other sensitive species aren't being addressed within this umbrella system.

Although KINHC has been fairly successful garnering support for habitat preservation, placing land under conservation easement, and purchasing small properties for preservation on Kiawah Island (Chapter 5), extremely high property values in this resort environment (prices ranged from \$2.2 million/ha to \$15.6 million/ha during an online search of available, undeveloped properties on 19 February 2007) make extensive preservation efforts through land purchase difficult, thereby emphasizing the importance of habitat quality and the prioritized allocation of preservation funds. Our analysis of habitat suitability could also be combined with data on availability and cost of potential properties within the GIS environment, facilitating a cost-benefit analysis of preservation opportunities to maximize the biological influence of habitat preservation funds.

In its current state, MHSI appears quite useful as a tool to identify the most important habitats for bobcats on Kiawah Island and help prioritize preservation efforts based on this relationship, although there is always room for improvement. Because input component index values and the size of the RSI moving window are easily altered in the MHSI computer program, this analysis could easily be fine-tuned if additional information on Kiawah Island bobcat ecology and habitats is collected. Surveys of vegetation structure and habitat features that test our assumptions that all forest and shrub habitats provide optimal concealment cover and the features necessary for denning would be beneficial. Also, estimates of habitat-specific alternative prey species abundance (i.e., other than cotton rat or eastern cottontail) could be used to alter the calculation of FSI to account for the suite of prey species available to a bobcat on Kiawah Island. Although no model will ever completely eliminate the need for on-site verification of habitat suitability at sites selected for preservation, fine-tuning component index values with such field examinations would only increase the accuracy of this index.

Based on research of the effects of habitat fragmentation and human disturbance on bobcat ecology in other portions of the U.S. (Lovallo & Anderson 1996; Nielsen & Woolf 2001; Crooks 2002; Tigas et al. 2002; Riley et al. 2003; Riley 2006), the abundant bobcat population on Kiawah Island is quite unique. Therefore, the bobcat would not likely suffice as an umbrella species for habitat preservation in many other suburban environments. However, the general framework we present for using habitat suitability to focus site-specific preservation efforts should be applicable to virtually any species, or group of species, and location for which life requisite and habitat data are available.

Other studies have used presence-absence models to identify habitat patches that are potentially beneficial to birds in developing landscapes (Darr et al. 1998; Watson et al. 2001; Rubino & Hess 2003). The best approach would likely depend on the goals of the project, the scale at which preservation efforts are focused, and the habitat and species life requisite data available. No matter the approach, it is important that the increasing number of local and regional land trust organizations (Land Trust Alliance 2006), and other entities that are striving to preserve habitat for wildlife in developing environments, have tools available to maximize the efficiency of their efforts. While all preserved "natural areas" likely provide some benefit to suburban wildlife, only the preservation of habitats that meet the specific life requisites (food, cover, reproduction, water) of a species will truly facilitate its persistence in these fragmented landscapes. In most situations, including Kiawah Island, the fate of sensitive species will ultimately depend on both the quality and quantity of preserved habitats; the latter of which will depend on numerous social, economic, and public education factors that are beyond the scope of this analysis but may be supplemented by disseminating information about the former.

Acknowledgments

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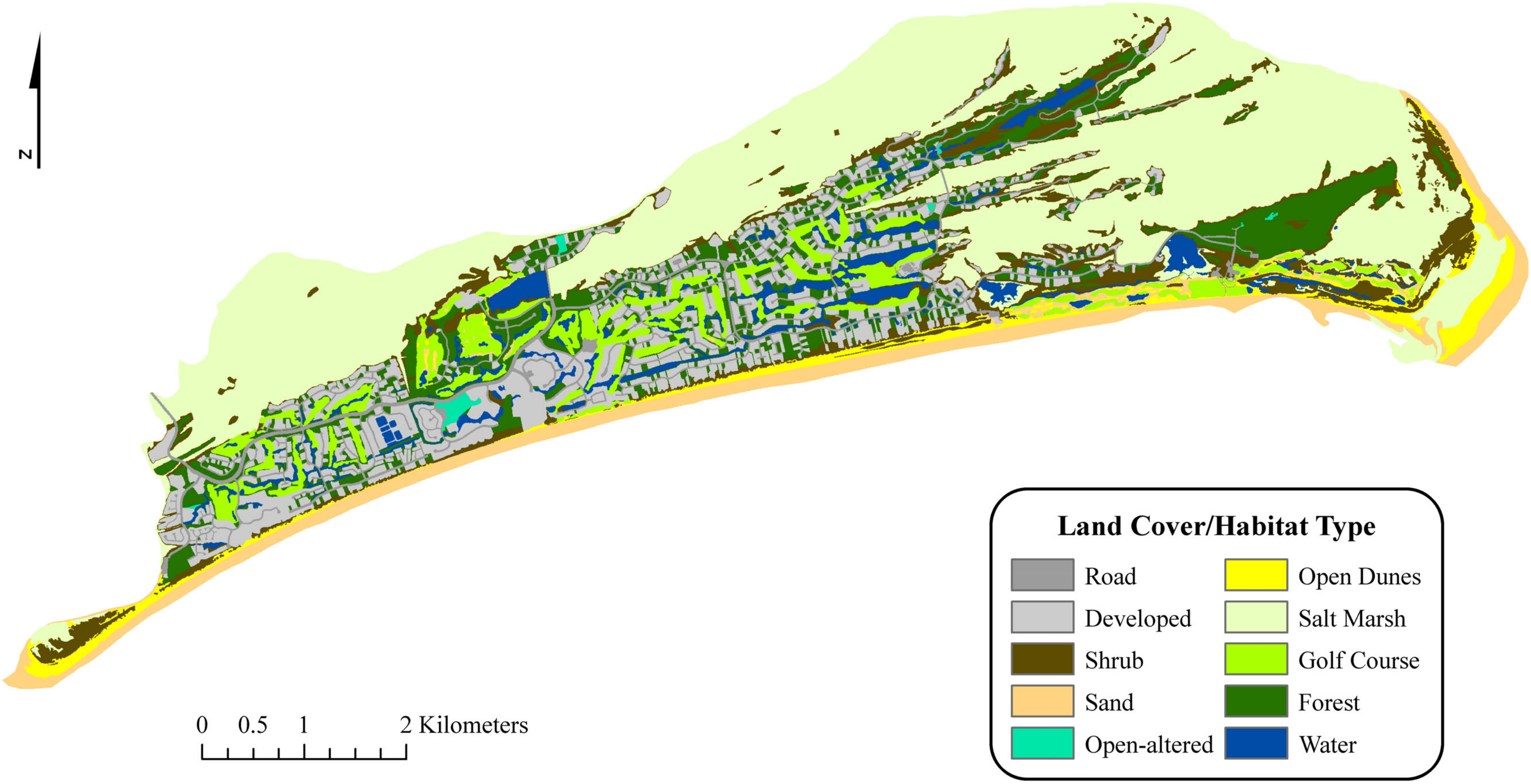

Figure 4.1. Map of habitat types on Kiawah Island, South Carolina during 2004−2005.

Table 4.1. Habitat-specific mean component index values (FSI = food suitability index, CSI = cover suitability index, RSI = reproductive suitability index), calculated from field or aerial orthophotography measurements, and pooled mean component index values used to calculate a bobcat habitat suitability index (MHSI) on Kiawah Island, South Carolina, USA, 2004−2005.

		$\bar{x}$ Measured Component Index Values (SE)		**Component Index Values Used in MHSI**		
Habitat	**n**[a]	**FSI**	**CSI**	**FSI**	**CSI**	**RSI**
Shrub	76	0.69 (0.02)	–	0.69	1.00	1.00
Forest	107	0.37 (0.02)	–	0.36 (0.02)[b]	1.00	1.00
Open Dunes	24	0.34 (0.03)	0.04 (0.01)		0.04	0.00
Open-altered	9	0.19 (0.03)	0.22 (0.05)	0.19	0.22	0.00
Developed	101	0.14 (0.01)	0.07 (0.01)	0.14	0.07	0.00
Road	47	0.10 (0.01)	–	0.10	0.00	0.00
Golf Course Salt Marsh[c] Sand	–	–	–	0.05	0.00	0.00
Water	–	–	–	0.00	0.00	0.00

Note: Assignment of non-measured component index values is described in the Methods.

[a] Number of sites sampled to calculate $\bar{x}$ measured component index values.

[b] Calculated from pooled data because $\bar{x}$ FSI did not differ between Forest and Open Dunes (Mann-Whitney U-Test, $P = 0.601$).

[c] Areas of salt marsh <150 m from upland habitats.

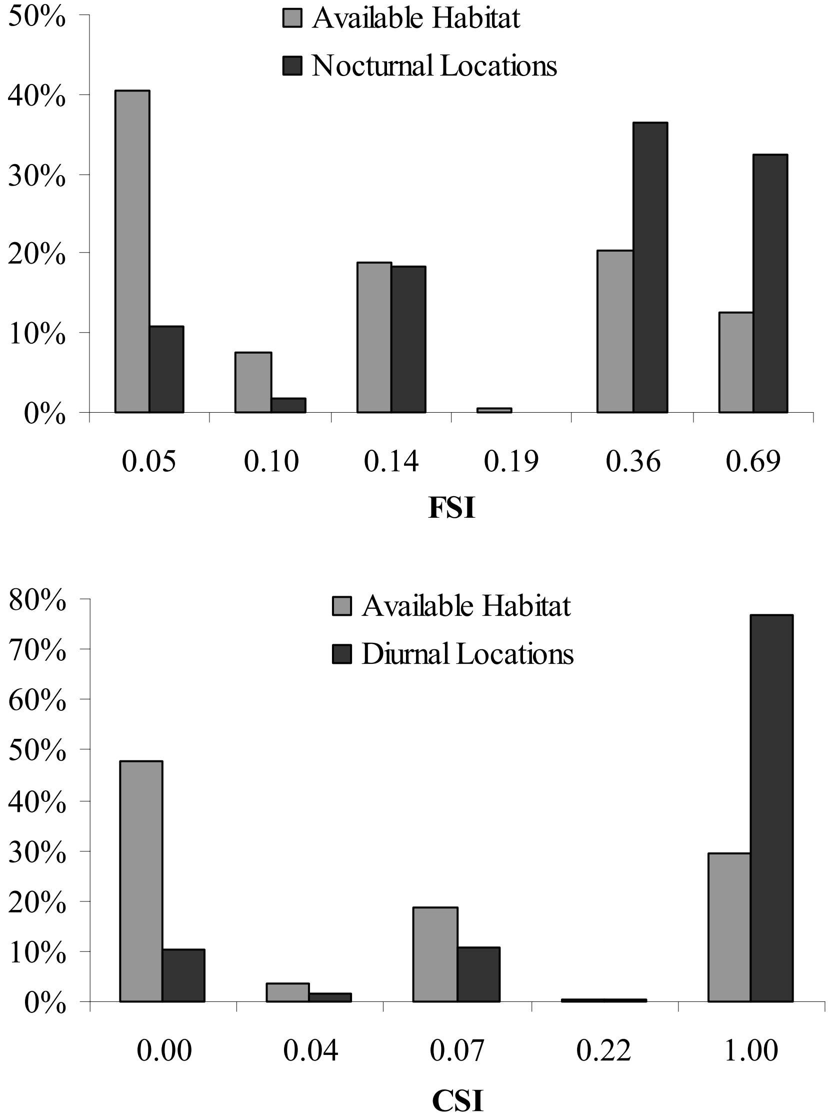

Figure 4.2. Comparisons of nocturnal (percentage of 68 ± 5.4 locations/bobcat) and diurnal (percentage of 85 ± 4.6 locations/bobcat) bobcat habitat use versus availability (percentage of 95% fixed kernel home range), summed over all bobcats, on Kiawah Island, South Carolina, USA, 2004−2005. Habitats are represented categorically by mean food suitability (FSI) and cover suitability (CSI) index values to assess validity of component indices.

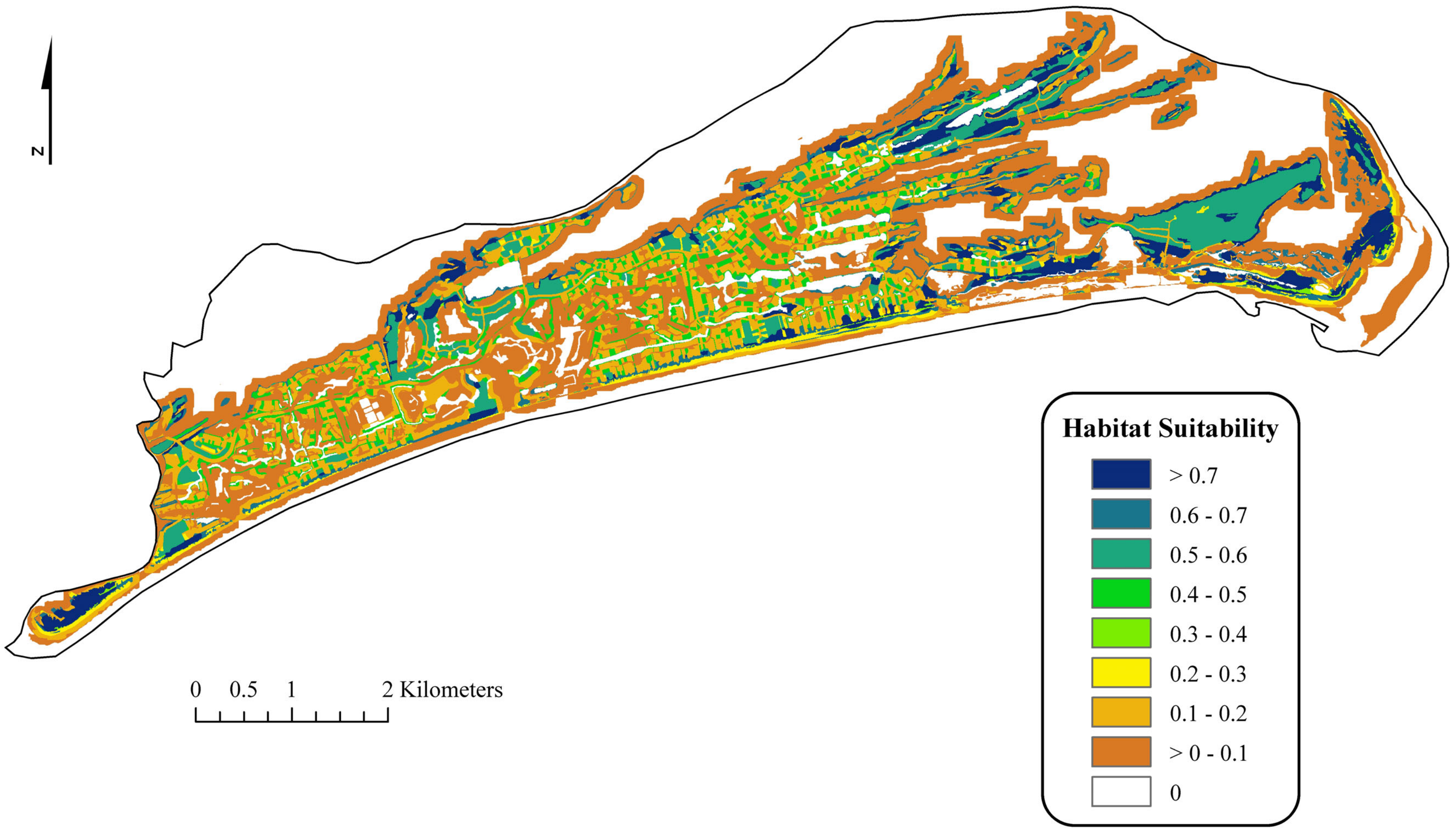

Figure 4.3. Raster grid of bobcat habitat suitability (MHSI) on Kiawah Island, South Carolina, USA, 2004−2005.

Table 4.2. Mean bobcat habitat suitability ($\bar{x}$ MHSI$_{hr}$) in 20 sections of Kiawah Island, South Carolina, USA, 2004–2005 and mean habitat suitability ($\bar{x}$ MHSI) groupings of undeveloped lots within each section, used to prioritize land preservation efforts at the island- and lot-level.

			Number of Undeveloped Lots		
Section	**$\bar{x}$ MHSI$_{hr}$[a]**	**No. of Undeveloped Lots**	**$\bar{x}$ MHSI[b] 0.4 – 0.5**	**$\bar{x}$ MHSI 0.5 – 0.6**	**$\bar{x}$ MHSI >0.6**
1	0.24	0	–	–	–
2	0.18	38	27	11	0
3	0.15	50	40	9	1
4	0.17	42	35	7	0
5	0.19	39	12	26	1
6	0.17	36	4	32	0
7	0.20	39	15	21	3
8	0.15	41	33	8	0
9	0.17	82	72	8	2
10	0.20	98	75	19	4
11	0.20	90	74	11	5
12	0.21	108	84	20	4
13	0.20	30	10	10	10
14	0.26	82	4	50	28
15	0.19	54	0	36	18
16	0.21	47	10	29	8
17	0.20	40	8	24	8
18	0.23	17	0	10	7
19	0.31	0	–	–	–
20	0.21	0	–	–	–
Total	0.20	933	503	331	99

[a] Calculated from MHSI$_{hr}$ raster grid (237-ha moving-window averaging of MHSI raster grid).

[b] Calculated from MHSI output raster grid.

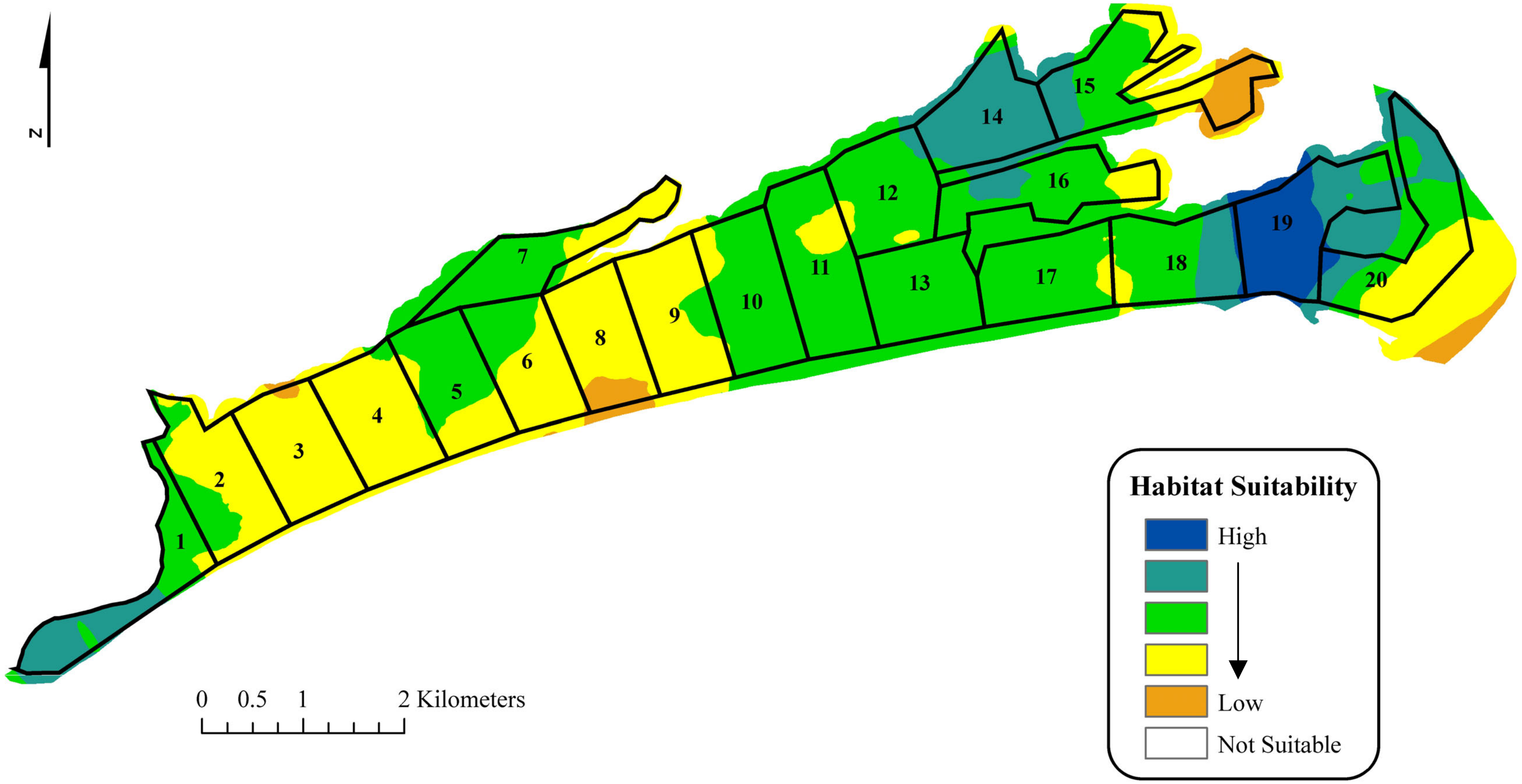

Figure 4.4. Map of bobcat habitat suitability on Kiawah Island, South Carolina, USA, 2004−2005 after 237-ha moving-window averaging ($MHSI_{hr}$), overlaid with 20 sections used to prioritize upland habitat preservation efforts at the island-level. Tidal waters and areas of salt marsh >150 m from upland habitats were removed prior to moving-window averaging (i.e., “not suitable”).

CHAPTER 5

THE BOBCAT AS AN ICON FOR INTEGRATING RESEARCH, EDUCATION, AND HABITAT PRESERVATION ON KIAWAH ISLAND, SOUTH CAROLINA [1]

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[1] Roberts, S. B., J. D. Jordan, P. Bettinger, and R. J. Warren. To be submitted to *Urban Ecosystems*.

Abstract: This paper describes a community response to the integration of research, education, and habitat preservation for bobcats (*Lynx rufus*) in the wildland-urban interface. Kiawah Island, South Carolina, a resort-style development, supports a relatively dense population of bobcats. During 2004–2005, we monitored 16 radio-collared bobcats (8 males and 8 females) to determine reproduction, survival, home range size, habitat use, and daily movement patterns. Telemetry locations and den monitoring of collared bobcats suggested shrubs (maritime shrub and salt shrub [salt marsh-upland interface] thickets) were important habitats and only large undeveloped tracts of maritime forest or shrub habitat (>2 ha) were used for den sites. A non-profit organization, the Kiawah Island Natural Habitat Conservancy (KINHC), used the telemetry data collected throughout this project to help educate residents about wildlife ecology and backyard habitat, to raise funds for habitat preservation, and to prioritize the protection of individual building lots on the island. They annually sponsor a social event (the "Bobcat Ball") where residents make tax-deductible donations and island maps depicting bobcat telemetry locations and home ranges are auctioned-off to benefit habitat protection goals. KINHC has recently protected over $3.1 million of land for wildlife conservation and is using additional funds to continue wildlife research on the island. Use of our research results to educate residents and help foster their interest in wildlife ecology has made the bobcat an icon for habitat preservation on Kiawah Island.

Key Words: bobcat, development, habitat preservation, icon species, flagship species, land trust, *Lynx rufus*, South Carolina, umbrella species.

Kiawah Island

Kiawah Island, South Carolina is a 3,500-ha coastal barrier island located approximately 25 km south of Charleston. Approximately 1,500 ha of the island is salt or brackish marsh, while the remainder is a mosaic of maritime forest, shrub thickets, brackish and freshwater ponds, golf courses, residential and resort developments, and barren sand (e.g., beach). The island is separated from other land masses to the north and west by the Kiawah River and to the east by the Stono River. A 2-lane road connects Kiawah Island to Seabrook Island at the narrowest point of the Kiawah River (~50 m at low tide), crossing approximately 550 m of salt marsh. During 2004−2005, Kiawah Island had a mean temperature of 27.6 ºC in July and 8.5 ºC in January, while precipitation averaged 114 cm annually (N. Shea, Kiawah Island Community Association, unpublished data).

Residential and resort development began on Kiawah Island in 1974. During 2004−2005, this gated community had more than 1,100 permanent residents and was visited by thousands of tourists each year. Of the approximately 3,000 lots available for single-family homes on the island, about 2,000 were developed. Virtually all resort development (all resort hotels and villas and 4 of 5 18-hole golf courses) and the majority of developed residential lots (89%) were concentrated on the western 1,100 ha of the island. With the possible exception of a cleared walking path for real estate purposes, the vegetation on undeveloped lots was usually unaltered. Lots platted for single-family homes comprised 28% (567 ha) of the island’s upland acreage, with a mean lot size of 0.19 ha (SE = 0.01 ha). The development and influx of people have dramatically changed the natural landscape of the island. Much of the maritime forest has been replaced with homes and landscaped yards, but construction regulations designed to bolster aesthetic appeal and maintain green space (Kiawah Island Architectural Review Board 2007) have preserved buffer areas between homes, canopy cover within each lot, and vegetation along marsh and pond edges, resulting in a mosaic of native and landscaped vegetation within developed areas. Additionally, a few relatively large (2–84 ha) un-platted patches of upland habitat were scattered throughout the island, the largest of which were located at the island's extreme west and east ends.

Bobcat Population

Since standardized scent-station surveys were initiated in 1997 (Diefenbach et al. 1994; Jordan, 1998), Kiawah Island has maintained a fairly stable, abundant bobcat (*Lynx rufus*) population. According to these surveys, there were about 30 bobcats (1.4 bobcats/upland [non-salt marsh] km^2) on the island during 2004−2005. This is notable, as the effects of development on bobcat ecology aren't well understood and past research has shown that bobcats generally avoid developed areas (Nielsen and Woolf, 2001; Tigas et al., 2002; Riley et al., 2003; Riley, 2006). Griffin (2001) showed that adult female bobcats in the more-developed western portion of the island had larger home ranges than those in the less-developed eastern portion of the island during 2000. He hypothesized these differences could be due to differences in habitat suitability or prey availability between the areas. Subsequent research we conducted on this site has shown that natural predation by bobcats is the major mortality factor limiting white-tailed deer (*Odocoileus virginianus*) population growth (Chapter 2). Thus there is currently little need for management programs to control this suburban deer herd. Without some form of control, suburban deer populations often grow to a level of overabundance, resulting in ecological damage, landscape shrubbery damage, and concerns regarding human safety and property damage from deer-vehicle collisions (see McAninch, 1995; McShea et al., 1997; Warren, 1997). Control of suburban deer populations through intensive management efforts (e.g., sharpshooting) is usually expensive and may be socially unacceptable to residents. The current natural control of deer populations on Kiawah Island is economically, environmentally, and socially beneficial to the island and its residents.

Importance of Wildlife to Kiawah Island

Property owners and tourists are drawn to Kiawah Island, South Carolina (www.kiawahisland.org) for a variety of reasons (world-renowned golf and tennis facilities, luxurious oceanfront resort, 15 km of beach, recreational opportunities, proximity to Charleston), not the least of which is an abundance of visible wildlife. Tourism and real estate are the economic bases of Kiawah Island, and the island's aesthetic value is one of the cornerstones of its appeal. Wildlife-related recreation (e.g., wildlife viewing, nature tours) is recognized as one of the major island attractions for those not interested in golf or tennis, making Kiawah appealing to families and groups of individuals with varied interests. Each year, more than 25,000 people participate in guided nature tours and wildlife education programs provided by the Kiawah Island Resort Nature Center (L. King, Kiawah Island Resort, personal communication) and countless others explore unguided. The Travel Channel rated Kiawah Island as "America's Best Wildlife Getaway Beach" during its 2002 special on America's best beaches. The Kiawah Island Resort, the only resort on the island, has incorporated the wildlife-based reputation of Kiawah Island in its advertising by adopting the slogan "Nature at its Finest". The positive advertising associated with Kiawah's abundant wildlife has led to increased tourism and real estate sales, which in turn has had a significant positive impact on the local economy of Charleston County (Hefner and Crotts, 2005).

The importance of wildlife to Kiawah Island residents is also evidenced in the island's long-standing commitment to wildlife research and monitoring. Beginning with an examination of deer ecology and herd health in 1997 (Jordan 1998), island entities have funded or facilitated research on bobcats (Griffin 2001), mink (*Mustela vison*; Butfiloski and Baker, 2006), loggerhead sea turtles (*Caretta caretta*; Stokes et al. 2006), and diamondback terrapins (*Malaclemys terrapin*; Gibbons et al. 2001). Additionally, the wildlife monitoring programs of the Town of Kiawah Island, Kiawah Island Community Association's Land and Lakes Department, and Kiawah Island Turtle Patrol provide a variety of wildlife information to residents and visitors on white-tailed deer, bobcat, gray fox (*Urocyon cinereoargenteus*), and alligator (*Alligator mississippiensis*) population trends; bird diversity trends; and loggerhead sea turtle, alligator, and raptor nesting.

The Kiawah Island Natural Habitat Conservancy

During the mid-1990s many residents were concerned over the rate of residential development on the island (about 81 new homes/year). These proactive residents felt that continued habitat loss to development may limit Kiawah Island's ability to maintain abundant, healthy wildlife populations. In 1997, a group of residents founded and chaired the Kiawah Island Natural Habitat Conservancy (KINHC), which is a 501(c)(3) non-profit organization designed to (1) educate visitors and residents about wildlife ecology and backyard habitat and (2) facilitate the preservation of wildlife habitat by purchasing properties with tax-deductible donations and by protecting the habitat on properties of willing participants with conservation easements.

From 1997−2003 KINHC focused on the development of numerous publications and videos designed to educate property owners and visitors on backyard habitat and landscaping with native vegetation. In addition to its education value, this outreach program acquainted property owners with the goals and staff of KINHC and established a donor base for future fund-raising activities. Property values on Kiawah Island are extremely high (prices ranged from $2.2 million/ha to $15.6 million/ha during an online search of available, undeveloped properties on 19 February 2007), making it difficult to conserve large quantities of property. From 1997−2003 KINHC purchased 1 property (0.29 ha) on the island and 1 was donated by a property owner (0.12 ha). They also became the secondary conservation easement holder (Ducks Unlimited is the primary easement holder) on a 61.4-ha property at the eastern end of Kiawah Island.

In 2003, KINHC agreed to partner with the Town of Kiawah Island in funding our bobcat research project, which was designed to investigate the ecology (habitat use, movement rates, interactions, survival, reproduction, home range size and location) of this native predator in relation to development. During April 2004−March 2005, we radio-monitored 16 bobcats (5 adult male, 5 adult female, 3 juvenile male, 3 juvenile female) on Kiawah Island to collect these data (Chapter 3). KINHC felt this research would aid in the identification of important habitat types for bobcats, and possibly important locations throughout the island, thereby allowing them to focus their preservation efforts on specific properties that would provide the greatest potential benefit to bobcats and other associated wildlife species. They also believed the mystique and appeal of this native predator would heighten the interest and support of residents for habitat preservation on the island.

Bobcats are charismatic mammals that use relatively large home ranges (compared to other resident species on Kiawah Island) encompassing a variety of habitats (Griffin 2001, Chapter 3), they serve important ecological and utilitarian roles on the island as an apex predator (i.e., keystone species and “deer controller”; Chapter 2), and previous research suggested their moderate sensitivity to habitat fragmentation may serve as a measurement of ecological function in human-altered landscapes (Crooks 2002). These ecological, aesthetic, and utilitarian attributes suggested bobcats would make an acceptable umbrella species (i.e., 1 species whose range and habitat requirements encompass those of a suite of species) and flagship species (i.e., appealing species used to draw public support) for habitat preservation on Kiawah Island (Caro and O'Doherty, 1999). Therefore, KINHC chose to use the bobcat as an icon of Kiawah Island's natural beauty and ecological function to guide and promote its education and habitat preservation efforts.

Integration of Research into Preservation, Education, and Fund-raising

Due to the extremely high property values on Kiawah Island, KINHC wanted to ensure they obtained the greatest wildlife benefit from their financial investment when they purchased habitat for preservation. Since 2004 they have been using telemetry data from our bobcat research to prioritize lots according to apparent trends in habitat use and movement patterns. For example, it was evident early-on in the study that shrub habitats were heavily utilized, certain locales were important for movements between portions of the island (e.g., heavily utilized patches where bobcat movements were restricted by aquatic features), and dens were always found in large (>2 ha) undeveloped patches. Therefore, undeveloped lots that contained large amounts of shrub habitat, undeveloped lots with shrub habitat that adjoined un-platted tracts of land (i.e., lot preservation would create larger contiguous undeveloped area), and undeveloped lots with shrub habitat in important locales were given priority. KINHC then considered these ecological priorities, along with real estate availability and cost, to optimize their preservation efforts.

KINHC also used our data to aid their educational and fundraising activities. Since their inception, KINHC has promoted landscaping with native vegetation and the preservation of understory shrubs and forbs around homes. Our bobcat research has provided empirical evidence of the importance of understory vegetation for them to incorporate in their educational activities. Since 2004 they have been using our data to educate property owners on the importance of understory vegetation, thus combating the "park-like" or "plantation" appearance (i.e., large, open grass yards with no understory cover) that was previously desired by some residents on Kiawah. They also incorporated these data into the latest edition of their "Landscaping for the Legacy" publication. This booklet educates all property owners about the benefits of landscaping with native species and preserving both the understory and canopy vegetation. The booklet also provides information on area businesses that specialize in landscaping with native vegetation.

Since they initially funded our research, KINHC has sponsored an annual social event called the Bobcat Ball to raise funds for habitat preservation. This event included a silent auction of donated artwork, dinner, live music, and beginning in 2005, an "adopt-a-bobcat" auction. The bobcat auction allowed guests the opportunity to "adopt" one of the radio-collared bobcats on the island. The winning bidder received information about the bobcat (weight, sex, denning history, etc.), a map of the bobcat's telemetry locations and home range overlaid on a Kiawah Island lot map, and they had the opportunity to name the bobcat on an adoption certificate. Throughout the year, the adopters received general updates on "their" bobcat (e.g., denning activity, additional telemetry locations, interesting observations by researchers). In addition to this event, KINHC has employed a variety of other fund-raising methods to benefit habitat preservation: a cooperative program with most of the island's vacation rental companies to include an optional $2-per-night room donation on all rental villas and resort rooms, appeals to island entities and corporate donors for substantial yearly donations and sponsorships, and a quarterly publication with KINHC news and updates that includes opportunities for donation.

The ecological needs and importance of the bobcat on Kiawah Island played a major role in all of these fund-raising endeavors.

Fund-raising and Habitat Preservation Benefits

The integration of our bobcat data into KINHC's fund-raising and habitat preservation efforts has been quite successful. At the 2005 Bobcat Ball event, 4 radio-collared bobcats were auctioned-off, raising $12,000 for habitat preservation. In all, KINHC received over $23,000 in donations during the event. At the 2006 event, 6 adopted bobcats raised a total of $16,150 and KINHC received $70,200 in total donations. During 2004−2006, KINHC purchased or received in donation an additional 7 properties (1.26 ha) valued at approximately $3.15 million in total (Table 5.1). These properties represented a >300% increase in preserved habitat area over a 3 year period when compared to the previous 6 years KINHC had been in existence (not including the large secondary conservation easement held with Ducks Unlimited). There also was a fairly large increase in cash donations from individuals and contributions from businesses during 2004−2006 (Figure 5.1). Total contributions (donations of cash and land) were >$1 million in 2005 and 2006. Although their recent success is undoubtedly a result of the innovative fund-raising efforts employed by KINHC staff and the generosity of island residents and corporate donors, it is very unlikely that so much natural habitat would have been preserved on Kiawah Island had they not integrated our wildlife research results with their education and fund-raising programs.

Continuation of Research

KINHC is also using a portion of the funds raised to continue bobcat research on Kiawah Island. Beginning in January 2007, KINHC and the Town of Kiawah Island initiated a cooperative project designed to examine the fine-scale movements and habitat use of Kiawah's bobcats. During this pilot study, they have fitted 4 bobcats with GPS-equipped collars that will record a location every 10 minutes, allowing for a detailed examination of how bobcats use and navigate the matrix of habitats and development on the island. This pilot study is being used to test the collar capabilities (i.e., GPS fix rate, location error) in the thick vegetation of Kiawah Island, but if results are positive then a larger scale project will be conducted during the fall and winter of 2007. KINHC also is using this innovative research to expand their “adopt-a-bobcat” program. During the 2007 Bobcat Ball residents will have the opportunity to “adopt” a bobcat prior to its capture and receive frequent updates of fine-scale movement data throughout monitoring. Preliminary evidence suggests this program is going to be a very successful fund-raising endeavor for KINHC and will provide data on suburban bobcat movements at a temporal resolution not previously documented.

The Bobcat as an Icon

The umbrella species approaches to habitat conservation has come under some scrutiny in the literature because the habitat needs of an umbrella species do not always encompass all habitat requirements of the suite of species or wildlife community it is meant to represent (Andelman and Fagan, 2000; Roberge and Angelstam, 2004). We do not claim that the habitat requirements of the bobcat are representative of the entire ecological community on Kiawah Island, but we believe using the bobcat as an icon for habitat preservation on Kiawah Island is currently the best option to quickly fund the preservation of a variety of upland habitats in the face of rapid development. Although the shrub habitats that bobcats prefer do not encompass the habitat needs of all of Kiawah’s wildlife (e.g., forest-associated birds), the preservation of platted properties to benefit bobcats will also benefit wildlife species associated with Kiawah’s maritime forest. Most platted properties on the island are predominantly covered in maritime forest.

Therefore, centering preservation efforts on a species associated with shrub habitats should actually result in the preservation of a greater diversity of upland habitats by focusing on properties that include a mix of shrubs and maritime forest. If KINHC's bobcat-focused preservation efforts continue to be successful, at least some portion of virtually all upland habitat types at risk from development on Kiawah Island will be preserved.

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Table 5.1. Platted properties preserved by the Kiawah Island Natural Habitat Conservancy (KINHC) on Kiawah Island, South Carolina, USA before (1997−2003) and after (2004−2006) integrating bobcat research data into fund-raising efforts.

Year	**Acquisition**[a]	**Area (ha)**	**Value ($US)**[b]
1999	Donation	0.12	450,000
2002	Purchase	0.29	350,000
2004	Purchase	0.27	495,000
2004	Combination	0.17	495,000
2005	Donation	0.11	450,000
2005	Purchase	0.20	435,000
2006	Donation	0.09	375,000
2006	Purchase	0.17	450,000
2006	Purchase	0.25	450,000

[a] Donation = property donated by owner, purchase = property purchased by KINHC through donations or grants, combination = portion of property value donated by owner and the remainder was purchased with donations or grants.

[b] Market value estimated by Kiawah Island Real Estate representative (January 2007).

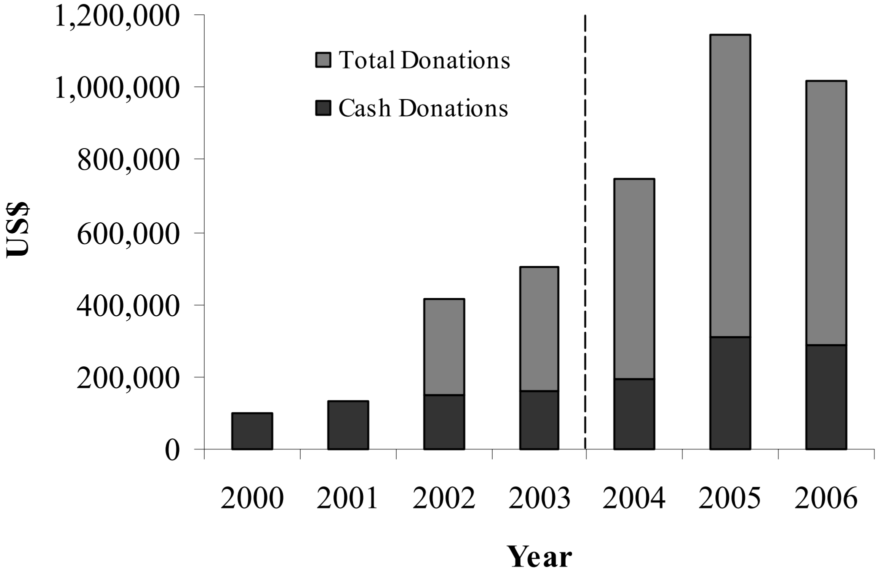

Figure 5.1. Total donations (includes contributions from business partnerships and donated property values) and cash donations from individuals received by the Kiawah Island Natural Habitat Conservancy (KINHC) before (2000−2003) and after (2004−2006) using the bobcat as an icon for their fund-raising and educational programs on Kiawah Island, South Carolina, USA.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This project was designed to integrate previous wildlife research and better understand the complex ecology of white-tailed deer (*Odocoileus virginianus*) and bobcats (*Lynx rufus*) on Kiawah Island, South Carolina, a developing coastal barrier island. By examining the interactions between these species and with their suburban environment, we also sought to provide information that could be used by island officials in the proactive maintenance of wildlife habitat to support this predator-prey relationship under continuing development pressure.

Throughout the project, we monitored deer survival and mortality sources and gained useful insight into the significant role bobcat predation played in the regulation of Kiawah's deer herd. Deer fawn survival was low during all years, but seemed to vary between years depending on the level of bobcat predation. Bobcats were responsible for the majority of fawn mortalities each year and were, therefore, the major factor limiting deer population growth during the project. Observations of collared bobcats and data collected from small mammal trapping suggested variation in prey selection between individuals or variation in rodent abundance may have led to yearly differences in fawn survival. Additionally, male fawns and fawns born in areas of higher habitat diversity were more likely to be killed by a bobcat within 2 weeks of birth. Because an increase in habitat diversity would generally correspond to an increase in fragmentation in our analysis, the fragmented suburban habitat of Kiawah Island was apparently facilitating the predatory efficiency of bobcats to some extent. However, development on the island to date has maintained an abundance of buffer strips and has not severely impacted many large patches of quality bobcat habitat. Therefore, there is likely a point where continued development will negatively affect the bobcat population and this predator-prey dynamic. Adult doe survival was high over all years and doe and fawn home ranges were relatively small, which supported Jordan's (1998) conclusions that Kiawah's deer are healthy and that food resources are fairly abundant. As healthy deer populations with abundant food resources can exhibit almost exponential population growth until they exceed the biological carrying capacity of their environment (McCullough 1997), these data elucidate the importance of low fawn recruitment in the restriction of Kiawah Island's deer herd.

We also monitored the majority of resident bobcats on Kiawah Island, which provided useful information on social structure, habitat use, home range size, movements, reproduction, and survival. Home ranges were relatively small and did not differ between sexes or seasons. Our observations of bobcat social interactions were similar to many published studies, although we did observe some females sharing an unusual amount of space and 1 instance where an older adult male was apparently supplanted by another adult male. We also found that males were able to interact with a large number of females within their fairly small home ranges. Population density, prey availability, and the distribution of important habitat resources likely played a role in all social interactions we observed. Survival was high and reproduction was adequate to replace losses. Bobcats selected shrub habitats over all other habitats, regardless of time of day, and selected large patches of forest or shrub habitat for denning. They moved less during the day, presumably to avoid interactions with humans, and used developed areas significantly more during nocturnal time periods when their movement rates were the greatest. We found that home and core range sizes were inversely related to the percentage of the range in shrub habitat.

In general, there were few significant differences between our data and comparable data collected on Kiawah Island during 2000 (i.e., home range size, reproduction, survival; Griffin 2001). Although there was evidence of behavioral modifications to avoid interaction with humans, these results suggest bobcats on Kiawah Island have adapted relatively well to development activities to date and are taking advantage of food resources in developed areas. This is likely due to the relatively “low-impact” development strategy employed on Kiawah Island (e.g., maintenance of buffers around homes and along aquatic features and dunes) and the existence of numerous undeveloped areas throughout the island for feeding, daytime cover, and den sites.

We also modified an existing bobcat habitat suitability index (HSI; Boyle and Fendley 1987) to incorporate habitat variables that may be more important to bobcats in suburban settings than in undeveloped landscapes (i.e., concealment cover and denning habitat). We found that the components of this modified habitat suitability index (MHSI) performed well in describing used habitats as suitable habitats and in identifying areas of higher cotton rat (*Sigmodon hispidus*) abundance as areas of high food suitability. Based on this index, areas of highest habitat suitability were not usually found in platted building lots, elucidating the importance of larger undeveloped patches of habitat. We also divided the island into 20 sections and estimated bobcat habitat suitability at the home range-level (MHSI_{hr}) to focus habitat preservation efforts island-wide. As expected, sections including large tracts of suitable habitat had the highest average suitability and more fragmented sections with little shrub habitat were considered less-suitable. We then showed how MHSI_{hr} could be used to prioritize habitat preservation efforts on specific sections of the island and MHSI could be used to prioritize available lots within selected sections.

This analysis reaffirmed the importance of shrub habitats and larger undeveloped patches to bobcat on Kiawah Island. Although it is impossible to predict how bobcats may adapt to future development activities, our data suggest future development that alters shrub habitats or the large undeveloped areas important to reproduction may have profound effects on the ecology and viability of the bobcat population and in turn the predator-prey dynamic between bobcats and deer. MHSI and $MHSI_{hr}$ are easily calculated with a windows-based computer program we developed and geographic information system (GIS) software, thereby allowing the Kiawah Island Natural Habitat Conservancy (KINHC) to regularly reassess their habitat preservation efforts as development continues. We believe the prioritization strategy we outline will facilitate the preservation of important bobcat habitats, and if preservation efforts are successful, the maintenance of the important bobcat-deer relationship described above.

In the final chapter, we describe how KINHC has used the bobcat as an icon to educate residents about the importance of wildlife and wildlife habitat and to raise funds for habitat preservation and future wildlife research on Kiawah Island. This program has been very successful so far, but we believe our research results and the habitat preservation strategy we describe will only increase its success. The viability of Kiawah Island's bobcat population and associated natural control of the island's deer herd may ultimately depend on the success of this habitat preservation effort.

Recommendations

Because of the considerable influence bobcat predation has on deer recruitment and the apparent variability in prey selection between individual bobcats, abundance should be kept as high as possible to increase the likelihood that some individuals will prey heavily on deer fawns (like #795 during 2004). Additionally, habitat preservation funds generated by Kiawah's wildlife icon appear crucial to the protection of habitat for a variety of wildlife species on the island. Therefore, the following recommendations focus on the preservation and improvement of bobcat habitat on Kiawah Island.

Habitat Preservation

Our den site monitoring suggests large (>2 ha) undeveloped patches of shrub or maritime forest habitat are important to bobcat reproduction on the island. The loss of suitable den sites due to future development, especially in the western portion of the island, is likely the most immediate threat to Kiawah's bobcat population. Areas with an average MHSI >0.5 in sections 1, 2, 5, 6, and 7 should receive highest priority as they likely represent the last available denning habitat in the western portion of the island. Additionally, extensive habitat fragmentation in sections 1, 14, and 19 could have wide-ranging negative effects on bobcat reproduction and overall habitat suitability. The preservation of large tracts of land in these areas would be very beneficial to the population as a whole. Secondary preservation efforts should be focused in the western sections of Kiawah Island (sections 1−9) in an attempt to retain interspersed patches of habitat for feeding and concealment (using MHSI to prioritize), particularly in sections with the lowest mean MHSI_{hr} (sections 3 and 8). Bobcat habitat suitability and associated preservation priorities should be reassessed periodically to account for the effects of continuing development (i.e., development of a lot impacts the habitat suitability of surrounding areas) and potentially changing development patterns (i.e., development of "new" neighborhood).

Habitat Improvements

Although some properties that have already been preserved may not provide optimal habitat conditions for bobcats and properties acquired through donation cannot be selected based on habitat quality, there are improvements that can be made. Due to prior land use practices, some forested areas on Kiawah Island have a relatively dense canopy of slash pine (*Pinus elliottii*) that prevents the growth of many shade-intolerant understory plant species. The creation of canopy openings, either through selective harvest or herbicide treatments (i.e., single-tree removal or removal of a small group of trees), would allow for sunlight penetration and understory regeneration. Increased understory growth would provide additional food for prey species, creating new hunting areas for bobcats. Shrubby areas in forest openings would also serve as daytime cover for bobcats and potentially den sites. Additionally, the resulting downed trees or standing snags would provide habitat for a variety of birds, small mammals, and herpetofauna.

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APPENDIX I

REPRODUCTIVE HISTORIES OF FEMALE WHITE-TAILED DEER MONITORED ON KIAWAH ISLAND, SOUTH CAROLINA, 2002−2005

Vaginal implant transmitter (VIT) monitoring of 54 does collared on Kiawah Island, South Carolina, USA during 2002−2005. The number of fawns captured (day/month) is listed, or the fate of the pregnancy/VIT monitoring is symbolized (▲ = doe was not recaptured, **X** = doe dead, □ = VIT expelled prematurely, ○ = no fawns located during search, ▼ = VIT signal lost, ● = not pregnant [doe was recaptured in late August to remove VIT before the breeding season], ■ = aborted/mummified fetus found, ─ = doe not collared), for each doe in each year.

Doe ID No.	2002	2003	2004	2005
B1	□	1 (6/13)	▲	▲
B3	▼	2 (6/2)	X	X
B4	○	1 (5/6)	2 (5/10)	▲
B5	○	1 (5/7)	1 (5/10)	2 (5/26)
B6	1 (5/8)	○	○	□
B7	1 (5/18)	X	X	X
B8	●	2 (6/13)	▲	▲
B10	2 (5/6)	2 (5/8)	2 (5/1)	X
B11	2 (5/25)	2 (5/20)	2 (5/28)	2 (5/26)
B13	●	1 (5/1)	●	▲
B14	2 (5/14)	▲	▲	■
B15	1 (5/17)	1 (4/28)	X	X
B16	2 (5/26)	1 (6/7)	1 (5/27)	2 (5/23)
B17	2 (6/4)	1 (7/3)	2 (6/27)	1 (6/12)
B18	■	2 (5/13)	X	X
B19	─	1 (5/22)	○	●
B20	─	1 (4/27)	●	▲
B21	─	─	1 (6/16)	1 (6/12)
B22	─	─	2 (4/24)	1 (4/23)
B23	─	─	1 (4/18)	X
B24	─	─	1 (5/24)	2 (5/8)
Y1	□	□	□	1 (6/26)
Y3	○	2 (5/2)	2 (5/21)	2 (5/16)
Y5	2 (5/8)	●	2 (5/13)	2 (5/7)
Y6	1 (5/10)	X	X	X

Y7	1 (5/17)	1 (5/5)	1 (5/13)	○
Y8	■	2 (4/25)	▲	▲
Y9	1 (5/1)	2 (5/31)	X	X
Y10	1 (4/23)	2 (4/16)	2 (5/5)	▲
Y11	○	X	X	X
Y12	2 (5/6)	1 (5/4)	1 (5/14)	2 (4/25)
Y14	●	●	1 (6/11)	X
Y15	2 (4/19)	2 (4/8)	X	X
Y16	2 (5/6)	1 (4/28)	●	X
Y17	■	○	X	X
Y18	2 (5/25)	X	X	X
Y19	–	2 (5/17)	1 (5/14)	2 (4/28)
Y20	–	2 (5/29)	1 (5/29)	2 (6/10)
Y22	–	2 (5/19)	X	X
Y23	–	–	1 (6/21)	■
Y24	–	–	1 (6/5)	●
Y25	–	–	2 (5/22)	2 (6/5)
Y37	–	–	–	2 (6/5)
Y50	–	–	–	2 (5/23)
G26	–	–	□	▲
G27	–	–	1 (5/29)	1 (6/7)
G28	–	–	○	1 (5/25)
G30	–	–	–	2 (4/11)
G33	–	–	–	1 (5/29)
G36	–	–	–	○
G40	–	–	–	●
G44	–	–	–	2 (5/19)
G45	–	–	–	2 (5/15)
G50	–	–	–	1 (4/27)

APPENDIX II

DESCRIPTIVE AND MORPHOLOGIC DATA FOR BOBCATS MONITORED ON KIAWAH ISLAND, SOUTH CAROLINA, 2004−2005

Area[a]	Bobcat ID	Sex	Age Class	Mass (kg)[b]	Total Length (cm)[c]	Heel Length (cm)	Tail Length (cm)
WE	460	Male	Adult	9.1	88	16.5	14
	795	Male	Adult	9.0	82	16	14
	445	Male	Adult	11.8	87	16	14
	584	Male	Juvenile	6.8	79	16	15
	691	Male	Juvenile	6.1	75	16	14.5
	954	Male	Juvenile	5.2	74	14.5	13
	421	Female	Adult	8.0	85	15.5	14
	492	Female	Adult	7.3	83	15.5	13
	754	Female	Adult	7.3	79.5	16	12.5
	613	Female	Juvenile	6.3	77	15	13.5
EE	874	Male	Adult	8.7	85.5	16.5	13
	974	Male	Adult	~10.5	89	16.5	13.5
	733	Female	Adult	8.3	86	16	13.5
	401	Female	Adult	~9.0	86	15.5	13
	674	Female	Juvenile	5.9	77	15	13
	544	Female	Juvenile	6.7	82	15	14

[a] WE = more-developed western end of island, EE = less-developed eastern end of island.

[b] Approximations (i.e., ~ kg) were researcher estimates due to an equipment malfunction that prevented actual measurements.

[c] Total length measurement from forehead to tip of tail.

APPENDIX III

DATA COLLECTED FROM BOBCAT DENS LOCATED ON KIAWAH ISLAND, SOUTH CAROLINA, 2004−2005

Area[a]	Female ID#	Date Located	Kittens[b]	Habitat Type[c]	Structure
WE	754	4/20/04	1 M	Forest	thick patch of understory vegetation
	421	4/21/04	1 M, 2 F	Shrub	open shrub patch
	492	4/20/05	2 F	Shrub	thick shrub patch
	754	4/20/05	2 M	Shrub	thick shrub patch
EE	544	5/10/05	1 Unk.	Forest	hollow stump
	674	6/26/05	2 F	Shrub	under downed tree

[a] WE = more-developed western end of island, EE = less-developed eastern end of island.

[b] M = male, F = female, Unk. = unknown sex (unable to physically examine kitten due to den structure).

[c] Habitat types delineated for habitat use and habitat suitability analyses (Chapters 2 and 3).

APPENDIX IV

JUVENILE DISPERSAL AND EXTRATERRITORIAL MOVEMENTS OF BOBCATS ON KIAWAH ISLAND, SOUTH CAROLINA, 2004−2005

All 3 juvenile males (#584, #954, #691) dispersed during monitoring, 2 of which moved throughout neighboring Seabrook Island before returning to Kiawah Island. Bobcat #584 was captured near the western tip of the island where his movements were focused until July, after which he moved through portions of Seabrook and then east-central Kiawah Island (Figure IV-1a). Shift in central tendency (i.e., distance between mean X-Y coordinates) between locations collected before 1 July and those collected after 23 September was 8.44 km. Bobcat #954 was captured in east-central Kiawah Island where his movements were focused through the majority of October, after which his movements throughout Seabrook Island and western Kiawah Island showed no discernable pattern (Figure IV-1b). Shift in central tendency between locations collected before and after 25 October was 7.44 km. We documented dispersal movements of bobcat #691 after the death of an adjacent adult male (#795; see Chapter 3). We only located bobcat #691 within bobcat #795's 95% fixed kernel (FK) home range on 2 occasions prior to his death on 13 December (Figure IV-2). After 13 December, bobcat #691 was frequently found within the vacated range, resulting in a 2.11 km westward shift in central tendency. For comparison, the largest seasonal shift in central tendency that we documented for a resident bobcat was a 1.05 km shift between the spring and summer seasons by a female bobcat that denned near the periphery of her 95% FK home range and subsequently concentrated her spring movements around the den site.

Dispersing juveniles did not establish home ranges within the territories of residents during the study, although juvenile males appeared to be tolerated within the home range of resident adult males (possibly their natal ranges) prior to dispersal. Movement behaviors of the 2 juvenile males that dispersed off of Kiawah Island and subsequently returned suggest Kiawah Island is in some way preferred over surrounding habitats. The fairly immediate dispersal and exploratory movements into the vacated home range of deceased adult male #795 suggests dispersing juveniles and adjacent adult males were aware of the vacancy through deterioration of scent markings and were potentially aware of the resources available in the vacated home range (Lovallo and Anderson 1995, Benson et al. 2004).

One adult male took an extraterritorial foray (Knick 1990) in February of 2005 (Figure IV-3). On 15 February 2005, adult male #460 was approximately 7.5 km outside of his 95% FK home range, and was approximately 175 m from adult female #733. On 18 February 2005, #460 was approximately 2.5 km outside his home range with adult female #492 (could not differentiate between their locations, so assumed together). Bobcat #460 was not located outside of his home range before or after this foray and no other bobcats exhibited distinct extraterritorial movements during monitoring. Although only 2 monitored females overlapped the home range of #460 during our study, his proximity to adult females during this foray suggests he may have used this excursion to encounter additional females, potentially increasing his breeding opportunities beyond the confines of his territory. In Idaho, Knick (1990) documented bobcats making extraterritorial forays to specific areas of increased prey availability 4−40 km outside of their home ranges. It seems reasonable to assume that a resident bobcat may venture outside of its home range to acquire additional life requisites, besides food, that are not adequately fulfilled within it (i.e., reproductive opportunities). Although we cannot confirm that #460 bred adult female #492, we located 2 very young kittens (a few days old based on sparse fur growth, little mobility, and closed eyes [Anderson and Lovallo 2003]) at #492's den 61 days after the encounter. Based on their review of the literature, McCord and Cardoza (1982) reported bobcat gestation ranges from 50−70 days, with a mean around 62 days. Bobcat #460 was not located on either of the 2 days prior to the documented encounter and may have been near #492 during this time period.

Literature Cited

Anderson, E. M., and M. J. Lovallo. 2003. Bobcat and lynx. Pages 758−786 *in* G. A. Feldhammer, B. C. Thompson, and J. A. Chapman, eds. Wild Mammals of North America. Johns Hopkins University Press, Baltimore, MD, USA.

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Lovallo, M. J., and E. M. Anderson. 1995. Range shift by a female bobcat (Lynx rufus) after removal of neighboring female. American Midland Naturalist 134:409−412.

McCord, C. M., and J. E. Cardoza. 1982. Bobcat and lynx. Pages 728−766 *in* J. A. Chapman and G. A. Feldhamer, eds. Wild mammals of North America. Johns Hopkins University Press, Baltimore, Maryland, USA.

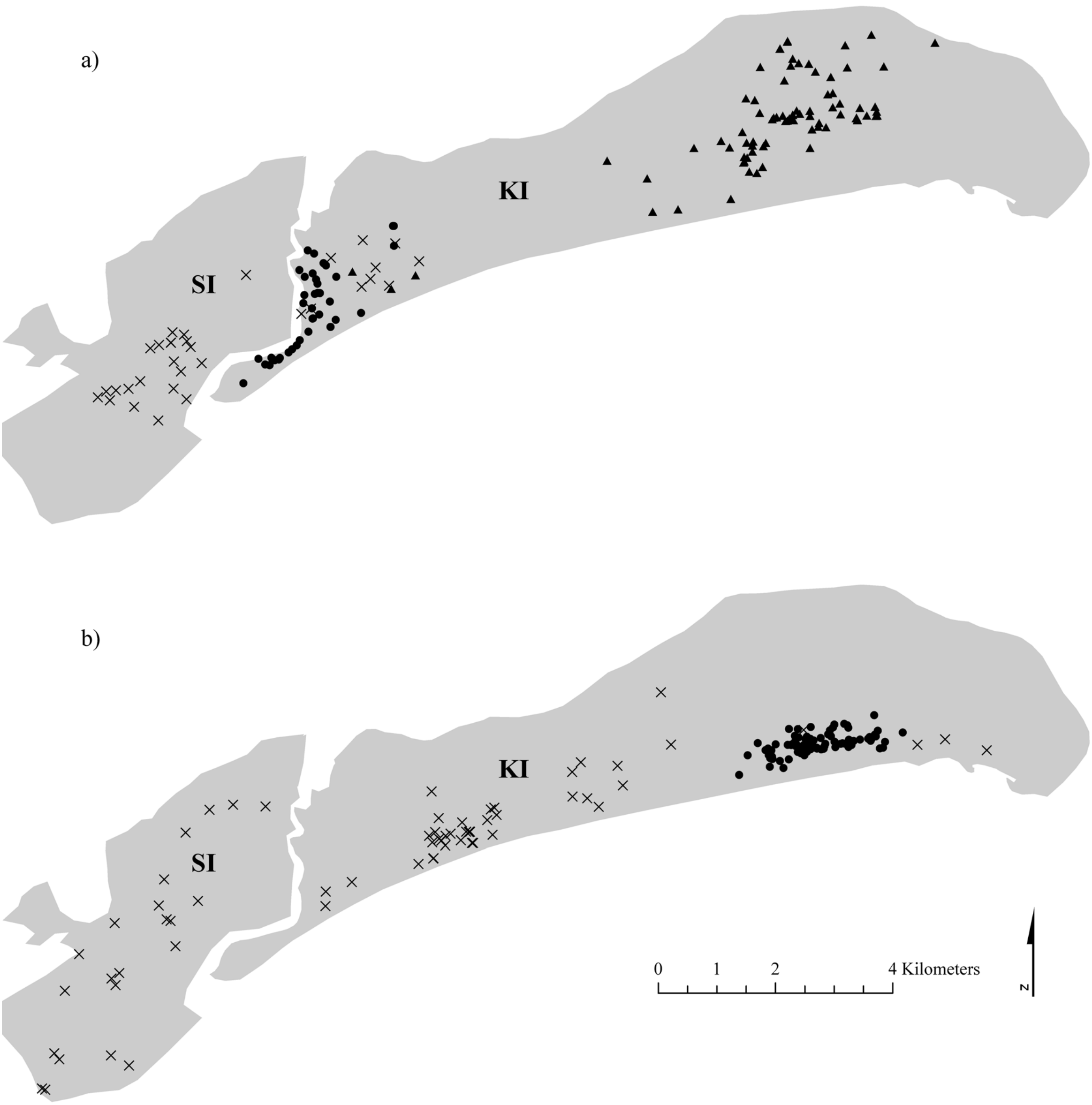

Figure IV-1. Dispersal movements of a) juvenile male bobcat #584 before 1 July 2004 (●), between 1 July 2004 and 23 September 2004 (x), and after 23 September 2004 (▲) and b) juvenile male bobcat #954 before (●) and after (x) 25 October 2004 on Kiawah Island (KI) and Seabrook Island (SI), South Carolina, USA.

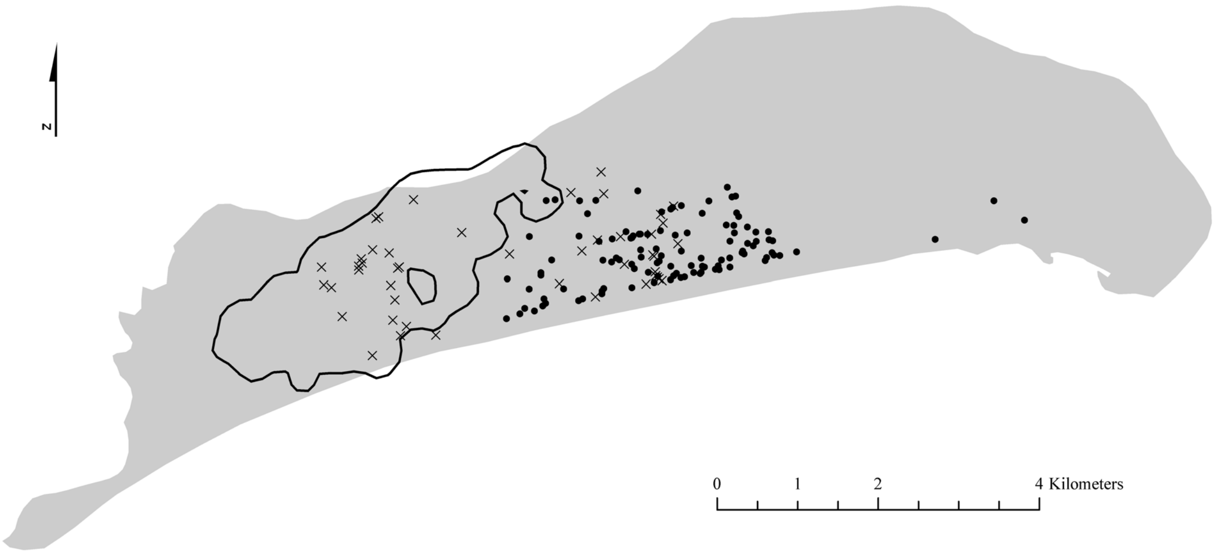

Figure IV-2. Juvenile male bobcat #694 movements before (●) and after (x) the death of adult male bobcat #795 (black outline; 95% FK home range) on Kiawah Island, South Carolina, USA, April 2004−March 2005.

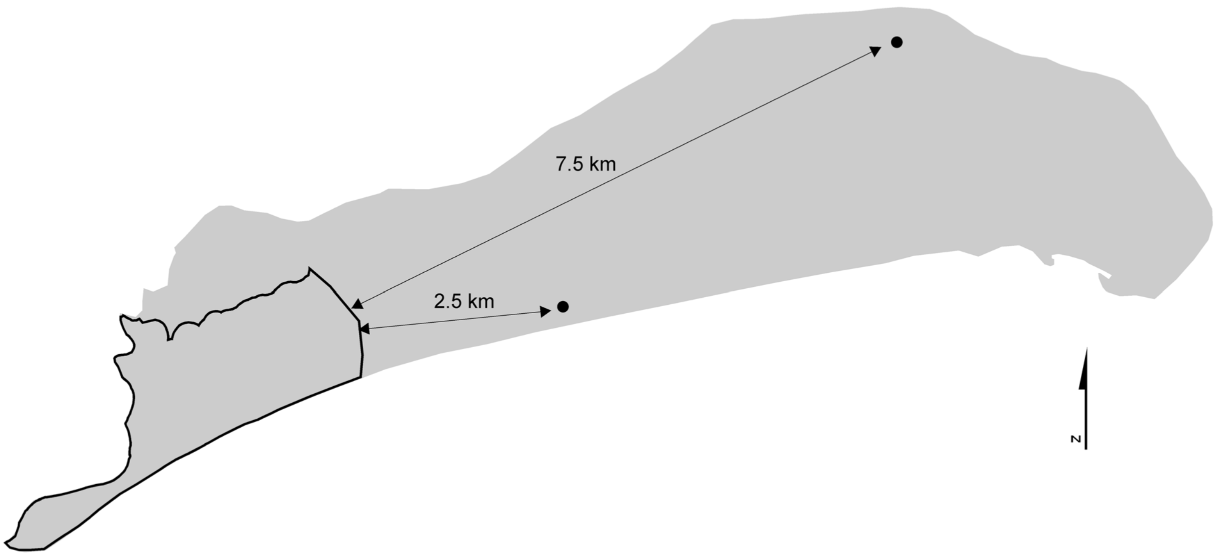

Figure IV-3. Distances between 2 locations collected during a winter season (locations collected on 15 and 18 February 2005) extraterritorial foray by adult male bobcat #460 and his modified 95% FK home range boundary (black outline), on Kiawah Island, South Carolina, USA.