Demographics, diet, movements, and survival of an isolated, unmanaged raccoon *Procyon lotor* (Procyonidae, Carnivora) population on the Outer Banks of North Carolina

**Abstract:** Raccoons (*Procyon lotor*) are highly adaptable meso-carnivores that inhabit many environments, including the Atlantic barrier islands, where their role as predators of declining, beach-nesting bird and turtle species is of particular interest. Population models that improve our understanding of predator-prey dynamics are receiving increasing attention in the literature; however, their effective application requires site-specific information on population parameters. We studied an unharvested raccoon population on the Outer Banks of North Carolina and evaluated spatial and seasonal differences in a number of population/demographic factors of raccoons inhabiting areas of high and low human activity. Raccoons denned and foraged primarily in salt marsh habitats but shifted their movements in response to changes in seasonal resource conditions. The population was skewed toward older animals and exhibited delayed breeding, typical of populations at high density with few sources of mortality. Diet and movement analysis indicated shorebird and turtle predation was attributed to a small number of individual raccoons. Although seasonal resources appeared adequate to sustain a high population density of raccoons, poor body condition and low recruitment suggested a population near carrying capacity.

**Keywords:** barrier island; ecology; meso-carnivore; *Procyon lotor*; raccoon.

**Introduction**

The raccoon *Procyon lotor* (Linnaeus 1758) has a broad distribution that spans North and Central America, owing in large part to their ability to adapt to a variety of resources and environmental conditions (Gehrt 2003). Historically important primarily as a furbearer, research on this omnivore has shifted in recent years to include their interactions with humans, their potential as vectors of zoonotic diseases, and their predatory effect on rare and endangered wildlife. Raccoons now inhabit a number of environments, such as coastal islands, where their role as predators can be amplified (Hartman et al. 1997, Ellis et al. 2007). Raccoons in the Atlantic coastal zone have been linked with low productivity of American oystercatchers (Davis et al. 2001, Martin et al. 2010), sea turtles (Stancyk et al. 1980, Ratnaswamy and Warren 1998, Engeman et al. 2006), black skimmers, and least terns (Erwin et al. 2001). Raccoon populations along the Atlantic seaboard can reach high densities owing to human activities that provide shelter and food, and the absence of large predators (Ratnaswamy et al. 1997, Smith and Engeman 2002, Barton and Roth 2007). However, even at low densities, raccoons can be devastating predators of ground-nesting species, especially in insular environments where prey populations are particularly vulnerable (Courchamp et al. 2003).

Although raccoons have been well researched across much of the eastern United States (Gehrt 2003), comprehensive ecological studies of raccoons on Atlantic coastal islands are limited to a few locations: St. Catherine’s Island, GA (Hudson 1978, Harman and Stains 1979, Lotze 1979, Anderson 1981), 10,000 Islands, FL (Bigler et al. 1981), and Merritt Island, FL (Barton and Roth 2007). In many coastal sites, raccoons inhabit protected areas such as national parks and wildlife refuges where mortality from hunting, trapping, or other anthropogenic influences (e.g., vehicles) is limited. Under these...
circumstances, mammalian predator populations can differ strikingly in demographics (Weston and Brisbin 2003) and survival (Gehrt and Fritzell 1999) from populations that are subject to hunting or sustained predator management programs. Recent efforts to model the population dynamics of raccoons (Martin et al. 2010) and other meso-predators (Roth et al. 2008) have shown that site-specific information on population/demographic parameters such as survivorship, age structure, sex ratios, diet, and movements are often necessary for building models that can improve our knowledge of predator-prey dynamics.

In this article, we evaluated the status of a raccoon population on South Core Banks, one of the few remaining undeveloped barrier islands along the Atlantic coast. The population has been largely unmanaged for several decades (i.e., no measurable harvest); however, seasonally intense human recreation (e.g., fishing camps, visitor contact stations) provides concentrated resources that are scattered along the island (<10% of the island’s area). We compared spatial and seasonal differences in the ecology of raccoons inhabiting areas of high and low human activity by contrasting their movements, seasonal activity patterns, demographics, diet, and survival. Our objective was to collect meaningful ecological information that could be used to improve our understanding of the dynamics between raccoons and their prey, information that is essential to increasing the efficacy of bird and turtle conservation on barrier islands.

Materials and methods

Study area

Our study took place within Cape Lookout National Seashore, a unit of the U.S. National Park Service located on the Outer Banks of North Carolina. All work occurred on South Core Banks, the southernmost island within the seashore (Figure 1). South Core Banks is 28.59 km² with vegetation and topography typical of the Atlantic barrier islands (Oosting 1954). The topographic profile of South Core Banks can be divided roughly into four communities that include wide, bare beaches and low (<3 m) sand dunes covered by grasslands, dense shrub-like vegetation, maritime forest, and large expanses of salt marsh (Godfrey and Godfrey 1976, Stalter and Lamont 1999). Core Sound separates the island from the mainland, and the only human access to South Core Banks is via boat or plane.

Animal captures

We captured 131 raccoons between May 2007 and June 2008 by using box traps (Tomahawk; Tomahawk Live Trap Company, Tomahawk, MI, USA) and Havahart (Havahart Woodstream Corp., Lititz, PA, USA). Traps were set both along the edge of the marsh and behind the dunes in an attempt to capture both marsh- and beach-foraging raccoons. We transported unmarked animals to a field station where they were anesthetized with an IM injection of 10 mg/kg Telazol (100 mg/ml) (Elkins-Sinn Incorporated, Cherry Hill, NJ, USA). We weighed and measured all animals and extracted a premolar tooth for cementum analysis (Matson’s Laboratory, Milltown, MT, USA) to estimate animal age (Johnson 1970). We fitted a subset of 60 animals with radiocollars equipped with mortality sensors [Advanced Telemetry Systems (ATS) Inc., Asanti, MN, USA]. Following recovery from anesthesia, we released all animals at the point of capture. We captured and euthanized 149 raccoons between August 2008 and April 2009, as part of an experiment to determine if raccoon management would increase the productivity of beach-nesting sea turtles and birds (Stocking et al. unpublished data). We
used forelimb-holding traps [EGG (The EGG Trap Company, Butte, ND, USA), Lil' Grizz (Quadad Performance Products Co., Bonnotts Mill, MO, USA), and Duffer (Duffer’s, Bern, KS, USA)], and box traps to capture raccoons in the removal experiment. After inducing anesthesia with 100 mg/ml Telazol IM (American Veterinary Medical Association 2007), we euthanized animals using an IV injection of Beuthanasia solution (pentobarbital sodium and phenytoin sodium) (Schering-Plough Animal Health Corp., Omaha, NE, USA). All fieldwork was conducted under protocol #07-0120-0 of the Institutional Animal Care and Use Committee at North Carolina State University (NCSU). Euthanized animals were frozen and necropsied at a later date. We used a two-sample removal model to estimate population density (Seber 1982). All data presented in this article were obtained before or concurrent with the removal effort.

**Home range length and activity patterns**

We collected location and movement data from radio-collared animals using a portable receiver (ATS Inc.) and a three-element hand-held Yagi antenna. We calculated movement asymptote curves between May and June 2007 to determine the number of locations (n=30) deemed necessary for calculating representative movement distances. We recorded locations on each animal during each of two seasons [fall/winter 2007: September 2007 through February 2008 (182 days) and spring/summer 2008: March through July 2008 (153 days)]. Locations were equally divided among four time periods: 0:00–6:00, 6:00–12:00, 12:00–18:00, and 18:00–00:00. To ensure independence between successive locations, recording sessions were a minimum of 8 h apart.

We tracked animals in upland habitats to determine their home range length and use of shorebird nesting areas and centers of human activity. The Atlantic barrier islands are generally long and narrow (Figure 1) and South Core Banks is no exception, averaging 0.5 km in width (range, 0.26–2.35 km). Locating animals by triangulation in such a linear environment would have produced unacceptably high polygon error or lack of precision in the confidence ellipse (Saltz and White 1990, Saltz 1994), resulting in home ranges incorporating expanses of either the Atlantic Ocean or the bayside waters of Core Sound. Therefore, we estimated linear home range size, a metric used with mammals associated with linear landscape features (Blundell et al. 2001, Melero et al. 2008, Ahlers et al. 2010).

We traversed the island using an access road bisecting the length of the island, recorded telemetry locations with a geographic positioning system when the signal vector was perpendicular to the nearshore beach or Core Sound. We fitted a probability density function to each home range and eliminated the points within the upper and lower 5% to calculate a 90% linear home range. We used signal strength, directionality, and visual identification of animals on the beach to determine whether an animal was on the ocean or the bayside of the road. Because of South Core Bank’s narrow width and flat topography, there was little opportunity for signal reflection or absorption (White and Garrott 1990). Linear home range size and frequency of beach use were compared between seasons and sexes using a t-test. We plotted individual linear home ranges in ArcMap and measured the percentage linear home range shift northeast or southwest along South Core Banks for each animal between the fall/winter and spring/summer seasons. We defined a home range shift as a displacement of the home range laterally along the island. Home range shifts were compared between sexes and locations relative to human activity using a t-test.

**Sexual maturity, litter size, and breeding season**

We removed reproductive tracts from each necropsied animal and weighed the baculum and testes. We determined male sexual maturity using baculum length and weight (Sanderson 1961, Johnson 1970) and classified males with a baculum weight of >2.5 g and length >90 mm as sexually mature (Kramer et al. 1999). We used testes weight to estimate the onset of the breeding season (Fritzell 1978). We removed the uterus from all females and examined them for evidence of uterine scars. Females were considered sexually mature if the uterus contained fetuses or if uterine scars were present (Johnson 1970). We assumed that the darkest set of uterine scars represented the most recently implanted placentii (Sanderson 1987) and used the number of fetuses present to calculate mean litter size. We estimated fetus age following Llewellyn (1953) and used the calculated fetal age to estimate the time of breeding. The respective data for each sex was combined with age data from the tooth analysis to establish the age of sexual maturity.

**Age distribution and survival**

We calculated the age distribution using an extracted tooth from all captured individuals (see the “Animal captures” section). We calculated survival using a staggered entry Kaplan-Meier design (Pollock et al. 1989) with data from
radiocollared animals of known fates. Animals that died within 2 weeks of collaring (n=3) were eliminated from the analysis to control for possible handling effects (Pollock et al. 1989). When the exact date of death was unknown, the midpoint between the last known date alive and the date of recovery was used. We analyzed annual survival for both sexes combined and separated. We compared annual survival for animals within human-dominated areas and those >1.61 km away from human-dominated areas using a t-test. We pooled data for all age classes due to the small number of yearlings and juveniles captured.

**Diet and physical condition**

We removed gastrointestinal tracts from each necropsied animal to examine variation in stomach contents by capture location and season. We weighed individual food items and identified each item to the lowest classification level possible. We estimated both the percentage of the total stomach weight and the frequency of occurrence for each diet item (Klare et al. 2011). We calculated the diet diversity using the Shannon-Weiner diversity index (Shannon 1948). We used weights and measurements collected from both live-trapped and euthanized animals to calculate body condition on the basis of the index described by Prange et al. (2003): CI=[body mass (kg)/body length (cm)]×100. We used a t-test to calculate body condition differences between the sexes and an ANOVA to calculate differences between animals within and outside of human-dominated areas.

**Results**

**Linear home range and activity patterns**

We constructed seasonal linear home range estimates for individual raccoons (26 fall/winter, 18 spring/summer). The average linear home range size over both seasons was 1.39 km (n=44, SE=1.3 km). Males (mean=1.63 km, n=27, SE=0.17 km) had significantly longer home ranges than females (mean=1.02 km, n=17, SE=0.18 km) when both seasons were combined (t=2.505, df=39.76, p=0.0165, α=0.05). Females had significantly shorter home ranges in spring/summer (mean=0.68 km, n=7, SE=0.2 km) than in fall/winter (mean=1.26 km, n=10, SE=0.24 km) (t=1.84, df=14.74, p=0.0426, α=0.05). We found no differences in linear home range size between animals captured within the human-dominated areas of the island (n=9, mean=1.22 km, SE=0.23 km) and those captured in areas located >1.61 km (∼1 mile) away from human influence (n=11, mean=1.36 km, SE=0.17 km) (t=0.478, df=25.35, p=0.3185, α=0.05).

The average home range shift from fall/winter to spring/summer was 33.21 % (n=16, SE=5.84%). Females (mean=47.73%, n=7, SE=8.56%) shifted a significantly larger portion of their home range than males (mean=21.92%, n=9, SE=5.87%) (t=2.49, df=11, p=0.015, α=0.05) when both seasons were combined. There was no significant difference in the amount of home range shift within (mean=30.22%, n=6, SE=7.53%) and outside (mean=33.62%, n=6, SE=14.19%) of human recreation areas (t=0.211, df=76, p=0.419, α=0.05).

Most individuals (83.5%, n=24) were located at least once on the beach, although the average amount of beach use per individual was small (mean=5.9% of all locations, n=24, SE=1.0%). Several (n=3) individuals showed a significantly higher percentage of beach use (10–20% of locations, SE=1.5%) than the rest of the general population (t=6.067, df=5.26, p=0.0015, α=0.05). Use of beach habitats was significantly higher in spring/summer (n=31, mean=9.0% of locations, SE=1.5%) than in fall/winter (n=31, mean=3.8% of locations, SE=1.0%) for both sexes combined (t=2.98, df=51.7, p=0.0022, α=0.05). Males (n=14, mean=7.6% of locations, SE=1.4%) foraged significantly more often on the beach than females (n=10, 3.5% of locations, SE=1.2%) when data from all seasons were combined (t=2.237, df=21.85, p=0.0179, α=0.05). No significant differences were found between males and females within individual seasons.

**Sexual maturity, litter size, and breeding season**

Eighty-five percent (n=72) of males and 73% (n=27) of females captured were sexually mature. The percentage of sexually mature animals increased annually up to age 4 years. No females <2 years old were sexually mature (n=6). Placental scarring indicated that sexually mature females did not breed every year. The average litter size was 2.67 (n=9, SE=0.17). Fetus ages and testes weights indicated that the breeding season begins in mid-February, with births increasing through March and April (animals were not collected between May and January).

**Diet and physical condition**

Twenty-five percent (n=32) of the 128 stomachs examined were empty. Of the remaining 96 animals with stomach contents, 68.7% (SE=4.6%) of the total weight
of those stomach contents were indigestible items (i.e., grass, sand, wood, shells). Animals captured within human-dominated areas had significantly more indigestible items in their stomachs ($n=48$, mean=75% stomach content weight, SE=5.5%) than animals captured outside of human-dominated areas ($n=5$, mean=17% stomach content weight, SE=17%) ($t=-3.219$, df=87, $p=0.0009$, $\alpha=0.05$).

The seasonal variation in diet was apparent. Fruits were the most common food item by weight and frequency in fall/winter; however, these were replaced by crustaceans in spring/summer (Figure 2). The majority of identifiable species found in stomachs were endemic to the marsh, not the beach (Table 1). Although birds did not represent a high percentage of the overall weight of food items consumed, bird feathers occurred in 8.3% ($n=8$) of stomachs over all seasons and doubled in fall/winter (16.7%, $n=6$). The frequency of bird remains in the stomachs increased with distance away from human activity (0 km: 2.1%, $n=1$; 1.61 km away: 13%, $n=3$; 3.21 km away: 20%, $n=2$; 4.81 km away: 40%, $n=2$). The most common bird species within all the feathers sampled was the clapper rail ($Rallus longirostris$, Boddart 1783), a species endemic to salt marshes. Other birds identified in raccoon stomachs included the common loon ($Gavia immer$, Brünnich 1764), sanderling ($Calidris alba$, Pallas 1764), and bufflehead ($Bucephala albeola$, Linnaeus 1758). We found no evidence of turtles or turtle eggs in the stomachs sampled.

Overall, our data show that raccoon diets are significantly less diverse in areas of high human activity ($H=1.717$, SE=0.016, $n=69$) than in areas away from human activity ($H=2.338$, SE=0.02, $n=51$) ($t=-23.9$, df=32, $p<0.0001$).

The average weight for males was 4.05 kg ($n=193$, SE=0.088 kg) over the study period, which was significantly higher than the average weight for females (mean=3.18 kg, $n=72$, SE=0.079 kg) ($t=7.331$, df=196, $p<0.001$, $\alpha=0.05$). The average condition index values were significantly higher for males (5.4, $n=193$, SE=0.12) was also significantly higher than females (4.3, $n=72$, SE=0.1) ($t=6.8$, df=196, $p<0.001$, $\alpha=0.05$). The condition index values were significantly higher in the fall/winter period (mean=5.77, $n=2$, SE=0.29) than in the spring/summer period (mean=4.66, $n=6$, SE=0.17) ($t=3.32$, df=6, $p=0.0152$) (Figure 3). Males were in significantly better condition in human-dominated areas (mean=5.84, SE=0.18) than areas of 4.81 km or more away (mean=4.8, SE=0.32) ($F=3.9098$, df=192, $p=0.0171$, $\alpha=0.05$), with no such significance for females (within human-dominated areas: mean=4.43, SE=0.14; 4.81 km or more away: $n=11$, mean=3.93, SE=0.38 ($F=0.7716$, df=71, $p=0.5475$, $\alpha=0.05$).

![Figure 2](Image)

**Figure 2** Principal foods of raccoons at Cape Lookout National Seashore during three seasons. Values are given as percentage total stomach weight and frequency of occurrence from stomach content analysis.

<table>
<thead>
<tr>
<th>Food item</th>
<th>Weight (%)</th>
<th>SE (%)</th>
<th>Frequency (%)</th>
<th>n</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Crustacean</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Emerita talpoida</em>, Say 1817</td>
<td>78.40</td>
<td>20.80</td>
<td>3.10</td>
<td>3</td>
<td>Beach</td>
</tr>
<tr>
<td><em>Callinectes sapidus</em>, Rathbun 1896</td>
<td>40</td>
<td>30.1</td>
<td>3.10</td>
<td>3</td>
<td>Marsh</td>
</tr>
<tr>
<td><em>Uca pugilator</em>, Bosc 1802</td>
<td>33</td>
<td>22</td>
<td>4.20</td>
<td>4</td>
<td>Marsh</td>
</tr>
<tr>
<td><strong>Fruit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ilex vomitoria</em>, Alton 1789</td>
<td>46.90</td>
<td>14</td>
<td>8.30</td>
<td>8</td>
<td>Marsh</td>
</tr>
<tr>
<td><em>Opuntia drumondii</em>, Haworth 1812</td>
<td>42.90</td>
<td>28.70</td>
<td>2.10</td>
<td>2</td>
<td>Marsh</td>
</tr>
<tr>
<td><em>Juniperus virginiana</em>, Linnaeus 1758</td>
<td>28.60</td>
<td>6.80</td>
<td>2.10</td>
<td>2</td>
<td>Marsh</td>
</tr>
<tr>
<td><strong>Insect</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Chrysops sp.</em>, Meigen 1803</td>
<td>56</td>
<td>18.50</td>
<td>5.20</td>
<td>5</td>
<td>Marsh</td>
</tr>
<tr>
<td><em>Dyscinetus morator</em>, Fabricius 1798</td>
<td>18.70</td>
<td>18</td>
<td>2.10</td>
<td>2</td>
<td>Marsh</td>
</tr>
</tbody>
</table>

Table 1 Most common (highest percentage total stomach weight and frequency of occurrence) identifiable species found in raccoon stomachs from all stomachs sampled ($n=96$).

The location (beach or marsh) where each item was foraged is given.
The annual survival within areas of high human activity (0.90, SE = 0.04, n = 25) was significantly higher than the annual survival for animals captured >1.61 km outside of those areas (n = 21, mean = 0.83, SE = 0.05) (t = 5.25929, df = 45, p < 0.01, α = 0.05). The causes of mortality for most animals could not be determined conclusively (Table 2), although dehydration and/or exposure were suspected where carcasses were found far from potential cover (n = 4). Several cases of parvovirus and poisoning were diagnosed during necropsy (Table 2).

We observed raccoons frequently denning beneath thick mats of black needlerush (Juncus roemerianus, Scheele 1849) (n = 10) and live oak (Quercus virginiana, Miller 1768) thickets (n = 6) that occur along the edge of salt marshes. In areas where human activities were concentrated, a few (n = 3) animals were observed denning under uprooted longleaf pines (Pinus palustris, Miller 1768), and several animals (n = 5) overwintered or raised their young in abandoned buildings.

**Discussion and conclusion**

We found that the ecology and demographics of this barrier island raccoon population reflect seasonal and spatial variations in resource distribution. We found little direct evidence of raccoons depredating nests of birds and turtles, although indirect evidence based on animal home ranges and diet suggests that a small number of individuals may be responsible for much of the predation on these species.

### Density, age distribution, survival, and denning

Our density estimate based on a two-sample removal was 12 individuals/km$^2$ (SE = 6) [N = 353 (SE = 164), area = 28.59 km$^2$]. The majority of animals were between 2 and 4 years old (n = 130), with 19% (n = 44) of the population being 7 years of age or older (Figure 4). The annual survival for all animals was estimated at 0.83 (n = 50, SE = 0.03). Male annual survival was significantly higher (n = 30, mean = 0.87, SE = 0.04) than female annual survival (n = 20, mean = 0.77, SE = 0.09) (t = 4.48345, df = 36, p < 0.01, α = 0.05). The percentage survival for males in the fall/winter period (182 days) was significantly higher (0.95, n = 20, SE = 0.04) than in the spring/summer period (153 days) (0.91, n = 24, SE = 0.04) (t = 2.428, df = 43, p = 0.02). Females also had significantly lower percentage survival in the fall/winter period (0.94, n = 17, SE = 0.068) than in the spring/summer period (0.88, n = 12, SE = 0.087) (t = 4.609, df = 28, p < 0.001). The annual survival within areas of high human activity (0.90, SE = 0.04, n = 25) was significantly higher than the annual survival for animals captured >1.61 km outside of those areas (n = 21, mean = 0.83, SE = 0.05) (t = 5.25929, df = 45, p < 0.01, α = 0.05). The causes of mortality for most animals could not be determined conclusively (Table 2), although dehydration and/or exposure were suspected where carcasses were found far from potential cover (n = 4). Several cases of parvovirus and poisoning were diagnosed during necropsy (Table 2).

**Figure 3** Body condition index values for raccoons captured on South Core Banks, NC, by season (May 2007, n = 38; June 2007, n = 19; July 2007, n = 37; August 2007, n = 9; October 2007, n = 6; May 2008, n = 13; June 2008, n = 6; December 2008, n = 82; April 2009, n = 67).

**Figure 4** Age distribution for raccoons captured on South Core Banks, NC (n = 229).

### Density, linear home range, and activity patterns

Several investigators have argued that high densities of raccoons on islands or in coastal environments correlate with high levels of nest failures in ground-nesting birds and sea turtles (Stancyk et al. 1980, Ratnaswamy and Warren 1998, Davis et al. 2001, Erwin et al. 2001, Engeman 2001). To explore this hypothesis further, we estimated the density of raccoons on South Core Banks, NC, using a two-sample removal method. The density estimate was 12 individuals/km$^2$ (SE = 6) [N = 353 (SE = 164), area = 28.59 km$^2$]. The majority of animals (n = 130) were between 2 and 4 years old, with 19% (n = 44) of the population being 7 years of age or older. The annual survival for all animals was estimated at 0.83 (n = 50, SE = 0.03).

To further investigate the ecology and demographics of the raccoon population on South Core Banks, NC, we estimated linear home range and activity patterns. Our density estimate based on a two-sample removal method was 12 individuals/km$^2$ (SE = 6) [N = 353 (SE = 164), area = 28.59 km$^2$]. The majority of animals (n = 130) were between 2 and 4 years old, with 19% (n = 44) of the population being 7 years of age or older. The annual survival for all animals was estimated at 0.83 (n = 50, SE = 0.03).

### Cause of mortality

<table>
<thead>
<tr>
<th>Cause of mortality</th>
<th>No. of animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parvovirus</td>
<td>3</td>
</tr>
<tr>
<td>Poisoning (agent unknown)</td>
<td>2</td>
</tr>
<tr>
<td>Unknown</td>
<td>7</td>
</tr>
</tbody>
</table>

**Table 2** Sources of mortality for radiocollared animals recovered dead on South Core Banks, NC, from May 2007 through July 2008 (n = 60).
et al. 2006); however, most of this evidence is anecdotal. The density of our barrier island population (12 animals/km², SE=6) was higher than most published studies of island raccoon populations (Hoff et al. 1977; Marco Island, FL; 7.9 animals/km²; Bigler et al. 1981; Big Key, FL; 2.2–6.5 animals/km²; Rosatte et al. 2007; Wolfe Island, Ontario, 2.4–8.4 animals/km²; Ratnaswamy et al. 1997; Canaveral National Seashore, 1.7 animals/km²), yet we saw little evidence of eggs, chicks, or hatchlings in the diets of the raccoons removed. Many raccoons were collected outside (n=35) of the shorebird and turtle nesting season (n=93 collected inside the nesting season), which could have affected our results. Despite little dietary evidence of predation, we found a significant increase in beach use in the spring and summer, which coincided with higher concentrations of potential prey, parturition, cub rearing, and increased human recreational activity. A few individuals (n=3) used the beach more frequently than the average population; however, the use of beach habitats overall was low, and most individuals foraged in the marshes. In some populations, raccoon predation on beach-nesting species has been attributed to a few offending individuals (Ratnaswamy et al. 1997, Ratnaswamy and Warren 1998, Engeman et al. 2003, Barton and Roth 2007), which we believe may be occurring on South Core Banks.

The linear home ranges of many individuals shifted along the island preceding the spring/summer nesting season. Females shifted a larger portion of their range during parturition and cub rearing, indicating that they are responding to changes in resource distribution to meet energy demands. Mammalian predators in other systems have been shown to alter their habitat use and foraging strategies when new food sources become available (Schneider et al. 1971, Koehler and Hornocker 1991). It is evident that raccoons altered their movement patterns on South Core Banks; however, it is unclear to what seasonal resources they were responding.

### Diet and condition

Overall, the condition of barrier island raccoons was poor. Condition index values for this population ranged from 4.28 to 5.98, which is lower than those reported in other studies using the same index (Prange et al. 2003: 8.5–14, Munscher 2004: 5.3–7.0). As expected, raccoons were in their best condition in the late fall and in relatively poor condition in the spring owing to winter food shortages (Mech et al. 1968, Moore and Kennedy 1985, Pitt et al. 2008). Our condition indices track both natural and anthropogenic patterns of food availability (Prange et al. 2004). The animals living in areas dominated by humans were in better condition, suggesting a positive association between proximity to humans and raccoon nutrition. On the other hand, the high prey diversity in the stomachs of individuals living further away from human activity suggests that raccoons forage opportunistically in a variety of natural habitats.

### Age distribution and survival

The annual survival of raccoons on South Core Banks was similar to that reported for unharvested raccoon populations in Texas (Gehrt and Fritzell 1999) and Illinois (Wilson 2002, Urbanek et al. 2009), although our population was unusual in containing several animals >7 years of age (19%, n=44). Of the few animals that died during the study, the sources of mortality were predominantly disease and human influence (poisoning), although exposure due to inappropriate den sites and scarce fresh water was suspected in several cases. Lack of vehicle mortality (Hasbrouck et al. 1992), supplementary anthropogenic food such as fishing by-catch, garbage generated by humans, and a lack of significant predators and competitors may explain why raccoons on the Outer Banks of North Carolina live longer than raccoons in most other habitats studied to date. Seasonal human activity on the island appears to help sustain this raccoon population through periods when resources are scarce and of poor quality; however, these activities are sparsely distributed and most raccoons are subsisting off of the island’s natural resources. A population skewed toward older individuals suggests that that barrier island raccoons may live closer to the carrying capacity of their habitats (K-selected) than raccoons in other environments (Pianka 1970). We believe that the life history traits of raccoons on South Core Banks reflect a population constrained by limited food and denning sites.

Most studies report that raccoons prefer denning in tree cavities, but they demonstrate behavioral plasticity and readily use a variety of natural or anthropogenic structures (Dorney 1954, Berner and Gysel 1967, Henner et al. 2004), rock outcrops (Berner and Gysel 1967), or ground burrows dug by other species (Stains 1956). Mech et al. (1966) found that raccoons denned in bog habitats in Minnesota using ground beds in marshes and swamps; however, there are few instances in the literature of raccoons using marsh substrates for dens. There are few buildings or trees large enough to serve as den sites on South Core Banks, and forested areas, where they occur, are limited to a few, widely spaced locations. In addition,
ground burrowing on South Core Banks is precluded by the high water table and flooding of marshes by the daily tidal cycle. Frequent flooding of marsh den sites caused by high tides and storms likely makes habitats on South Core Banks suboptimal especially in terms of thermoregulation and during periods when the young are confined to the den. Frequent denning in salt marsh habitats suggests that few other denning options are available to raccoons on South Core Banks.

A prevalence of older animals can result from limited recruitment due to high density and limited or low-quality food resources (Clutton-Brock et al. 1987). Indeed, many captured individuals had empty stomachs and the majority of full stomachs contained a large amount of indigestible matter, indicating that resources may be limited, likely due to strong competition and seasonal food scarcity. The relatively low litter sizes (n=9, mean=2.67, SE=0.17) observed on our study site is also indicative of a population near carrying capacity (Clutton-Brock et al. 1987). Zeveloff and Doer (1981) found a litter size of 2.9 (n=14) for raccoons in western North Carolina, and Dunn and Chapman (1983) reported an average litter size of 3.2 (n=10) for raccoons in Maryland. We also found that both male and female raccoons on South Core Banks bred later in life compared with other populations (Stuewer 1943, Junge and Sanderson 1982, Dunn and Chapman 1983), another characteristic of populations close to carrying capacity. Condition index data provide additional support for this hypothesis. A lack of adequate nutrition has been shown to delay sexual development in other mammalian species (Glass and Swerdlff 1980, Pau and Milner 1984, Schwartz et al. 1988, Svendsen and White 1997, Cook et al. 2001). Furthermore, poor nutrition may explain the high levels of female mortality observed during the spring/summer period when females are raising their young. Other studies have found that male raccoons survive at lower rates than females, and they concluded that the larger home ranges of males expose them to greater mortality factors (i.e., disease, vehicles, predators) (Gehrt and Fritzell 1999). We found the opposite in our population; the condition and survival of females were significantly lower than those of males, suggesting that although resources may be abundant enough to sustain a high raccoon density on South Core Banks, focal areas of resource abundance vary in magnitude spatially and seasonally, necessitating shifts and increases in raccoon home ranges more readily accomplished by males than females.

The role of barrier islands as important stopover and breeding sites for a number of species of special concern makes understanding the ecology of predators in these landscapes of particular importance. Recent models of optimal predator control (Martin et al. 2010) have proved useful in assessing different predator management strategies; however, empirical information from in-depth life history studies is still needed to identify relevant ecological constraints and tradeoffs and to set realistic boundaries on model parameters (Beckman and Lackey 2008). In the case of South Core Banks, our data indicate that predator control efforts would be most effective when targeting offending individuals rather than investing in a population-wide effort (Martin et al. 2010). We also believe that decreasing the availability of human resources for this population would result in a reduction in population density closer to its natural carrying capacity.

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