Raccoon Removal on Sea Turtle Nesting Beaches

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ABSTRACT Predator removal can be an effective strategy for reducing mortality rates of prey species. Because removal programs must continue indefinitely to remain effective, trapping creates a source–sink dynamic that can alter predator spatial distribution and demography. We investigated the intraspecific effects of predator removal by comparing 2 Florida, USA, raccoon (Procyon lotor) populations that are managed to decrease sea turtle egg mortality. Long-term removal created an extremely male-biased population (>10:1), but the proportion of juveniles did not differ between sites. Stable isotope analyses indicate that raccoons on the removal beach originated from inland habitats. Our results suggest that adult males dominate the reclamation of removal areas and the presence of juveniles on the beach is due to predispersal behavior. Because raccoons are highly omnivorous and mobile, intensive management at a small scale may have broader impacts across the landscape that predator-removal programs should consider. (JOURNAL OF WILDLIFE MANAGEMENT 71(4):1234–1237; 2007)

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KEY WORDS beach ecology, Caretta caretta, diet, dispersal, loggerhead turtle, predator removal, Procyon lotor, raccoon, stable isotopes.

Lethal removal of predators can be an effective strategy to reduce mortality of endangered prey species (Davis and Whiting 1977, Schroeder 1981, Stancyk 1982, Ratnaswamy and Warren 1998). However, many of the benefits of predator removal are contingent upon the persistence of removal programs. Several studies have demonstrated that predation rates quickly return to preremoval levels when predator control ceases (Chesness et al. 1968, Duebbert and Lokemoen 1980, Greenwood 1986) and, therefore, control measures must become a permanent management activity unless combined with other strategies (e.g., habitat improvement; Côté and Sutherland 1997). Removed animals can be quickly replaced by other individuals (Stancyk 1982), creating a source–sink dynamic that can affect local population demographics (Jacob and Wegner 2005). Raccoon (Procyon lotor) predation is among the highest causes of egg mortality for sea turtles in southeastern United States (Stancyk 1982). Management activities to enhance the reproductive success of these species have included removing raccoons from nesting beaches (Ratnaswamy et al. 1997). To better understand the effects of long-term removal programs on target predators, we compared demographic and dietary characteristics of an unmanaged raccoon population to one that has historically experienced intensive annual trapping. This comparison allowed us to infer the demographic effects of removal programs, where recolonizing animals originate, and consequences of long-term removal for management and conservation goals.

We predicted that long-term removal would alter raccoon movement patterns and ultimately restructure the demographics of the population. Because we expected itinerant males to fill vacant habitats, we were interested in how increased mobility affected diet. By measuring the ratios of the stable isotopes of carbon and nitrogen in raccoons, we were able to compare the dietary history of the populations, specifically the importance of marine and terrestrial food sources. Because raccoons are predators and important components of allochthonous nutrient flow in coastal systems (Bouchard and Bjorndal 2000), we were ultimately interested in how cascading effects of predator removal may affect the primary goal of sea turtle conservation.

STUDY AREA

We collected raccoons from beaches at 2 east-central Florida, USA study sites approximately 75 km apart. Merritt Island (28º34’57”N, 80º34’27”W) and Archie Carr (27º53’40”N, 80º27’56”W) National Wildlife Refuges were important nesting beaches for the loggerhead turtle (Caretta caretta). In response to high predation rates, raccoon removal has been used to reduce nest predation (Popotnik and Epstein 2002) at Merritt Island since 1978. Raccoons had not been controlled at Archie Carr until the initiation of our study in 2003 and, thus, represented an unmanaged reference population. At the time of our study these management treatments were unique to these study sites, preventing further replication.

METHODS

Trapping was conducted April–October 2003 by United States Fish and Wildlife Service personnel. In the long-term removal area, traps were set every night at intervals of one trap per linear beach kilometer. For the reference population, personnel monitoring turtle nesting activity reported areas of high predation, and trapping effort was concentrated in those areas. When available, to increase our sample size, we collected road-killed raccoons, all of which we found within 100 m of the beach. Our procedures were approved by the University of Central Florida Institutional Animal Care and Use Committee (project no. 03-15).

We determined body mass, body length (tip of rostrum to base of tail), sex, and reproductive condition for each raccoon. We identified females as reproductive by the presence of fetuses in the uterus or swollen nipples. We used...
body mass and length to calculate an index of body condition: (mass/length$^3$) $\times 10^5$ (Hasbrouck et al. 1992).

We removed the lower mandible of each animal to determine the age (Fancy 1980). We x-rayed mandibles at the University of Central Florida Radiological Sciences Laboratory. We viewed backlit radiographs to determine the size of the pulp cavity of each mandibular canine. We distinguished juveniles (<1 yr) from adults (>1 yr) by their open pulp cavities (Grue and Jensen 1976, Kuehn and Berg 1981).

We identified stomach contents to the lowest possible taxonomic level and quantified diet by determining the frequency of occurrence of contents (see Anthony et al. 2000). We used stable isotope analysis to compare diets over a longer time frame than possible by observing stomach contents (Tieszen et al. 1983, Hobson and Clark 1992).

Stable isotope ratios in an animal’s tissues are related to its food (DeNiro and Epstein 1978, 1981; Roth and Hobson 2000), and this technique is becoming widespread for reconstructing the diets of animals (Kelly 2000, Roth 2003). We collected spleen samples from each animal for stable isotope analysis. Since the stable-carbon isotope ratios of lipids can differ from other compounds (DeNiro and Epstein 1978, Tieszen et al. 1983), variations in lipid concentration can significantly influence isotope measurements (Rau et al. 1992). Therefore, we removed lipids from our samples using a Soxhlet apparatus with petroleum ether for >8 hours. We measured stable isotope ratios on a continuous-flow isotope ratio mass spectrometer in the National Center for Forensic Science at the University of Central Florida. Stable isotope signatures are expressed in $\delta$ notation and the standards for $^{13}$C and $^{15}$N are Pee Dee Belemnite and atmospheric N$_2$, respectively. Measurement precision was within 0.1 parts per thousand for carbon and 0.2 parts per thousand for nitrogen.

To determine if road-killed animals could be used to increase our sample size, we compared road-killed and beach-caught raccoons from the reference population. We compared date of collection and body condition with a Mann–Whitney $U$-test, and we compared sex ratio and age distribution with a Fisher’s exact test. We used the same comparisons to determine if the demography of the 2 populations differed. We used a Fisher’s exact test to compare the proportion of empty stomachs and a Mann–Whitney $U$-test to compare $\delta^{13}$C and $\delta^{15}$N of road-killed and beach-caught raccoons. We compared the proportion of stomachs containing sea turtle, ghost crab (Oxypode quadrata), plant, animal, and parasites and the proportion of empty stomachs with a Fisher’s exact test. We compared stable isotope values between sites, as well as between sexes and age classes within populations, with a Mann–Whitney $U$-test. We used Spearman’s rho correlation to determine relationships between $\delta^{13}$C and $\delta^{15}$N and date of collection. We considered results to be significant at $\alpha = 0.05$ (Moran 2003). We present results as mean ± standard error unless otherwise indicated.

**RESULTS**

We sampled 58 raccoons: 23 (21 M and 2 F; 5 juv, 16 ad, 2 undetermined age) from the long-term removal site and 35 (18 M and 17 F; 8 juv, 23 ad, 4 undetermined age) from the reference population (including 6 road-killed individuals). Within the reference population, there were no differences between road-killed and beach-trapped animals in mean date of collection (19 Jul ± 11 d and 29 Jul ± 9 d, respectively; Mann–Whitney $U = -0.93$, $P = 0.35$), condition (2.98 ± 0.16 and 3.12 ± 0.10, respectively; $U = -0.80$, $P = 0.42$), sex ratio (1 M:1 F for both; Fisher’s exact test, $P = 0.64$), or age (1 juv:2 ad and 1 juv:3 ad, respectively; $P = 0.50$).

On average, raccoons from the long-term removal area were captured 7 weeks earlier ($U = -3.93$, $P < 0.001$) and were almost twice as likely to be male (Fisher’s exact test, $P = 0.001$) compared to the reference population. The proportion of juveniles did not differ between the beaches ($P = 0.57$), and body condition of raccoons from the removal area (2.80 ± 0.11) and from the reference population (3.10 ± 0.09) also did not differ ($U = -1.77$, $P = 0.08$). From the reference population 6 of the 17 females were pregnant or lactating, whereas neither of the 2 females from the long-term removal area were pregnant or lactating.

Empty stomachs were more frequent in road-killed (4/6) than beach-caught (1/26 stomachs examined) raccoons (Fisher’s exact test, $P < 0.001$), and road-killed raccoons had lower $\delta^{13}$N values (7.5 ± 0.3 parts per thousand) than beach-caught raccoons (8.9 ± 0.6 parts per thousand; Mann–Whitney $U = -2.05$, $P = 0.040$; $\delta^{13}$C values did not differ; $U = -0.47$, $P = 0.64$). Therefore, we excluded road-killed raccoons from dietary comparisons of the beaches. We detected a wide variety of foods in the stomachs, although hair, fruits and vegetation were the most common at both sites (Table 1). Empty stomachs were >10 times as frequent in the long-term removal area (Fisher’s exact test, $P = 0.015$). We found no difference in the occurrence of remains of sea turtles ($P = 0.22$) or ghost crabs ($P = 0.45$). Plant matter was more common in the reference population ($P = 0.002$), although animal matter did not differ ($P = 0.61$).

Raccoons from the reference population ($n = 27$, $\delta^{15}$N = 8.84 ± 0.26 parts per thousand, $\delta^{13}$C = -19.28 ± 0.34 parts per thousand) had higher $\delta^{15}$N (Mann–Whitney $U = -2.58$, $P = 0.010$) and $\delta^{13}$C ($U = -2.84$, $P = 0.005$) values than those from the long-term removal area ($n = 21$, $\delta^{15}$N = 7.94 ± 0.16 parts per thousand, $\delta^{13}$C = -20.80 ± 0.29 parts per thousand). Capture date was unrelated to stable isotope ratios in both the reference population ($\delta^{15}$N, $r = 0.005$, $P = 0.10$; $\delta^{13}$C, $r = -0.17$, $P = 0.37$) and at the long-term removal area ($\delta^{15}$N, $r = 0.108$, $P = 0.68$; $\delta^{13}$C, $r = -0.017$, $P = 0.95$). Within sites, adults and juveniles did not differ in the reference ($\delta^{15}$N, $U = -0.32$, $P = 0.75$; $\delta^{13}$C, $U = -1.30$, $P = 0.20$) or removal population ($\delta^{15}$N, $U = 0.58$, $P = 0.56$; $\delta^{13}$C, $U = -1.88$, $P = 0.07$).

**DISCUSSION**

Our evidence suggests that long-term trapping can greatly affect local raccoon populations, which may potentially
Table 1. Stomach contents of raccoons from a long-term removal area (n = 23) and a reference population (n = 26) in east-central Florida, USA, during April–October 2003. Values are total number of stomachs and percentage at each site with that food type present.

<table>
<thead>
<tr>
<th>Food category</th>
<th>Removal</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>%</td>
</tr>
<tr>
<td>Hair or fur</td>
<td>10</td>
<td>43.5</td>
</tr>
<tr>
<td>Fruit, seed, or berry</td>
<td>6</td>
<td>26.1</td>
</tr>
<tr>
<td>Brazilian pepper, <em>Schinus terebinthifolius</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saw palmetto, <em>Serenoa repens</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sand bean, <em>Sphagnum ulvae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gallberry holly, <em>Ilex glabra</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Greenbrier, <em>Smilax sp.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grapevine, <em>Vitis sp.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other vegetation</td>
<td>6</td>
<td>26.1</td>
</tr>
<tr>
<td>Marine turtle</td>
<td>1</td>
<td>4.3</td>
</tr>
<tr>
<td>Loggerhead</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Green turtle, <em>Chelonia mydas</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other reptiles</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Brown anole, <em>Anolis sagrei</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crustacean</td>
<td>2</td>
<td>8.7</td>
</tr>
<tr>
<td>Ghost crab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other invertebrates</td>
<td>5</td>
<td>21.7</td>
</tr>
<tr>
<td>Roaches Order: <em>Blatra</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blue dasher, <em>Pachyplex longipennis</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carolina saddlebags dragonfly, <em>Tramea carolina</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orb weavers Family: <em>Araneidae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beetles Family: <em>Carabidae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Giant water bug Family: <em>Belostomidae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grasshoppers Family: <em>Acrididae</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chafers, <em>Aromala sp.</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Garbage</td>
<td>1</td>
<td>4.3</td>
</tr>
<tr>
<td>Plastic and paper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Empty stomachs</td>
<td>7</td>
<td>30.4</td>
</tr>
</tbody>
</table>

Influence raccoons across the landscape. Because raccoons that use the beach resources in the long-term removal area are subject to increased mortality, a source–sink dynamic may have been created. Males are more likely to recolonize vacant habitats because of their large home range, tendency to travel in search of mates, and male-biased natal dispersal. Because females are highly philopatric, they move little during the course of their lifetime (Gehrt and Fritzell 1997, Walker and Sunquist 1997). This behavioral difference between sexes explains the high proportion of males at the long-term removal beach. The sex ratio we have reported (10.5 M:1 F) is exceptionally high, and we are unaware of any report of a more strongly male-biased sex ratio. Preferentially removing wide-ranging males, however, may create a female-biased sex ratio in the source population.

Despite an apparent lack of females at the removal beach, there was no difference in the proportion of juveniles between sites. Based on the literature and our analysis of female reproductive status, we estimated that the juveniles we sampled were 8–12 months old and were unlikely to have dispersed from their natal ranges (Gehrt and Fritzell 1998). We suggest the similar proportion of juveniles is due to the dispersal behavior in subadult raccoons, in which young animals travel for distances (>1 km) from their mother (Gehrt and Fritzell 1998). Given that the summer home range of female raccoons is relatively small (median <75 ha; Gehrt and Fritzell 1997), predispersal movements are likely to place subadult males on beaches that their mothers do not access. Because beach trapping is indiscriminant in its removal of resident or transient raccoons, the effects of trapping may manifest several km inland. To test this effect, we compared the stable isotope ratios between the populations. Marine foods are enriched in both δ13C and δ15N (Ehleringer et al. 1986), and raccoons from the removal site had lower values for both isotopes. This isotopic difference suggests recolonizing raccoons had foraged on a higher proportion of terrestrial food sources and probably arrived from more inland areas.

Predispersal movements also explain why the δ13C and δ15N values did not differ between juveniles and adults. In the removal area, we sampled few females because of their limited beach use and, therefore, our comparison was actually between juvenile and adult males (the 2 groups with incentive [maternal social bonds and reproductive opportunities] to use both beach and terrestrial habitats). Because adult males and juveniles were using the landscape similarly, it is not surprising that their diets would also be similar.

Several other differences between the sites could impact raccoon populations (e.g., human influence, total land area). Because of our low sample size and these uncontrolled factors, direct application of our conclusions may be best suited for local management. However, our conclusions are consistent with current understanding of dispersal, predator control, and sea turtle nesting-beach ecology and offer insight to anyone interested in these issues. Raccoons are native predators on sea turtle nesting beaches, not invasives that threaten biological integrity, and they can be important seed dispersers and predators on a variety of species (Lotze and Anderson 1979, Wilson 1993, Hartman et al. 1997). Our results support the conclusion of Ratnaswamy and Warren (1998) that the ecological connectivity of raccoons should be assessed if the objectives of sea turtle conservation are to be compatible with those of ecosystem management.

**MANAGEMENT IMPLICATIONS**

Raccoon predation on sea turtle eggs is widely accepted as a conservation concern, and predator control is an important tool for sea turtle conservation on many beaches (Stancyk 1982). However, our research demonstrates that long-term removal programs can affect diet and demography in raccoon populations and suggest trapping on nesting beaches primarily removes surplus dispersing from source populations. If reducing the density of raccoons where sea turtles nest continues to be a management strategy, manipulating the source population rather than the sink should be considered.

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