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DECREASED NEST MORTALITY FOR THE CAROLINA DIAMONDBACK TERRAPIN (*MALACLEMYS TERRAPIN CENTRATA*) FOLLOWING REMOVAL OF RACCOONS (*PROCYON LOTOR*) FROM A NESTING BEACH IN NORTHEASTERN FLORIDA

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***Abstract.*—Raccoons (*Procyon lotor*) can account for > 90% of nest failures of the Diamondback Terrapin (*Malaclemys terrapin*) in some areas. Previous studies have demonstrated that predator removal can decrease predation of turtle nests, thus increasing nest survivorship. We removed Raccoons from an island beach used by Diamondback Terrapins for nesting in northeastern Florida. Prior to predator removal, Raccoons depredated 53.5% of monitored nests and 80% of all nests found in 1997 and 50.9% of monitored nests and 76.0% of all nests found in 2000 on this island beach. We removed 29 Raccoons between February and September 2005 and monitored Diamondback Terrapin nesting from 25 April to 31 October 2005. Nest predation by Raccoons dropped to 12.0% and the overall predation rate fell to 17.2%. We again monitored the nesting beach in 2006 without predator removal. Nest predation by Raccoons was once again very high, claiming 86.7% of monitored nests and over 70.0% of all the nests found.**

Key Words.—conservation; experiment; monitored nests; predation; predator removal; survival

INTRODUCTION

Predator abundance is strongly correlated with adverse effects to prey population dynamics (Garrot et al. 1993; Munscher 2007). Raccoons (*Procyon lotor*) are omnivorous, taking advantage seasonally of locally abundant food sources (Gerht et al. 2002). Increased Raccoon populations and geographic range extension has been well documented (Gerht et al. 2002; Lariviere 2004) as has increased predatory pressure from these increases (MacLaren 1992; Schmidt 2003). Human activities, particularly suburban sprawl and associated habitat fragmentation, have been linked to increased Raccoon populations (Hoffman and Gottschang 1977; Gerht et al. 2002).

In Florida, Raccoons have been documented to negatively impact over 180 species of ground dwelling or nesting animals (MacLaren 1992). Raccoons are major nest predators for numerous turtle species (Landers et al. 1980; Ehrhart and Witherington 1987; Jackson and Walker 1997; Congdon et al. 2000). One technique to reduce depredation of turtle nests is to remove Raccoons from nesting areas. Christiansen and Gallaway (1984) found that removal of Raccoons from a Yellow Mud Turtle (*Kinosternon flavescens*) nesting area in Iowa virtually eliminated Raccoon-attributed nest predation. Similarly, Garmestani and Percival (2005) removed 14 Raccoons from four sea turtle island nesting beaches (ranging in size from 19–57 ha) in the Ten Thousand Islands National Wildlife Refuge, Florida, and nest predation rates decreased from between 76–100% to 0%.

Diamondback Terrapins (*Malaclemys terrapin*; Fig. 1) occupy a wide range of coastal habitats as far north as Cape Cod, Massachusetts, south along Florida, and west along the Gulf Coast to Corpus Christi, Texas (Ernst and Lovich 2009). Predation on nests, hatchlings, and adults was identified as an important threat to survival for this species (Butler et al. 2006). In Gateway National Recreation Area in New York and New Jersey, terrapin populations were free of most nest predation until nuisance Raccoons were illegally released there in the 1980s, and now most of the 92% predation of Diamondback Terrapin nests is attributable to Raccoons (Feinberg and Burke 2003). In a two year study, Butler et al. (2004) determined that over 75% of terrapin nests deposited on an island nesting beach in northeastern Florida were destroyed by predators. The most frequent nest predator in that investigation was the Raccoon, similar to several other Diamondback Terrapin nesting studies (Burger 1977; Goodwin 1994; Roosenburg and Place 1995). Raccoons also can be significant predators of adult terrapins (Seigel 1980a; Feinberg and Burke 2003).

We revisited the study site of Butler et al. (2004) with the goal to remove as many Raccoons as possible

FIGURE 1. A: An adult female Carolina Diamondback Terrapin (*Malaclemys terrapin centrata*) at our study site on her way back into the Intracoastal Waterway in Duval County, Florida. B: Visible tracks leading to and away from a nest of a Diamondback Terrapin. C: A discovered and monitored nest. D: Four hatchling Diamondback Terrapins from a successful nest. (Photographed by Tabitha Barbee)

from this nesting beach of Diamondback Terrapins in northeast Florida before and throughout the 2005 nesting season. We compared our observed nesting success to that of Butler et al. (2004). We expected that predator removal would result in fewer adult Diamondback Terrapin deaths on the beach, fewer depredated nests, and a larger proportion of successfully emerged nests in comparison to years when nests were monitored with no predator removal.

MATERIALS AND METHODS

Study site.—The nesting beach of Diamondback Terrapins that we used was located on Saw Pit Island, a small, approximately 100 ha island that was roughly triangular shaped within the Intracoastal Waterway in Duval County, Florida (Fig. 2). This island is managed by Big Talbot Island State Park. The island was dominated by salt marsh habitat with interconnecting tidal creeks. The island is bordered by three waterways: Gunnison Cut on the west, the Nassau River on the north, and Sawpit Creek to the southeast (Munscher 2007). Three other islands are adjacent to it. Amelia Island is situated to the north with a bridge that connects the two, another bridge connects the nesting island to Big Talbot Island to the south, and Black Hammock Island is located to the west across Gunnison Cut (Fig. 2). A 750 m long nesting beach occupied the northeastern side of the triangle and ranged in width from about 10–25 m at high tide. The beach had large open sandy areas interspersed with vegetation such as Dunegrass (*Ammophila breviligulata*), Saltgrass (*Distichilis spicata*), and Saltwort (*Batis maritime*). Outside of the nesting beach, the island was dominated by saltmarsh vegetated by cordgrasses (*Spartina alterniflora* and *S. patens*) and was not typically used by nesting Diamondback Terrapins (Munscher 2007). Two small tree stands were located on the western side of the island, which we named West Woods North (WWN) and West Woods South (WWS). Smaller wooded areas occurred along the nesting beach and were referred to by us as East Woods North (EWN) and East Woods South (EWS). Two small tree stands were located at the very southern tip of the island and we referred to them as South Woods (SW; Fig. 2).

FIGURE 2. Aerial photograph (2005) of the study site on Saw Pit Island, Duval County, Florida, USA. (Aerial imagery from the Florida Department of Environmental Protection: Land Boundary Information System).

Raccoon removal.—We trapped Raccoons daily from 7 February until 25 April 2005, and after that time until 22 September 2005 only when we detected Raccoon activity. We monitored Raccoon presence and movements daily at 14 track stations located primarily in the wooded areas WWN, WWS, EWN, and EWS, and elsewhere on the beach where we observed tracks. Traps were set at areas with high Raccoon activity such as on Raccoon trails, adjacent to trails under shrubs (usually Wax Myrtle, *Myrica cerifera*); at the base of Southern Red Cedar (*Juniper silicicola*), or near communal scat logs (Ratnaswamy et al. 1997). We used a combination of nine single-door Tomahawk # 108 and Havahart # 1079 live-traps (both 81.3 cm × 30.5 cm × 25.4 cm; Tomahawk Live Trap Co., Tomahawk, Wisconsin, USA and Woodstream Havahart Co., Steamboat Rock, Iowa, USA). We sedated captured Raccoons on site with an intramuscular injection of ketamine hydrochloride (10 mg/kg) while Raccoons were still in the trap, and then euthanized them with Euthasol (1 ml/4.5 kg; Bigler and Hoff 1974; Seal and Kreeger 1987). Dead Raccoons that we removed from the island were used in diet, age, and parasite studies (Munscher 2007).

Surveying for adult Diamondback Terrapin mortality.—Prior to the start of the nesting season, we surveyed the study area for dead terrapins from previous seasons, which we removed from the beach. We distinguished adult males and females using carapace length (CL). Sexual dimorphism is large in the species with females obtaining sizes up to 238 mm CL and males up to approximately 140 mm CL (Ernst and Lovich 2009). In cases where shells were disarticulated, we estimated carapace length by assembling shell bones.

Nest monitoring.—Using the protocol of Butler et al. (2004), two to four researchers walked the length of the nesting beach and back daily from 25 April through 31 October, 2005 searching for sign of terrapin nesting or emergence. We located three primary nest types: (1) intact nests (monitored), where adult Diamondback Terrapin crawls were traced to soil disturbances, which proved to be nests; (2) depredated nests, where we found eggshell fragments discarded by predators near excavated nest cavities; and (3) emerged nests, where we traced backwards hatchling crawls leading from nests and we confirmed nests by the presence of other hatchlings or eggshells still within the cavity. Nests that were monitored from deposition to hatching or depredation events are referred to as "monitored nests." Nests that were found > 1 day post oviposition are referred to as "other nests."

For monitored nests we recorded intact nests within 24 h of oviposition and the presence of eggs was confirmed by pressing a finger into the sand until the nest cavity and eggs were felt. We marked intact nests with a numbered survey stake placed 5 m away at an angle of 240º from the nest so that curious predators such as Raccoons would not be attracted to the marked nests (Butler et al. 2004). We monitored these nests daily to determine if they were still intact, emerged, inundated, or depredated. Data from Butler et al. (2004) was revaluated to align with definitions provided herein. We defined a successful emerged nest as any nest that had at least one hatchling emerge (Walde et al. 2007). Depredated nests were nests that were completely taken by a predator. When we found depredated nests, we attempted to identify the predator (usually by tracks). We also removed all eggshell fragments, filled in holes, and removed animal tracks so they would not be recorded on subsequent days. At the end of October, we excavated all remaining intact nests to determine their status. Nests on the study beach averaged 68.9 days to emergence (Butler et al. 2004), therefore, by early July, we began searching for emergence holes, hatchling crawls, or hatchlings.

Data analysis.—We used a chi-square test of independence to compare the number of depredated nests versus nests with other fates (successful and other non-predation failure) for only monitored nests between years. A *P*-value of ≤ 0.05 was considered significant. Only monitored nest data was used for statistical comparisons because of the method for obtaining the data was consistent between years. We made only qualitative comparisons of other nests between years.

RESULTS

In 1,762 trap nights, we captured and removed 23 male and six female Raccoons from the island nesting beach. We determined that 18 males were adults (dried lens weight (lw) > 120 mg) and five were subadults (lw = 105–120 mg; Johnson 1970). All six females were adults. We captured nine Raccoons prior to the turtle nesting season, 14 during the period of nest deposition (late April through July) and six thereafter. We also caught two Virginia Opossums (*Didelphis virginiana*), one Feral Cat (*Felis catus*), one Northern Cardinal (*Cardinalis cardinalis*), and one Boat-tailed Grackle (*Quiscalus major*).

Prior to the start of nesting, we collected carcasses of 45 adult female Diamondback Terrapins that had died in previous years. Males have never been recorded on the nesting beach (Joseph Butler, pers. obs.). We found no new dead adults during the active season from 25 April through 31 October 2005.

In 2005 we recorded 192 Diamondback Terrapin nests, 93 of which we monitored from deposition throughout the life of the nest (Table 1). Of the 93 monitored nests, 58 of the 93 (62.4%) hatched with no depredation. Seven (7.5%) nests were depredated before hatching and storms washed out 22 (23.7%) monitored nests. Eggs did not develop or hatch in one monitored nest (1.1%) that was inundated intermittently during the season. On 31 October we excavated five nests that had not hatched but found no eggs, and we believe these to have been washed out (Table 1).

We found 99 other nests in 2005, 73 (73.7%) were discovered by following hatchling crawls to successfully emerged nests and 26 were unmarked depredated nests. Of the total 192 nests found, 33 (17.2%) were depredated during the study, and Raccoons were responsible for 23 (12.0% of total nests) of those (Fig. 3). Fish Crows (*Corvus ossifragus*) and Virginia Opossums each destroyed two nests (n = 4, 2.1%), prior to hatching (Fig. 3).

In 2006, we monitored 45 nests for the duration of the season. Of those nests, we determined five (11.1%) to

TABLE 1. Fates of monitored nests of Diamondback Terrapins (*Malaclemys terrapin*) for all four study years on Saw Pit Island, Duval County, Florida. Numbers under years are the number of nests found and parentheses denote percent of total nests found. Data from 1997 and 2000 (Butler et al. 2004) have been modified to align datasets. Nests for which fates were unknown were nests that could not be located after initial discovery and marking and were possibly washed out.

	Year			
	1997	2000	2005	2006
Fate / number of nests	114	112	93	45
Successful	26 (22.8)	38 (33.9)	58 (62.4)	5 (11.1)
Depredated	61 (53.5)	57 (50.9)	7 (7.5)	39 (86.7)
Other Failure				
Undeveloped/unhatched	2 (1.8)	3 (2.7)	1 (1.1)	0 (0.0)
Washed out	25 (21.9)	5 (4.5)	22 (23.7)	1 (2.2)
Unknown	0 (0.0)	9 (8.01)	5 (5.4)	0 (0.0)

be successful and 39 (86.7%) were depredated (Table 1). We found one nest (2.2%) that was washed out, but no other nests were undeveloped or unhatched (Table 1).

Nests also suffered from hatchling predation through the nesting season. Other predators such as Fire Ants (*Solenopsis invicta*) raided recently hatched nests and preyed upon hatchlings. We found Fire Ants in 10 (5.2%) nests in 2005 and all these events occurred subsequent to hatching. Three nests (1.6%) were depredated by Ghost Crabs (*Ocypode quadrata*). In May and June, before hatching, crabs dragged or pushed some or all of the intact eggs out of three nests and onto the surface. In only one case had the eggs been penetrated, but all were destroyed by heat. These nests had been deposited near crab holes, or crabs had established new holes near the nests. Later in the season, four hatched nests were attacked, and one or more dead hatchling turtles were found near the mouths of nearby crab holes. In three of these cases, crawls leading from emergence holes suggested some hatchlings escaped this fate. Plant roots were implicated in the partial failure of three nests of the total 192 surveyed (1.6%).

The number of depredated monitored nests we observed in 2005 was compared to the number of monitored nests with other fates (both successful and non-predation failure) from Butler's study in 1997 and 2000 (Butler et al. 2004) and from data collected in 2006 (Joseph Butler, unpubl. data). Comparisons were also made between years. When comparing the number of depredated nests for all years, the proportions were significantly different (χ^2 = 89.22, df = 3, $P < 0.001$). When year 2005 was removed from the analysis, the proportions of depredated nests were still significantly different (χ^2 = 18.44, df = 2, $P < 0.001$) due to the high proportion of depredated nests in 2006 (Table 2). When years 1997, 2000 (Butler et al. 2004), and 2005 were compared, the proportion of depredated nests was significantly different (χ^2 = 55.37, df = 2, $P < 0.001$). The proportion of depredated nests in 1997 and 2000 were not significantly different from each other (χ^2 = 0.16, df = 1, $P = 0.694$) but the proportion of depredated nests in 2005 and 2006 were significantly different from each other (χ^2 = 85.47, df = 1, $P < 0.001$).

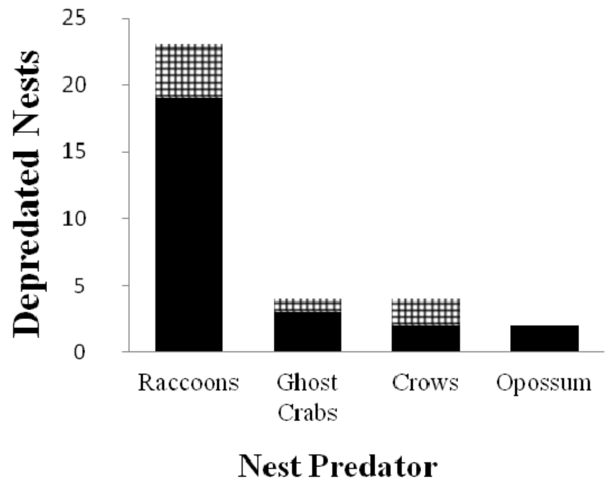

Figure 3. Total number of depredated Diamondback Terrapin (*Malaclemys terrapin*) nests found in 2005 on Saw Pit Island, Dubal County, Florida, for each suspected or known predator. Hatched portions represent nests monitored throughout the incubation period. Dark portions are nests that were found later in the incubation period, generally following depredation.

DISCUSSION

Reduction of Raccoons from a Diamondback Terrapin nesting beach was an effective mechanism for decreasing nest depredation and increasing the number of nests where emergence occurred. Our analyses show that the proportion of depredated nests was significantly lower in 2005 when we removed Raccoons, and the proportion of depredated nests in 2006 was higher than in 1997 and 2000. Furthermore, removal of Raccoons may have also reduced adult Diamondback Terrapin mortality. In 2005 we found fewer turtle nests than we did in the two previous years. There are several factors that could account for fewer nests and still be in agreement with reduced Raccoon depredation. While researchers can locate intact Diamondback Terrapin nests by following crawls, it is much easier to find depredated nests. Those nests predated by Raccoons are especially obvious, with open nest cavities and visible eggshell fragments. Therefore, when Raccoons are eliminated as nest predators, there are fewer depredated nests to be observed. For example, over 75% of depredated nests located by Butler et al. (2004) were those found already depredated. However, in 2005, only

TABLE 2. Comparison of the number of Diamondback Terrapin (*Malaclemys terrapin*) nests recorded, monitored nests, other depredated nests, and other successful emergences from intact nests in 2005 to those in 1997, 2000, and 2006 on Saw Pit Island, Duval County, Florida. Numbers of each are followed by percentages of total nests discovered in parentheses when appropriate. Data from 1997 and 2000 (Butler et al. 2004) have been modified to align datasets.

	1997	2000	2005	2006
Monitored Nests (See Table 1)	114	112	93	45
Other Depredated Nests	301 (66.3)	288 (63.2)	26 (13.5)	256 (70.7)
Other Successfully Emerged Nests	39	56	73	61
Total Nests Discovered	454	456	192	362

13.5% of nests (26 of 192) were found because of obvious signs of predation. Another factor in the lower nest count in 2005 could be the loss of the 45 adult female Diamondback Terrapins found dead on the island prior to the nesting season. In some populations, Diamondback Terrapins oviposit two or even three times each season (Seigel 1980b, 1984; Roosenburg and Dunham 1997; Feinberg and Burke 2003). The loss of 45 adult female Diamondback Terrapins at our study site may account for a reduction in 45–135 nests in 2005.

While we never observed Diamondback Terrapins being killed by Raccoons, and carcasses were weathered such that we could not be certain of the cause of death, other studies have implicated Raccoons in the death of adult Diamondback Terrapins. Seigel (1980a) observed a terrapin being killed by a Raccoon and reported that at least 10% of female Diamondback Terrapins at Merritt Island National Wildlife Refuge, Florida, were killed by Raccoons during his study. He further suggested that predation on adult terrapins could be one cause of an apparent long term decline of that population (Seigel 1993). Similarly, Feinberg and Burke (2003) attributed most adult Diamondback Terrapin mortality at Gateway National Recreation Area to predation by Raccoons. We believe that a large proportion of the 45 dead adult Diamondback Terrapins we collected were killed by Raccoons. Furthermore, after successfully removing 29 Raccoons from our study area, we did not record a single adult Diamondback Terrapin death for the duration of our survey.

Fish Crows, Fire Ants, and plant roots are probably not directly affected by Raccoon population levels. Fish Crows are present on the nesting beach only during the early part of the season when they also nest on the island. They are diurnal predators that find nests by watching Diamondback Terrapins lay them. Fire Ants appear to depredate hatchlings rather than intact eggs, while most nest predation by Raccoons occurs within 24 h of oviposition (Feinberg and Burke 2003; Butler et al. 2006). Other studies have recorded plant roots causing egg mortality as roots either penetrate eggshells or become so thick that they impede hatching (Lazell and Auger 1981; Stegmann et al. 1988; Roosenburg 1992; Butler et al. 2004). It is conceivable that with Raccoons removed, more nests would survive to become surrounded by plant roots. We recorded three nests that failed to hatch completely due to plant root interference in 2005 compared to zero in 1997 and two in 2000.

We have demonstrated that Raccoon removal can be a successful management tool for lowering predation of Diamondback Terrapin nests and enhancing successful emergence on a small island nesting beach. When this technique is employed, it will be necessary for the researchers to exercise persistence and diligence in their trapping protocol. For example, in 2005, after nearly two weeks with no Raccoon tracks noted, new tracks were observed over a four day period and nine nests experienced predation by Raccoons. Once trapping resumed, five more nests were depredated before three Raccoons, likely responsible for some or all of those predation events, were captured. Had those nests not been destroyed, total nest predation would have been 19 (9.8%) and nest predation by Raccoons would have been nine (4.7%).

During the nesting season following the study (2006), Raccoons were not removed and depredation on Diamondback Terrapin nests returned to nearly 70% with most of the damage again caused by Raccoons (Joseph Butler, pers. obs.). This suggests that Raccoons emigrated onto the island from surrounding islands (Fig. 2) to fill open niches. Another interesting observation is that the proportion of nests depredated in 2006 was greater than in all three previous study years. We attribute this to the hurricane (Ophelia) and tropical storm (Tammy) damage to the island in 2005 that resulted in far less available nesting habitat for Diamondback Terrapins. This loss of habitat could have resulted in nest "clumping," making it easier for predators to find more nests. Raccoon reduction during one Diamondback Terrapin nesting season does not assure continued decreased nest depredation in subsequent years. For removal of Raccoons to be successful, removal must occur each nesting season. Furthermore, it may be important to monitor and trap in surrounding areas to reduce local Raccoon source populations.

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