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NESTING MOUNDS WITH PROTECTIVE BOXES AND AN ELECTRIC WIRE AS TOOLS TO MITIGATE DIAMOND-BACKED TERRAPIN (*MALACLEMYS TERRAPIN*) NEST PREDATION

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***Abstract.*—Diamond-backed Terrapin (*Malaclemys terrapin*) nests are susceptible to predation by a variety of meso-predators, predominately Raccoons (*Procyon lotor*). The Downing-Musgrove Causeway (DMC) leading to Jekyll Island, Georgia, USA, is a hot spot for nesting Diamond-backed Terrapins with road mortality and nest predation driving population declines. We designed and constructed artificial nest mounds with protective nest boxes to intercept female terrapins prior to accessing the causeway while simultaneously providing nest security from predators. Initial data indicated that terrapins nested on constructed nest mounds, but that predators were accessing nests within the boxes. In 2013, we used a battery and solar panel to electrify antipredator wiring that was placed along the entrances of connected nest boxes. We used time-lapse photography from wildlife cameras to document nesting terrapins and to estimate nest predation rates. We compared nest predation rates of electrified nest boxes to those without. Only one nest out of 27 was depredated in boxes with an electric wire. Conversely, 100% of known nests were depredated when no electric wire was present. We excavated nest boxes in autumn and/or spring and found high rates of egg survivorship and hatching success. The results of this study suggest that artificial nesting mounds can be used to promote recruitment of terrapins by protecting nests at local hotspots so long as proper defenses are in place.**

Key Words.—nest box, nest excavation, nest mound, *Procyon lotor*, Raccoon

INTRODUCTION

The Diamond-backed Terrapin (*Malaclemys terrapin*) is the only species of North American emydid turtle to subsist solely in brackish water (Wood 1977), thriving along the eastern seaboard as far north as Cape Cod, Massachusetts and south around Florida to Texas in the Gulf of Mexico. Female terrapins emerge from salt marshes in late spring through summer in search of ground above the high tide line on which to nest (Burger and Montevecchi 1975). Causeways that bisect coastal marshes, connecting the mainland to barrier islands, provide well-drained, elevated land that attracts gravid female terrapins but subjects them to vehicle induced mortality (Wood and Herlands 1997; Grosse et al. 2011; Crawford et al. 2014a, b). Diamond-backed Terrapins are currently listed as a Species of Concern in Georgia (Georgia Department of Natural Resources 2005) and several long-term studies suggest that the species as a whole is in peril (Seigel 1993; Gibbons et al. 2001; Dorcas et al. 2007; Hart and Lee 2007).

Even small reductions in numbers of adults can have a relatively large impact on long-lived turtle populations (Congdon et al. 1993; Heppell 1998). Therefore, mitigating the mortality of adult female terrapins is the first and foremost priority to prevent further declines in terrapin populations. However, reduced recruitment due to nest predation by mammalian meso-predators, predominately Raccoons (*Procyon lotor*; Burger 1977; Goodwin 1994; Munscher et al. 2012), is further exacerbating decline. Raccoons routinely visit turtle nesting sites during the nesting season, possibly by following the fresh scent trails of female turtles (Strickland et al. 2010) and cueing in on fresh oviposition by-products (e.g., urates; Burke et al. 2005), rather than the smell of buried eggs *per se*. Raccoon populations around human developments are usually food-subsidized (Smith and Engemen 2002), resulting in larger populations (Gerht et al. 2002) and increased predation pressure on turtle nests (Schmidt 2003). Therefore, cost-effective techniques that provide suitable and safe nesting areas that intercept terrapins before they reach the road could mitigate population declines (Crawford et al. 2014a).

Our long-term research program with Diamond-backed Terrapins at Jekyll Island, Georgia, USA aims to mitigate terrapin road mortality while increasing recruitment by protecting nests from predators. In 2009, we constructed nesting mounds above the high tide line between the saltmarsh and road surface at local areas of concentrated nesting (Crawford et al. 2014b). Additionally, we protected these nesting areas by constructing boxes made of lumber and hardware cloth to prevent nest predator entry (Buhlmann and Osborn

2011). While initial studies documented some terrapin activity in nest boxes (Grosse et al. 2015), formal estimates of nesting females were not obtained. Furthermore, nest predations were recorded in nest boxes (Grosse et al. 2015) suggesting that the boxes were not predator proof. Prior studies provide evidence that electrified wires attached to nest boxes might offer a suitable deterrent to mammalian nest predators (Lokemoen 1982; Mayer and Ryan 1991; Bennett et al. 2009). In 2013, we conducted a predator deterrent study and modified nest boxes at our most active site with an electric wire and monitored terrapin nesting activity with wildlife cameras. The specific goals for this study were to: (1) estimate the number of female terrapins nesting at a monitored nesting mound; (2) document the number of depredated nests within nest boxes on nest mounds; (3) determine the efficacy of an electric wire to prevent nest predation; and (4) determine nest survivorship to hatching.

Materials and Methods

In 2009, we established 12 elevated, well-drained nesting mounds, each approximately 7.3 m long (24 ft) × 3.6 m wide (12 ft) × 1.2 m tall (4 ft) using dredge material along the shoulders of the 8.7 km Downing Musgrove Causeway (DMC) leading to Jekyll Island, Georgia, USA. We added nesting boxes to the tops of the mounds designed to protect nests from Raccoon predation (Fig. 1A). These nesting boxes measured 3.7 m long (12 ft) × 1.2 m wide (4 ft) × 0.6 m tall (2 ft). An 8.9 cm (3.5 in) horizontal gap between two wood boards at the base allowed terrapins to enter, but discouraged predators (Fig. 1B). The lower board was buried underground, but flush with the surface (Fig. 1C). In 2010, we installed 15.2 m (50 ft) sections of Tenax® plastic fencing (TENAX Corporation, Baltimore, Maryland, USA) with 1.3 cm (0.5 in) mesh on three nest mounds to help funnel turtles to the nest mounds and boxes (Fig. 1D).

Based on results of studies conducted from 2009–2010, in 2011 we relocated six of the 12 nest boxes and consolidated them at a local concentrated nesting area (i.e., a 100 m section of roadway where 21–40 female terrapins were documented crossing in a nesting season; Crawford et al. 2014b). This hotspot, designated 79 South (79S, Fig. 2A), runs adjacent to the intersection of a tidal creek (Cedar Creek, Fig. 2B) and the DMC. We placed the six nest boxes (labeled A through F) linearly end-to-end on a newly constructed 22.9 m long (75 ft) nest mound (Fig. 1E, Fig. 2A). We modified all boxes by placing a 3.8 cm × 8.9 cm (1.5 in × 3.5 in) wood beam in the 3.7 m (12 ft) road-side gaps, and wire mesh in the 1.2 m (4 ft) side gaps, thus providing entry and exit to terrapins from the salt marsh side only. This design prevented females from continuing through the box and onto the road. Consolidation of boxes effectively created a 22.0 m long (72 ft) nest box atop the mound to maximize the likelihood that it would intercept the natural path of females leaving Cedar Creek in search of adequate nesting grounds. Additionally, we added 5 m of Tenax® plastic fencing to both ends to help funnel terrapins to the mound that might otherwise go towards the road.

Prior to the start of the 2013 nesting season, we placed an electric wire along the opening of the six nesting boxes (A-F) at Site 79S. We used a Zareba Red Snap'r®, battery-powered fence charger (Woodstream Corporation, Lititz, Pennsylvania, USA), 17-gauge aluminum wire, a galvanized grounding rod, rechargeable 12V deep cycle marine battery, and a Sunforce 1.5-Watt Powersports Charger (Sunforce Products Inc., Montreal West, Québec, Canada) to help maintain charge on the battery. However, the battery needed to be replaced and recharged fully every 2–3 weeks. We placed the fence charger, battery, and solar panel inside a plastic bin with latching lid. We drilled two holes into the bin to run the ground and fence wires; the holes were then sealed with silicone to prevent rain water from entering. We placed the bin with the electric fence equipment in the front right corner of Box A to prevent other animals or the public from disturbing the equipment. The electrified wire ran along the entire nest box entrance at a height equal to the top clearance level of the opening. To keep the wire taut and prevent contact with the box, we used plastic wire insulators along the line as needed (Fig. 1F).

We monitored the six nesting boxes (A-F) at Site 79S for nesting terrapins and depredated nests (10 May 2013 to 11 July 2013; the entire study period) using two Cuddeback Attack® IR wildlife cameras (Cuddeback Digital, De Pere, Wisconsin, USA) set for time-lapse photography (one photo every 12 s). We set cameras approximately 3 m above the ground on a wooden support structure (Fig. 1G). We positioned Camera 1 on the eastern side of the wood post and adjusted to view Box A alone and Camera 2 on the western side of the wood post and was adjusted to view the line of Boxes C-F giving it a greater field of view, but smaller resolution compared to the camera focused on Box A. Box B was in a blind spot of both cameras and although it received the same treatments as C-F, we did not include it in the camera trap analysis. Ambient light levels detected by light sensors within the cameras determined recording times for cameras, allowing only for diurnal pictures. Therefore, the time cameras spent recording varied daily based on sunrise and sunset, but were operational approximately 0600 to 2030.

We visited Site 79S four to five times per week to collect data on nest predation and collect/replace SD cards in cameras. Any depredated nests within a box were noted and the contents removed to prevent

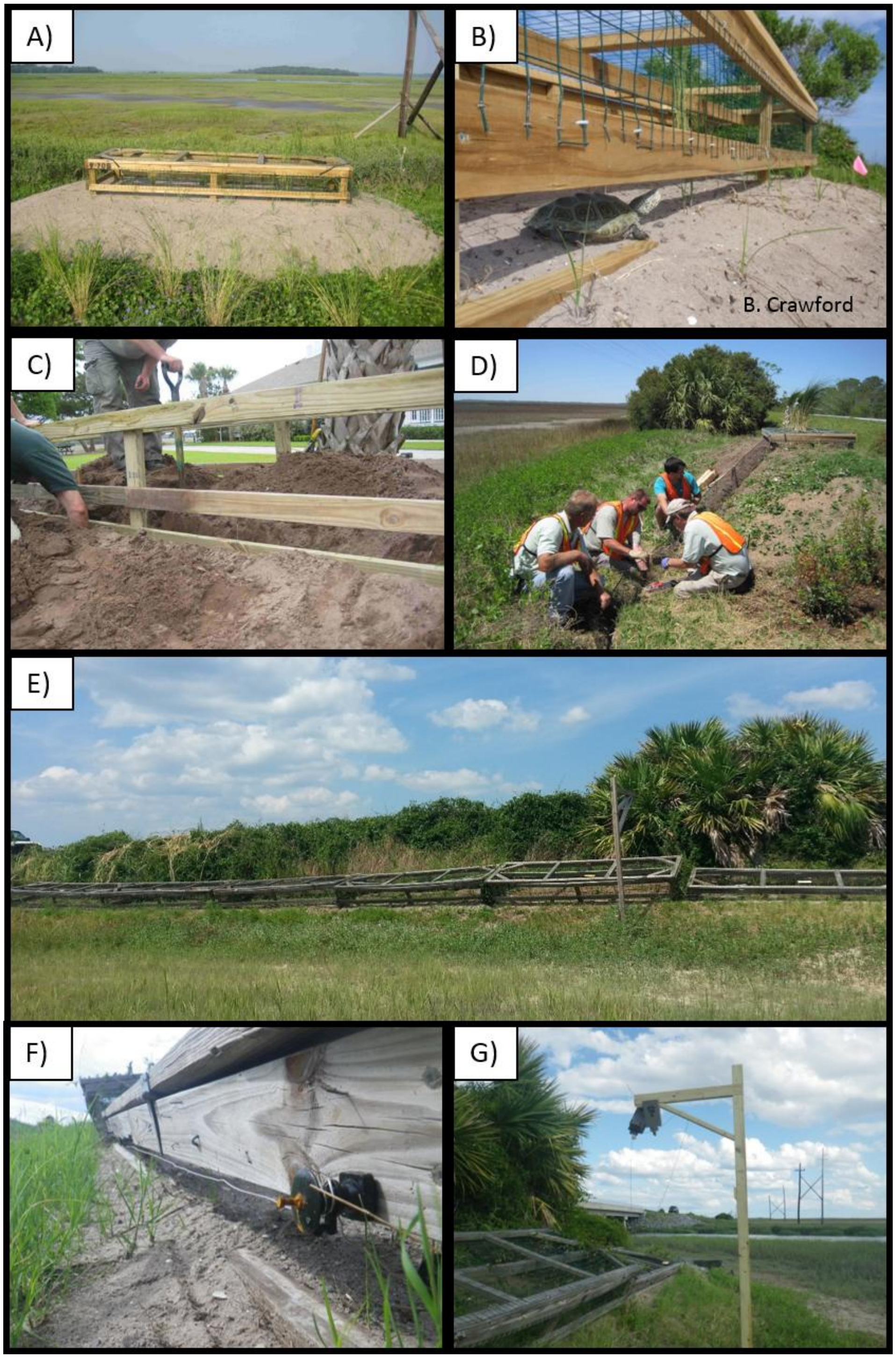

FIGURE 1. (A) Nest box of Diamond-backed Terrapins (*Malaclemys terrapin*) situated on top of nest mound open towards the marsh. (B) 8.9 cm opening to nest boxes are the width of 3.8 cm × 8.9 cm (i.e., standard 2 × 4), allowing the average terrapin shell height to clear the opening. (C) Nest boxes were dug into nest mounds to prevent Raccoons from digging under the structure to reach nests. (D) Tenax® drift fences extended from nest boxes to direct terrapins to nest boxes. A causeway is visible in the back right corner of the image. (E) A line of six boxes at Site 79S to intercept terrapins. (F) Electric wire on Box A set directly above the clearance of the box opening with black wire insulators to prevent contact with the wooden frame. (G) Two Cuddeback Attack IR® cameras placed on 3.05 m tall wooden support structure. Camera on left is looking directly down at Box A. Camera on the right is looking down the line of boxes, beginning in the foreground. (Photographed by Brian Crawford [B], Daniel Quinn [E, F, and G], and Kurt Buhlmann [A, C, and D]).

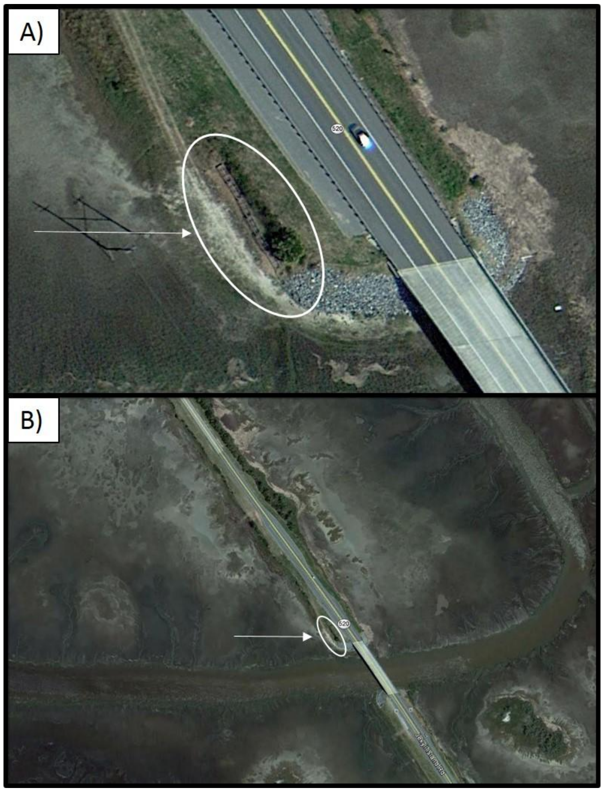

FIGURE 2. (A) Aerial image of six nesting boxes of Diamond-backed Terrapins (*Malaclemys terrapin*) at Site 79S along the Downing-Musgrove Causeway (DMC) leading to Jekyll Island, Georgia, USA, from U.S. Highway 17. Arrow points to boxes (Photograph from Google Images). (B) Aerial image of Cedar Creek running under the DMC adjacent to Site 79S. Arrow points to boxes (Photograph from Google Images).

accidental recounts. When analyzing photographs, we recorded female terrapin activity from the time an individual appeared in the camera to the time the terrapin left the field of view of the camera. We estimated a nesting event based on the amount of time a terrapin was in a box. Terrapins typically take a minimum of 20 min to nest along the DMC (pers. obs.), so any individuals within a box for ≥ 20 min were presumed to have nested if they exited back towards the salt marsh. We defined nest predation rate (hereafter predation rate) as a percentage of counted nests relative to those we found depredated within boxes. We used Cuddeback Trophy Room™ software (Cuddeback Digital, De Pere, Wisconsin, USA) to view all images from cameras.

We divided the study into two time periods: Period 1 lasted from 10 May 2013 through 14 June 2013 (35 d) and Period 2 lasted from 15 June 2013 through 11 July 2013 (26 d). During Period 1, we activated the electric wire along the entrance to Box A (the easternmost box in the line). Boxes B-F went unprotected during Period 1, with no wire present. During Period 2, we extended the electric fence from Box A to run the length of all six boxes (A-F). We compared predation rates between Box A and Boxes C-F during Period 1, when only Box A was electrified. We also compared predation rate in Boxes C-F between Period 1 (not-electrified) and Period 2 (electrified). Finally, we summarized overall predation rate in boxes protected by an electric wire compared to non-electrified boxes throughout the entire study period. We used Fisher's Exact Test in Program R (Version 3.1.0; R Development Core Team 2014) to identify effects ($\alpha = 0.05$) of the electric wire on predation rate in each of our three comparisons. We excavated a portion of nest boxes in November 2013 and the remainder in April 2014 to enumerate the number and survivorship of nests. We dug to a depth of 20–25 cm (8–10 in) and counted hatched eggs, unhatched eggs, and overwintering hatchlings.

RESULTS

Period 1.—During Period 1, we recorded 41 females entering boxes at Site 79S (Table 1) of which 41.4% nested. Twenty entered Box A (49%) and 21 entered Boxes C-F (51%). Of those that entered, we estimated that 40% nested in Box A, and 43% nested in Boxes C-F. We recorded zero nest predations in Box A (0% predation rate); however, we found all estimated nests were depredated in Boxes C-F (100% predation rate) plus seven more (i.e., the estimated number of nests was nine but the depredated nest count was 16; see Discussion). Predation rate in Box A was significantly lower than Boxes C-F (Fisher's Exact Test; $P < 0.001$).

Period 2.—During Period 2, we recorded 33 females entering boxes visible to cameras at Site 79S of which 58% nested. Twenty-two entered Box A (67%) and 11 entered Boxes C-F (33%). Of those that entered, we estimated that 59% nested in Box A and 55% nested in Boxes C-F. We recorded one nest predation in Box A (7.1% predation rate) and zero in Boxes C-F (0% predation rate). The depredated nest in Box A was not actually ingested as all other predated nests in this study, but the eggs were found on the surface of the soil, broken open with yolk and embryos still present. However, the exact nest location was out of the field of view of the camera and therefore we did not witness the event directly and have recorded it as a depredated nest (but see Discussion). Predation rate in Box A was not different than Boxes C-F (Fisher's Exact Test, $P = 1.00$). Comparing Boxes C-F predation rate in Period 2 with Period 1, Boxes C-F in Period 1 had a significantly higher predation rate than Boxes C-F during Period 2 (Fisher's Exact Test, $P < 0.01$).

TABLE 1. Nest activity of Diamond-backed Terrapins (*Malaclemys terrapin*) in 2013 at six nesting boxes at Site 79S along the Downing-Musgrove Causeway in Glynn County, Georgia, USA, based on camera trap observations and nest predation counts. For No. false crawls, females that entered presumably left before nesting. For No. depredated, asterisks (*) indicate higher nest predation than estimated number of nests based on camera trap data. Not all terrapins that entered were seen on the cameras, which led to more predation in unprotected boxes than the number of nests estimated (See Discussion).

	Boxes		
Period	A	C-F	Total
1 (Electric wire on Box A only)			
No. of females entered	20	21	41
No. confirmed nests	8	9	17
No. false crawls	12	12	24
No. depredated	0	16*	16*
Predation rate	0%	100%	-
2 (Electric Wire on all boxes)			
No of females entered	22	11	33
No. confirmed nests	13	6	19
No. false crawled	9	5	14
No. depredated	1	0	1
Predation rate	7.1%	0%	-
Combined (1 and 2)	Elect.	Non-Elect.	
No of females entered	53	21	74
No. confirmed nests	27	9	36
No. false crawled	26	12	38
No. depredated	1	16*	17*
Predation rate	3.8%	100%	-

Periods 1 and 2 combined.—After combining Periods 1 and 2 to compare the entire season of data on electrified and non-electrified boxes, we recorded 74 females entering boxes of which 49% nested. Fifty-three females (72%) entered boxes that had an electric wire (i.e., Box A during Periods 1 and 2 and Boxes C-F during Period 2) and 21 entered boxes without an electric wire (28%). Of these, we estimated that 51% nested in boxes with an electric wire and 43% nested in boxes without an electric wire (i.e., same as Period 1 results for Boxes C-F). Only one nest of 27 was depredated throughout the study (3.4% predation rate) when an electric wire was present, whereas all known nests were depredated when an electric wire was not present (100% predation rate). Ultimately, electrified boxes had a lower predation rate than non-electrified boxes (Fishers Exact Test, $P < 0.001$).

Nest excavation.**—**We found 22 live overwintering hatchlings in November 2013 at Site 79S, and we only excavated approximately 17% of the total nest box area. We excavated the remaining 83% in April 2014. We found 203 hatched eggs comprising 37 clutches (including Box B). We discovered more nests in boxes closer to the edge of the water (i.e., Box A; Fig. 3). Although the electric wire had been turned off after the nesting season ended, we found no signs of mammalian predation, but there were several instances of Fire Ant (*Solenopsis invicta*) predation on hatchlings (Table 2). We found hatchlings, presumably overwintering, within their nest chambers in November. Because they had been disturbed, we collected the 22 live hatchlings and reared them over the winter at the Georgia Sea Turtle Center (GSTC) as part of a separate head-starting study. During April 2014, we recovered four additional live, overwintering hatchlings, which were released at the salt marsh edge. Since we only excavated 17% of nest mounds in November, we assumed that most overwintering hatchlings had already left the nest by mid-April when the second excavation occurred.

DISCUSSION

Data from this study demonstrated that an electrified wire is an effective deterrent to Raccoons attempting to enter nest boxes. Without an electric wire, we documented complete destruction of all nests, suggesting that nest mounds and boxes may actually attract predators and hinder recruitment if not adequately protected. Conversely, only one of 27 nests was destroyed while an electric wire was activated. This depredated nest, whose eggs were found broken, but uneaten on the surface, may actually have been incidentally excavated by another nesting terrapin, as another intact clutch of eggs was later found below the destroyed one.

We feel it is unlikely that all Raccoons that attempt to gain access into the nest boxes succeed. Rather, the majority of depredations may be due to a small number of individual Raccoons that learn how to gain access and ultimately destroy all or most of the nests. These individuals may be exhibiting habit depredation, as termed by Leopold (1933), which can be detrimental to applied management efforts. Although it is possible to target and trap select Raccoons that learn how to predate nests, our collective experiences here and elsewhere indicate that public outcry regarding lethal dispatch of Raccoons, as well as ecological concerns over relocation of live Raccoons, make this a challenging problem. We were able to address this issue by using an electric wire. This wire was situated such that it would not contact the carapace of a terrapin and our photographic evidence suggested that the electric wire did not deter terrapins from entering and using the nest boxes. So, while nest mounds may become predator targets, they can be protected. More importantly, in this specific case, they helped prevent the loss of adult female terrapins to road mortality (i.e., reduced mortality on the adjacent road after line of boxes was placed at Site 79S in 2011; Brian Crawford, pers. comm.).

Unfortunately, we were not able to capture every nesting event on our cameras. Based on our camera data collected during Period 1, we predicted that there should have been only nine nests at Boxes C-F, yet we found 16

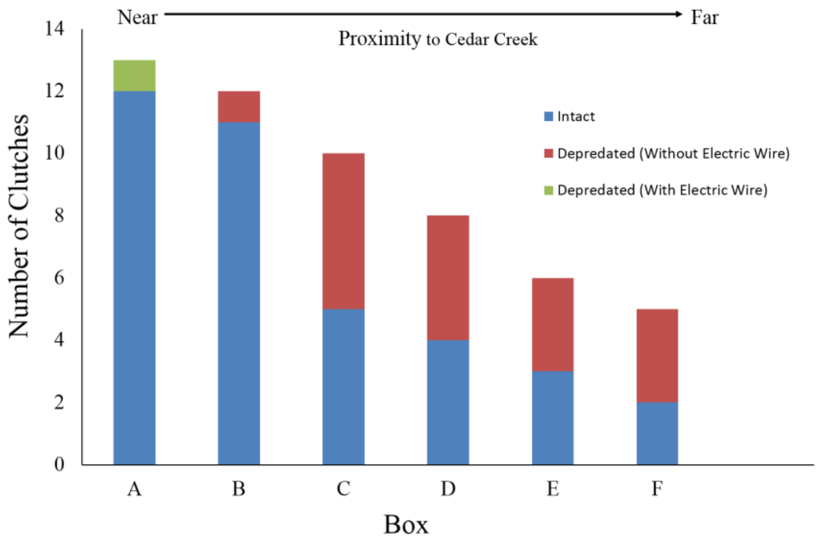

FIGURE 3. Number of nests of Diamond-backed Terrapins (*Malaclemys terrapin*) laid per nest box at Site 79S adjacent to the DMC. The number laid was based on depredation counts and excavation data. Box A is nearest to the adjacent tidal creek (i.e., Cedar Creek, where terrapins stage prior to nesting) at approximately 10 m and Box F is farthest at 22 m.

depredated nests. These data imply that we failed to document some nesting females with the cameras, perhaps because our cameras were not designed to operate at night. While nocturnal nesting is relatively rare around the DMC (Crawford 2011), other studies have documented nesting between nightfall and dawn (Wood and Herlands 1997; Szerlag and McRobert 2006) and this may account for the additional number of nests. It is also possible that some terrapins were simply not spotted on the cameras due to the relatively small resolution available from Camera 2 or the 12 s time lapse. We may have also overestimated the minimum nesting time (observed to be about 20 min in this study) by some female terrapins, and therefore some of the presumed false crawls we documented were actually successful nesting events. Because of the increased numbers of nests, we feel that our nest estimates are conservative and that there were likely more nests at Site 79S than what we counted in photographs. This conclusion is further supported by the larger number of nests excavated at the site the following autumn and spring. Specifically, we excavated 26 clutches (excluding Box B), seven more than we would have expected based on our camera data. So while we may have been unable to account for the exact number of nests in boxes based on our cameras, it is likely that nesting occurred at the site at rates equal to or greater than what we estimated. We think that the striking difference in predation rates between boxes that were protected and those that were not serves to demonstrate that the exact number of nests may be inconsequential to our conclusions.

In addition to helping verify the number of clutches at Site 79S, the nest excavation data enabled us to quantify clutch survival, further supporting our hypothesis that nest boxes could be a valuable conservation tool. Our excavations of the nest boxes post-nesting season indicated that at least 37 nests successfully hatched. Even though the electric wire was turned off before eggs would have hatched, we saw no further signs of nest predation when we excavated nests. We suggest that these results provide strong evidence that Raccoons reduce their search effort after the female turtles are no longer on land searching for nest sites. Cautiously, we suggest that nest boxes may only need to be electrified while the females are actively nesting, making this potential conservation tool more attractive to implement.

We also suggest that nest mounds constructed in the pathways used by numerous terrapins can intercept females on nesting forays, provide them with suitable nesting sites, and likely prevent their mortality on roadways. Wildlife fencing is often used to facilitate (in conjunction with wildlife tunnels under roads) the movement of animals from one side of a roadway to the other (Taylor and Goldingay 2003; Dodd et al. 2004; Aresco 2005). However, our objective for female terrapins approaching salt marsh causeways is to provide them nesting sites before they reach the road. Without nesting sites, terrapins may either walk around fence ends or simply nest in unsuitable soils along the fence barrier, thus enabling predators to readily search for and pillage nests (pers. obs.). Nest boxes placed on top of

TABLE 2. Nest mound excavation by Diamond-backed Terrapins (*Malaclemys terrapin*) for each box at Site 79S from November 2013 and April 2014. Mortality on nest post hatching was due to Fire Ants (*Solenopsis invicta*).

	Box						Totals	Totals
Attribute	A	B	C	D	E	F	(A and C-F)	(all Boxes)
No. hatched eggs	90	56	17	17	12	11	147	203
No. nests	12	11	5	4	3	2	26	37
No. nests with mortality	1	0	0	1	0	0	2	2
Overwintering hatchlings found Nov. 2013	11	0	6	5	0	0	22	22
Overwintering Hatchings found April 2014	4	0	0	0	0	0	4	4

nest mounds along a fence line and in an orientation that facilitates terrapin entry from the salt marsh while blocking exit to the causeway increases the likelihood that female terrapins searching for nest sites will nest inside the boxes, and then return to the salt marsh post-nesting, as we have observed at Site 79S.

Although nest mounds with protected boxes were successful in this study, it would be impractical to place them the entire 8.7 km length of the DMC, much less the longer roadways that affect the species elsewhere (e.g., Wood and Herlands 1997). Instead, they are most effective when used in areas where large numbers of terrapins are known to cross. Driver awareness and outreach programs, as well as traffic warning lights, reduced speed limits, and speed bumps could further reduce mortalities (Crawford et al. 2014a). We recommend the use of nest mounds with electrified boxes along hotspots on the DMC and other roadways to help increase nest survival and hatching success while potentially reducing female road mortality. Furthermore, we suggest that this technique could benefit other turtle species that face the combined threats of female road mortality and nest predation during the nesting season.

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