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Abstract

Four years of data from a high-density marine turtle nesting beach at John D. MacArthur Beach State Park, Florida were examined along with data on raccoon road-kills from adjacent roads, and data on park attendance (as an index of local traffic) to make inferences about raccoon activity patterns relative to turtle nesting. Raccoon road-kills were found to diminish substantially during turtle nesting, even though local traffic was constant or increasing. Opossums, the only other mammal consistently found as road-kills, did not show a decrease during turtle nesting season, but they are not known as a primary predator of turtle nests. We concluded that during turtle nesting raccoons are drawn to the beach to prey on the abundant food resource of turtle eggs, and they do not leave the beach until the end of turtle nesting season. High numbers of raccoon road-kills during the fall-winter, followed by a decrease in the spring around the start of turtle nesting season, might be used as indicators to initiate management actions to protect turtle nests.

Resumen

Cuatro años de datos recolectados de una playa de anidamiento de alta densidad de tortugas marinas en John D. MacArthur Beach State Park, Florida fueron analizados conjuntamente con registros de mapaches atropellados en carreteras contiguas y datos de visitación al parque (como un indicador del tráfico local) para inferir patrones de actividad del mapache con relación con el anidamiento de tortugas. Los mapaches atropellados se reducen sustancialmente durante la desova de tortugas, aunque el trafico local se mantuvo constante en aumento. La comadreja, el único otro mamífero encontrado consistentemente atropellado, no mostró una reducción en su población durante la desova de tortugas, pero no son conocidos como un depredador primario de los nidos de tortugas. Hemos concluido que durante la época de la desova de tortugas, los mapaches son atraídos a la playa por la abundancia de huevos de tortugas y no dejan la playa hasta el final de la temporada de la desova de tortugas. Los números elevados de mapaches atropellados durante el otoño-invierno, seguido por una reducción en la primavera alrededor del comienzo de la temporada de la desova de tortugas, puede ser usado como un indicador para iniciar acciones de manejo para protección de los nidos de tortugas.

Introduction

Predation is a critical threat to many endangered or even locally rare species (Hecht and Nickerson 1999), and predation losses can have an increased deleterious impact due to the compounding effects of habitat loss and altered predator communities (Reynolds and Tapper 1996). In this regard, raccoons *Procyon lotor* cause substantial destruction of marine turtle nests in Florida and throughout the southeastern United States (Stancyk 1982); thus, they exemplify an abundant native vertebrate that negatively impacts the conservation of endangered species (e.g., Garrott et al. 1993). While urbanization and development of coastal Florida have reduced the beach areas where marine turtles successfully nest, raccoons have prospered in the face of urbanization. They flourish in close association with humans where their populations often receive artificial support through refuse or direct feeding (Dickman 1987; Dickman and Doncaster 1987; Riley et al. 1998; Smith and Engeman 2002). Increased availability and concentration of food, den sites or other refuges may induce dense populations of wildlife species that inhabit urban environments (e.g., Dickman 1987; Dickman and Doncaster 1987; Riley et al.1998), and raccoons have been observed to achieve extraordinary densities (up to 238/km^2) in urban, coastal Florida (Smith and Engeman 2002). In addition, predators are known to recognize and key on high-density nesting areas (Lariviere and Messier 1998, Mroziak et al. 2000). Here, we examine four years of data from a high-density turtle nesting beach enclosed within an urban setting. We examine raccoon road-kill data from area roads during the same years to evaluate whether a raccoon migration to the high-density of nests is indicated.

Methods

Study site

John D. MacArthur Beach State Park (MBSP) is located on Singer Island in Palm Beach County, Florida, USA. It

Figures 1-4. This series of photos detail the lives of loggerhead turtles at John D. MacArthur Beach State Park, FL. Female loggerheads build a nest in the beach (top photo) and lay their eggs in the sand (second photo from the top). If raccoons or other predators find the nest, eggs will be eaten (second photo from the bottom), otherwise, hatchlings will emerge and head towards the ocean (botoom photo). Photos courtesy of Richard Engeman

Month	Mean number of nests deposited	Mean park attendance (1000s)	Mean # of roadkills	
			Raccoons	Opossums
January	0.00	7.653	5.50	0.50
February	0.00	9.098	3.25	0.50
March	0.00	12.608	1.25	1.00
April	2.50	11.280	1.25	0.75
May	213.75	8.071	1.75	0.25
June	518.50	6.344	0.25	0.25
July	485.25	8.777	0.50	0.50
August	106.50	7.551	0.75	0.50
September	1.75	5.121	2.50	1.25
October	0.00	4.816	3.25	1.00
November	0.00	5.166	8.75	1.75
December	0.00	6.362	6.75	0.25

Table 1. Yearly averages from 1995-1998 for marine turtle nest deposition (3 species combined), raccoon road-kills, opossum road-kills, and visitor attendance at John D. MacArthur Beach State Park, Florida.

consists of 65 tidal wetland / submerged ha, and 71 upland ha for a combined total of 136 ha. Terrestrial plant communities consist of maritime hammock (49 ha) and beach dune (9.3 ha). MBSP is encapsulated within the City of North Palm Beach, and is surrounded by suburban infrastructure to the north and south. The property is bordered to the east by the Atlantic Ocean, and the Intracoastal Waterway (a large bulkheaded estuary) truncates the entire western boundary. State Road A-1-A runs through MBSP parallel to the Intracoastal Waterway on the west side of Singer Island. This length of road is 2.6 km with a speed limit of 72 kph. The park also has another 1.1 km of infrastructure roads with a speed limit of 24 kph. No roads are immediately parallel to the beach on the Atlantic coast. Thus, wildlife from the beach would be unlikely to appear on the roads within a short time period.

There are 3 km of Atlantic Coast beach available for nesting by three threatened and endangered species of marine turtles (U.S. Fish and Wildlife Service 1994): loggerhead *Caretta caretta*, green *Chelonia mydas*, and leatherback *Dermochelys coriacea* turtles. Over the past 10 years, this span of beach has received an average of approximately 1,300 marine turtle nests each year (Desjardin et al. 2001).

Marine turtle nesting and road-kill surveys

During 1995-1998, MBSP rangers inspected the 3 km of beach each day from 1 March through 30 September. Surveys were initiated within 0.5 hr after sunrise and the number of new turtle nests was recorded each day, and those numbers were tabulated monthly.

A daily road-kill survey was conducted during 1995-1998, and consisted of slowly searching park and adjacent road surfaces for dead wildlife while driving ca. 8-24 kph (e.g., Smith et al. 1994; Bard et al. 2002; Shwiff et al. 2003; Smith et al. 2003). Surveys were initiated between 07:45-08:15 a.m. The numbers of each species observed as road-kills were recorded, and also tabulated monthly. To assess whether road-kills were a reflection of human traffic instead of reflecting a response to turtle nesting, we obtained park attendance data to index traffic volume on the roads in the area.

Data analyses

Several quantitative approaches were applied to the nesting and road-kill data to ascertain the existence of a relationship between turtle nesting and raccoon activity. The most direct approach was to examine the correlation between monthly nest deposition and road-kills. The number of nests currently in the beach each month might have provided a more refined variable to relate with raccoon activity, but this could not be calculated because nest removal rates due to hatching, predation, overwash, etc. were not available. Most months, turtle nesting was zero, but during the summer (nesting season), it ranged to over 650 nests / mo, making the nesting data non-normal. Therefore, Spearman's rank correlation (r) was used to measure the strength of relationship between turtle nesting and the other variables.

Another analysis compared average monthly road-kill rates between the times when turtle nests were being deposited and when they were not being deposited. This was carried out as a randomized block design where year was the blocking factor and it was analyzed

as a mixed linear model (e.g., McLean et al 1991; Wolfinger et al. 1991) using SAS PROC MIXED, with a restricted maximum likelihood estimation (REML) procedure (Littell et al. 1996).

Comparative analyses were conducted where activity also was indexed by road-kills for other mammals. These data were analyzed in the same manner as that for the raccoons. These analyses provided an indication of whether raccoon activity patterns were typical for mammals, and therefore a function of other external forces, or whether raccoon activity stood out by itself relative to turtle nesting. Park attendance data were analyzed in the same fashion to see if traffic patterns in the area followed the same patterns as raccoon road-kills, or if raccoon road-kills could not be explained by traffic patterns.

Results

Over the four years, turtle nests were only deposited in April-September. Very few nests were deposited in April and September, but very large numbers were deposited May-August (Table 1). Thus, very few eggs were in the beach sand in April, but many remained in the sand in September from previous months of turtle nesting.

The results were striking for the analytical approaches used to relate turtle nesting to raccoon activity. Raccoon activity as indexed by road-kills was dramatically lower during months with turtle nesting than during non-nesting months ($F_{1,3} = 10.94$, $p = 0.04$). The only other mammal recorded more frequently than as incidental road-kills (i.e., > 5/yr, on average) were opossums *Didelphis virginiana*, which showed no difference between nesting months and non-nesting months ($F_{1,3} = 1.34$, $p > 0.3$). As would be expected, after viewing the above results, raccoon road-kills showed a negative rank correlation ($r = -0.60$, $p < 0.0001$) with turtle nest deposition, again indicating that when nest deposition rates were high, few raccoons were along the roads. In contrast, the correlation of opossum road-kills with turtle nesting was not distinguishable from 0 ($r = -0.17$, $p = 0.24$).

Park attendance was not strongly related to raccoon road-kills at $r = -0.22$ ($p = .14$). No differences were detected in park attendance between nesting and non-nesting months ($F_{1,3} = 0.45$, $p > 0.50$). Both attendance results indicate that the raccoon road-kill rate was not related to local area traffic, or if so, the relationship was very minor and opposite of what would be expected with fewer raccoon road-kills at times of higher traffic volume.

Discussion

The difference in raccoon road-kill rates between turtle nesting and non-nesting months was compelling. While we did not have data on traffic flows, park attendance data during the summer when few raccoons were being killed by traffic did not diminish when compared to fall-winter months when raccoon road-kills were highest. Furthermore, it would not be reasonable to expect traffic to decrease near a beach during summer holidays. In support of this, road-kills of opossums, only known to very rarely act as a primary predator of turtle nests (Woolard et al. in press), were not found to be less during turtle nesting season.

Our only practical explanation for these results is that raccoons were actively moving about the MBSP area until the beginning of turtle nesting. At that time they appeared attracted to the abundant food resource on the beach that thousands of nests of turtle eggs represent, as occurs commonly along the Atlantic coast of Florida (Stancyk 1982; Bain et al. 1997; Mroziak et al. 2000; Engeman et al. 2003). They would not leave the beach until that food resource diminished. Afterwards, they dispersed from the beach, and again were vulnerable to becoming road-kills. The relationship of raccoon road-kills to turtle nesting might be applied to assist marine turtle conservation at beaches with high nest predation. High numbers of road-kills during the fall-winter, followed by a decrease in raccoon road-kills in spring around the start of turtle nesting might be used as

indicators to initiate management actions to protect turtle nests.

Evidence suggests that raccoon migrations to turtle nesting beaches may have a cultural ("learned") component (passed on from one generation to the next), because on some beaches most raccoon predation occurs on the night of egg deposition (Anderson 1981), while on others, predation rarely occurs then (Ehrhart and Witherington 1986; Engeman et al. 2003). A migration to a nesting beach that is culturally produced could well be lost over a few generations. For example, Engeman et al. (2003) demonstrated that a passive tracking system can be used to optimize predator management. As a consequence, predation on a high-density turtle nesting beach at Hobe Sound National Wildlife Refuge (HSNWR), 21 km north of MBSP, dropped from 42% to 29% in one year (Engeman et al. 2003). A further two years of this practice through 2002 reduced predation by raccoons and armadillos (*Dasypus novemcinctus*) on turtle nests to 9% (HSNWR, unpublished data). This suggests that a cultural cycle of turtle nest predation by raccoons at HSNWR may have been broken.

The chronology of the raccoon reproductive cycle, taken into consideration with our road-kill data, supports the premise of raccoons focusing their activities on the beach during turtle nesting season. Raccoon litters in Florida are typically born in March and April, with weaning from mid-May to July (Kern 2002). Thus, one would expect young of the year to inflate road-kill statistics during summer when turtles are nesting. However, that the opposite occurred could be attributed to the young accompanying mothers to the beach and also would suggest a cultural component to turtle nest predation.

Predation was the primary factor affecting the success of turtle nests at MBSP, with a depredation rate of 42.6% in 2001 (Desjardin et al. 2001). It is logical that similar predator management at MBSP as at nearby HSNWR could yield similar results. Engeman et al. (2002) demonstrated that a $5000 contract to manage predators during turtle nesting at HSNWR in 2000 yielded an $8.4 million return in marine turtle hatchlings using only a minimal monetary valuation for individual hatchlings. Investment in similar predation management strategies at MBSP might prove equally beneficial.

We can extrapolate in a logical fashion on how this might work at MBSP. If an average of 1,300 turtle nests are deposited annually at MBSP, then a 43% predation rate implies the loss of approximately 560 nests. With loggerhead turtles comprising approximately 98% of nests (Desjardin et al. 2001), an estimate of an average of 100 eggs/nest (Desjardin et al. 2001; Engeman et al. 2002) would be conservative. Thus, an average of at least 56,000 eggs would be lost to predation annually. Assuming a hatching rate similar to the 75% reported for HSNWR (Engeman et al. 2003) suggests an average net loss of 42,000 hatchlings/year at MBSP due to nest predation. Just halving the predation rate would produce an average of 21,000 more hatchlings/year. Because the MBSP beach is only 60% the length of the beach at HSNWR, it is logical to assume that expenditures at MBSP for the same level of predator management would be no more than that at HSNWR. Applying the same conservative turtle valuation as Engeman et al. (2002) suggests that a savings of over $2 million in turtle resources could result.

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