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Assessing the effectiveness of different sea turtle nest protection strategies against coyotes

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ABSTRACT

Depredation of sea turtle nests, where a nest is either partially or completely predated by a predator, is particularly detrimental to the reproductive output of sea turtles and consequently a concern for sea turtle conservation efforts globally. To minimize depredation of sea turtle nests, several protective strategies have been trialed against different predators. However, although information on their effectiveness exists, information on the effectiveness of strategies aiming to mitigate depredation by coyotes, which is an issue at loggerhead turtle, *Caretta caretta*, nesting beaches in Florida and globally is inexistent. To inform future management of sea turtle nest depredation by coyotes, this study evaluated the effectiveness of three nest protection strategies (self-releasing metal cage, self-releasing plastic cage, and self-releasing metal screen). Further, to obtain insights into coyote behavior during depredation activities and inform management strategies, we used infrared camera surveillance to monitor sea turtle nests. Self-releasing plastic cages were found to be the most effective strategy at mitigating coyote depredation on loggerhead nests. Our findings provide important information for consideration when developing depredation mitigation strategies in the region and globally.

1. Introduction

Sea turtles face an array of threats in both their terrestrial and oceanic habitats (Jackson et al., 2001; Miller et al., 2003; Pauly et al., 2005; Wallace et al., 2010a; Wallace et al., 2010b), as a consequence, they are listed as vulnerable, endangered, or critically endangered by the International Union for Conservation of Nature (IUCN; IUCN, 2019). At their terrestrial nesting grounds, these threats include, but are not limited to coastal development (Fuentes et al., 2016; Lopez et al., 2015; Sella and Fuentes, 2019; Sella et al., 2019), changes in climate (Butt et al., 2016; Fuentes et al., 2011; Fuentes et al., 2019; Montero et al., 2018), nesting obstructions (Cope, 2016; Woodward, 2012), pollution (Beckwith and Fuentes, 2018; Erb and Wyneken, 2019; Garrison and Fuentes, 2019; Laist, 2011), inundation (Brazier, 2012; Brost et al., 2015; Butler et al., 2020), poaching (Catry et al., 2009; Nel, 2006; Nel et al., 2013), and depredation (Eckert et al., 1999; Erb and Wyneken, 2019; Greenwood et al., 2010; Stewart and Wyneken, 2004), all of which negatively affect nests, hatchlings and ultimately, sea turtle productivity (Brost et al., 2015; Ehrhart and Witherington, 1987). Sea turtle nest depredation, an event where a nest is either partially or completely predated by a predator (Eskew, 2012) is particularly detrimental to nest productivity and is a concern for sea turtle conservation efforts globally (Conant et al., 2009; Eskew, 2012; Hof et al., 2020; Lei and Booth, 2017; Margaritoulis, 2005; NMFS and FWS, 2008).

Depredation has impacted many sea turtle nesting grounds globally (Brost et al., 2015; Butler et al., 2020; Engeman et al., 2016; Engeman et al., 2006; Hecht and Nickerson, 1999; Hof et al., 2020; Lei and Booth, 2017; Whytlaw et al., 2013) and it is likely that continued and future expansion of coastal development may increase predation since development may limit food availability for different fauna forcing them to seek alternative food sources, which could result on predation of sea turtle nests (Barton and Roth, 2008; Engeman et al., 2002a, 2002b; Engeman et al., 2005; Gompper, 2002; Lamont et al., 1998). For example, urbanization of coastal areas in Florida increased the abundance of mesopredators (i.e. raccoons), consequentially increasing the levels of nest depredation on beaches closest to human development (Engeman et al., 2005). Predation in coastal areas can also increase because of introduced-predator strategies to mitigate particular nuisance species (Leighton et al., 2011; Soule et al., 1988). For example, mongooses were introduced in Barbados for rodent control but became the main predator of hawksbill turtle, *Eretmochelys imbricata,* eggs along the coast of Barbados (Leighton et al., 2011). Also, certain predator

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removal strategies (e.g., raccoon removal) could increase levels of depredation as primary predators (i.e. raccoons) naturally limit secondary predator abundances (i.e. ghost crabs), whereby reducing primary predator populations, could result in drastic increases in secondary predator abundances, in turn intensifying the overall predation of sea turtle nests (Barton and Roth, 2008).

Species known for depredating on sea turtles and their nests vary geographically but predominantly includes raccoons (*Procyon lotor*; Barton and Roth, 2007; Engeman et al., 2005), ghost crabs (*Ocypode quadrata*; Marco et al., 2015), fire ants (*Solenopsis invicta*; (Greenwood et al., 2010), mongooses (*Herpestes javanicus*; Leighton et al., 2011), skunks (*Mephitis mephitis*; Mroziak et al., 2000), wild cats (*Felis libica*; Weir et al., 2007), armadillos (*Dasypus novemcinctus*; Engeman et al., 2005), wild dogs (*Canis familiaris*; Korein et al., 2019; Pheasey et al., 2018), Jackals (*Canis aureus*; Brown and Macdonald, 1995), red foxes (*Vulpes vulpes*; Yerli et al., 1997), goannas (*Varanus spp;* Blamires, 2004; Hof et al., 2020; Lei and Booth, 2017), feral pigs (*Sus scrufa;* Fuentes et al., 2015; Nordberg et al., 2019), and coyotes (*Canis latranus*; Eskew, 2012). Coyotes, in particular, are an issue at loggerhead (*Caretta caretta)* and green (*Chelonia mydas*) sea turtle nesting beaches in Florida. Coyotes have been documented in 65 of Florida's 67 counties (Main et al., 2000) and continue to be documented on important sea turtle nesting beaches throughout Florida (Brost et al., 2015; Lamont et al., 1998). Several, protective strategies (i.e. restraining cages, self-releasing metal cages, self-releasing metal screens, plastic mesh) have been trialed, with various results, to minimize depredation of sea turtle nests in Florida and at various locations globally (Eskew, 2012; Hof et al., 2020; Korein et al., 2019; Lamont et al., 2012; Lei and Booth, 2017). Nevertheless, the effectiveness of strategies at mitigating depredation from coyotes has not been systematically assessed (Buzuleciu et al., 2015; King, 2016). Further, there is an identified need to explore the use of alternative materials (e.g., magnetically inert metal, wood, or plastic materials) in protective strategies to mitigate depredation of sea turtle nests (FWC, 2016; Irwin et al., 2004). Historically, the primary material used for protection strategies has been magnetic metal (e.g., galvanized steel). Irwin et al. (2004) hypothesized that these metal cages can potentially affect the magnetic orientation and navigation behavior of hatchling sea turtles. However, limited research on the potential implications to the actual navigational ability of hatchlings has been conducted using magnets around the egg chamber (Fuxjager et al., 2014; Salmon, 2019) and no experimental study has tested the effects of metal cages, which are placed above the nest and cause a much lower distortion of the magnetic field (Irwin et al., 2004). Here, we evaluated the effectiveness of three nest protection strategies (self-releasing metal screen, self-releasing metal cage, and self-releasing plastic cage) at protecting loggerhead sea turtle nests from coyote depredation. Additionally, we used infrared camera surveillance to monitor sea turtle nests to obtain insights into coyote behavior during depredation activities to potentially inform deployment and placement of the protective strategies trialed.

2. Methods and materials

2.1. Study site and species

This study was conducted at T.H. Stone Memorial St. Joseph Peninsula State Park (SJPSP), which has approximately 32 km of protected coastline located on the north end of the St. Joseph Peninsula in the Northern Gulf of Mexico (NGM; Fig. 1). For monitoring purposes SJPSP is divided into three sections (A, B, and C), with our study including sections A and B. These sections are in a Wilderness Preserve within the State Park, which was selected due to its pristine nature and lack of human disturbance. Section C is located towards the southern region of the State Park predominantly used recreationally. This remote seafront is an important loggerhead nesting ground for the NGM Loggerhead Recovery Unit (NGM RU; Conant et al., 2009; NMFS and FWS, 2008). This RU is one of the smallest loggerhead RUs in the United States, with an approximate population size of 881 adult females (CI 95%: 284–1714; Ceriani et al., 2019) and an annual average of 1100 nests (range 552–2297) deposited from 1989 to 2018. SJPSP is also one of the Index beaches in the northern Gulf of Mexico, where consistent and standardized nesting survey monitoring has been in place since 1997 (Ceriani et al., 2019). Sea turtle nests have not been consistently protected from predators at SJPSP, although some predator removal and inconsistent use of self-releasing metal cages have been implemented between 2012 and 2018.

2.2. Nesting beach and sea turtle nest monitoring

Monitoring by foot was conducted at dawn from the 15th May to 31st August 2018. For every sea turtle activity encountered, we recorded activity type (nest or non-nesting emergence), date, GPS location and, if the activity was a nest, we recorded the distance of the nest to the high-water mark and the dunes. For each nest, the egg chamber was located (FWC, 2016) prior to treatment deployment. Each confirmed nest was monitored daily for disturbance (i.e. depredation attempts and events, and inundation) until 70 days after the laid date or 72 h after the first sign of hatchling emergence (FWC, 2016). A depredation attempt was defined as a predatory attempt that amounted to digging or scratching around the nest, but where no eggs were taken. A depredation event was defined as a partial or complete predatory event resulting in sea turtle eggs being taken from the nest (Eskew, 2012). If a nest was depredated, information on the date of depredation, predator type, estimated number of eggs depredated (count of eggs damaged/destroyed in or around the egg chamber), and damage to the protection treatment was recorded (see Section 2.2.1 for description of protection treatments). Each nest was classified into three categories based on coyote activities: 1) nests that experienced only depredation attempts were classified as “attempts only”, 2) nests that experienced both depredation attempts and events were classified as “both attempts and events”, and 3) nests that experienced only depredation events were classified as “events only”. For our analyses, depredated nests were quantified from nests that experienced “events only” and “both attempts and events”. However, we only considered depredation by coyotes, since ghost crab depredation was not effectively quantified and is generally considered as a minor threat, where only a small portion of eggs are taken from nests having little impact on hatching success (Brost et al., 2015). Further, the nest protection strategies trialed here were designed for above-surface predation, while ghost crab depredation takes place underground.

Nests were inventoried either 72 h after the first sign of hatchling emergence or 70 days after the eggs were deposited (Brost et al., 2015; FWC, 2016). Nest inventory consisted of excavating the remains of each nest where remnants of the egg chamber (empty shells > 50% of a whole egg's surface area, unhatched whole eggs, damaged eggs, pipped-dead hatchling, pipped-alive hatchling, live hatchlings, dead hatchlings) were quantified to estimate clutch sizes of each nest, hatching and emergence success.

2.2.1. Protection treatments and analysis of their effectiveness

For each identified nest we deployed three protection treatments (self-releasing metal screen, self-releasing metal cage, and self-releasing plastic cage) in rotation with a control nest to allow for random treatment assignment (Supplementary Fig. 1). All treatments were considered “self-releasing” in that the spacing within the mesh material is large enough to allow hatchlings to emerge from the nest without assistance. Control nests received no treatment and were marked similarly to the other nests with stakes for nest identification. All treatments were deployed in accordance with the Florida Fish and Wildlife Conservation Commission's Marine Turtle Conservation Handbook (FWC, 2016). Although the use of magnetically inert material (e.g. anodised aluminum) for protective strategies is encouraged and has

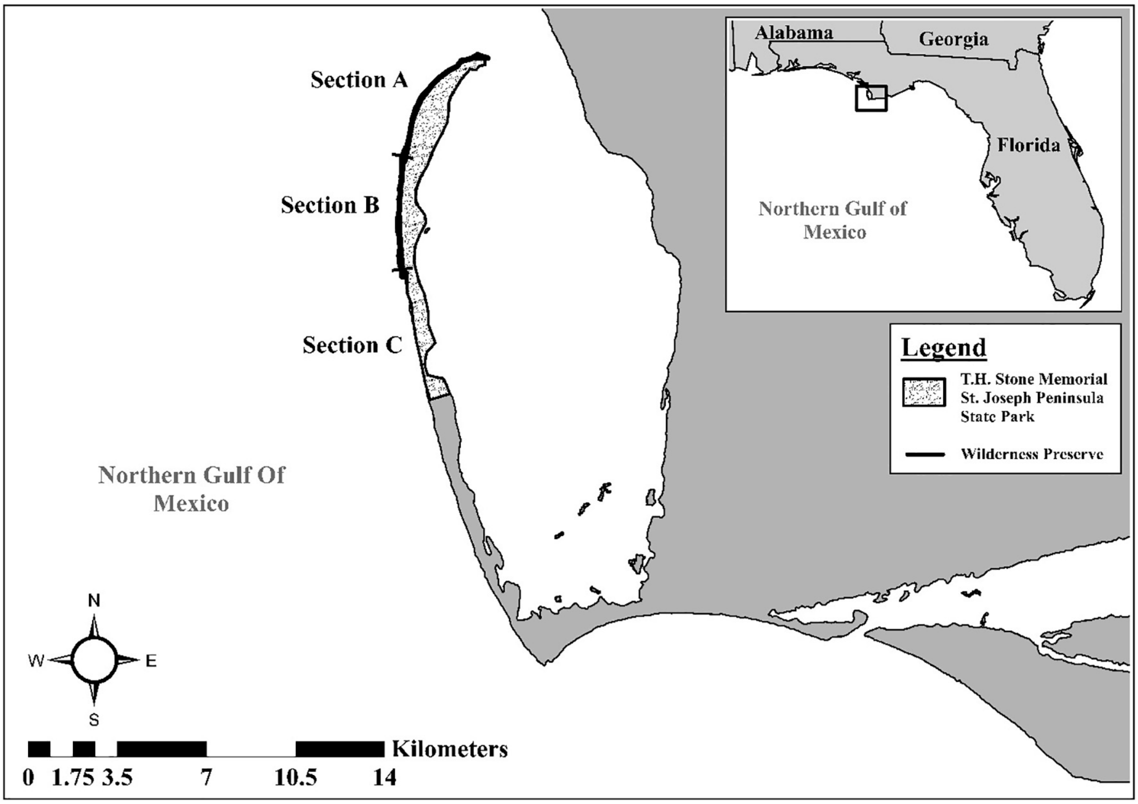

Fig. 1. T. H. Stone Memorial St. Joseph Peninsula State Park (SJPSP) divided into sections (A, B,C) for monitoring purposes, each approximately 4.5 km in length. Dark line representing the Wilderness Preserve (Section A and B) and Section C being the public recreational area within the park.

proven successful against goanna Varanus (Hof et al., 2020; Lei and Booth, 2017) and foxes (Demetropoulos and Hadjichristophorou, 2010), here we used the same material (galvanized steel) and design currently used in the self-releasing metal screens and the self-releasing metal cages at nesting beaches in Florida. This allows us to evaluate the efficacy of current methods against alternative strategies and inform future management decisions in Florida.

Self-releasing metal screens consisted of welded utility wire (91 cm × 91 cm) with 5 cm × 10 cm mesh to allow hatchlings to easily emerge from the nests (Supplementary Fig. 1B). To secure the self-releasing metal screen, three 22 cm plastic tent pegs were distributed around the nest with one in the front ocean-facing side and two in the back dune-facing side-while three wooden stakes were used in the opposite configuration. The self-releasing metal screens were buried approximately 5 cm below the sand surface.

Self-releasing metal cages consisted of three pieces of wielded utility wire (91 cm × 61 cm) secured together by plastic zip ties-with four 15 cm flanges protruding outwards from the base of the frame where the base was open to the egg chamber (Supplementary Fig. 1C). The "self-releasing" cage had a mesh (5 cm × 10 cm) which allowed hatchlings to easily emerge from the nests. The bottom edge of the sides of these cages was buried approximately 30 cm under the sand with the flanges acting as a secondary protection strategy to secure the cages in place. One stake was secured to the dune-side of the cage to indicate nest identification.

Self-releasing plastic cages were similar in size to the metal cages, but rather than using metal wire to construct the cages, we used highly durable PVC (polyvinyl chloride) piping for the framework of the cage (Supplementary Fig. 1D). A Tenax C–Flex polypropylene fencing, was used with a 5 cm × 10 cm mesh zip-tied to the framework allowing for hatchling to easily emerge from the nests. These cages were made entirely of plastic materials to test the effectiveness for an alternative "metal-less" protective strategy. The cages were secured by burying them approximately 30 cm under the sand with the flanges acting as a secondary protection. One stake was secured to the dune-side of the cage to indicate nest identification.

To obtain more information on how coyotes attempt to and successfully depredate on nests, battery-powered infrared trail cameras (RECONYX Hyper Fire High Output Covert IR 3.1 Megapixel Digital Scouting Cameras; Supplementary Fig. 1E) were installed to monitor nests with different protection strategies. Cameras were positioned approximately 90 cm above the surface and 4 m seaward of selected nests to capture potential depredation events (Eskew, 2012; Larrucea et al., 2007). The cameras were secured to two PVC pipes and attached to a metal Wolf Fang anchor that was placed into the sand with a driver and mallet. These cameras had no glow to avoid detection by coyotes and the specifications of the camera were set to a speed of 2 frames per second and a trigger speed of 0.2 s allowing rapid detection of any movement around the nests.

After the nesting season, we plotted all occurrences of coyote activity (i.e. depredation attempts and events) against the cumulative number of sea turtle nests laid and incubating through time (May–October) to assess if any potential trend in coyote activity existed in relation to nest density for the 2018 nesting season (Fig. 2). For our analysis treatment was considered a categorical variable and number of nests predated a continuous variable. Generalized linear models (GLM) specified in the binomial family with a logit function were used (Nelder and Wedderburn, 1972), to determine if treatment type had any effect on depredation events (Model 1) and depredation attempts (Model 2). For this, depredation events received a "1" in Model 1, depredation attempts received a "1" for Model 2, and unaffected nests received "0" for both models (Supplementary material). The significance of the treatment was determined using the analysis of variance (ANOVA) function of the *car* package, with "Type II" (Fox and Weisberg, 2019). Pairwise comparisons after GLMs were performed with estimated marginal means using the emmeans function available in the *emmeans*

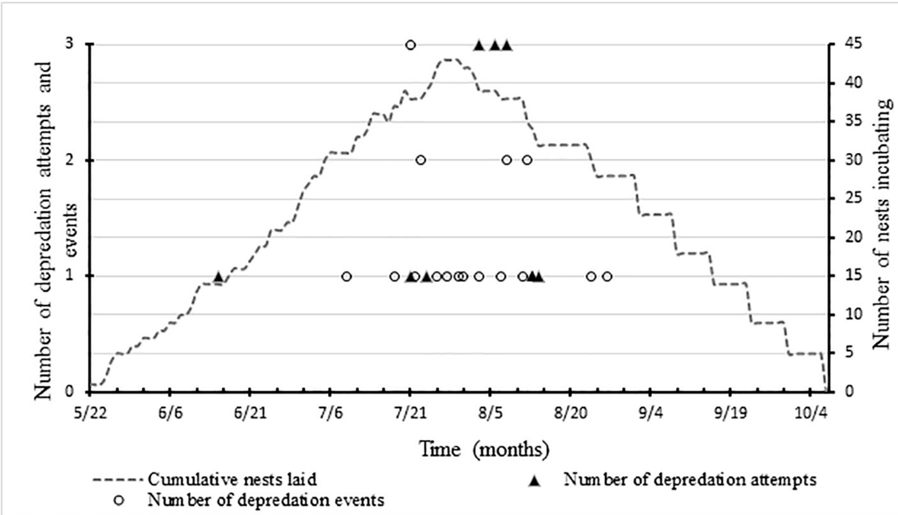

Fig. 2. Temporal scale analysis of the cumulative number of nests, included in the study, laid and incubated in relation to coyote depredation attempts and events during the 2018 sea turtle nesting season at SJPSP. The dashed line indicates the cumulative number of nests laid as well as incubating, while the symbols indicate when depredation attempts, and events took place throughout the nesting season.

(Lenth, 2020) package (Supplementary material). All analyses were conducted in R Studio version 1.3.959 (RStudio Team, 2020).

3. Results

3.1. Loggerhead activity and depredation

A total of 45 nests were considered for our analysis; seven other nests laid during the study period were not considered since they were washed out by storms. Nests had an estimated clutch size of 98 ± 19 SD eggs per nest (62–134 range). Depredation attempts and events occurred independently of one another with no clear pattern between the number of depredation attempts it took for a nest to experience a depredation event. Some nests ($n = 4$) experienced both depredation attempts and events, some experienced only attempts ($n = 5$) or only events ($n = 18$), with the remaining 22 nests experiencing no disturbance from coyotes (Table 1). Of the nests that experienced depredation events, four nests were completely depredated (Table 1) and the remaining nests ($n = 14$) experienced partial depredation. On average, an estimated 49 ± 31 SD eggs (12–106 range) were depredated per nest by coyotes. It took coyotes an average of 44 ± 16 SD days (5–70 range) from when nests were laid to depredate them. The average number of days from lay date to depredation decreased per month as the nesting season progressed (May: 60 days, June: 48 days, July: 31 days); however, only 1 nest laid in June experienced a depredation event and no new nests were laid in August (Fig. 2).

3.2. Effectiveness of protection strategies

Eleven nests were assigned to the control treatment, self-releasing metal screens and self-releasing metal cages, whereas self-releasing plastic cages were deployed on 12 nests (Table 1). Coyote depredation varied between treatments, with coyotes depredating nine control nests, four self-releasing metal screened nests, four self-releasing metal caged nests, and one self-releasing plastic caged nest (Table 1). Treatment was found to have a significant effect on events (Model 1, Chi-squared = 14.415, Df = 3, $P = 0.0023$), with plastic cages being the only treatment significantly different than the control (Tukey's HSD Tests, $P = 0.0148$, Fig. 3, Table 2). However, treatment was found to have no significant effect on depredation attempts (Model 2, Chi-squared = 0.47544, Df = 3, $p = 0.924$).

Table 1
Total number and proportion of nests unaffected by depredation, nests that experienced depredation attempts only, nests that experienced depredation events only, and nests that experienced both depredation attempts and events.

Nests	Control	Self-releasing metal screen	Self-releasing metal cage	Self-releasing plastic cage	Total
Unaffected	1 (9%)	6 (55%)	6 (55%)	9 (75%)	22
Attempts only	1 (9%)	1 (9%)	1 (9%)	2 (17%)	5
Events only	8 (73%)	3 (27%)	2 (18%)	1 (8%)	14
Attempts and events	1 (9%)	1 (9%)	2 (18%)	0 (0%)	4
Total	11	11	11	12	45

3.3. Camera surveillance and coyote depredation behavior

A total of 13 nests (five with self-releasing metal screens, four with self-releasing metal cages, and four with self-releasing plastic cages) were monitored with cameras during the nesting season (Supplementary Fig. 1E) with 11 (84.6% of the monitored nests) recording coyote activity during the nesting season. Seven of the 13 nests had camera surveillance for only part of the incubation period (13–45 days) since cameras had to be removed during storms or when nests were completely depredated. Our footage indicated that coyote activity was predominantly nocturnal, occurring between 9 pm and 5 am, with individual adults or juvenile coyotes (up to two individual coyotes on any given night) seen examining nests and surrounding areas. Most footage revealed coyotes sniffing and scratching around the protection strategy attempting to find an ideal location to breach the

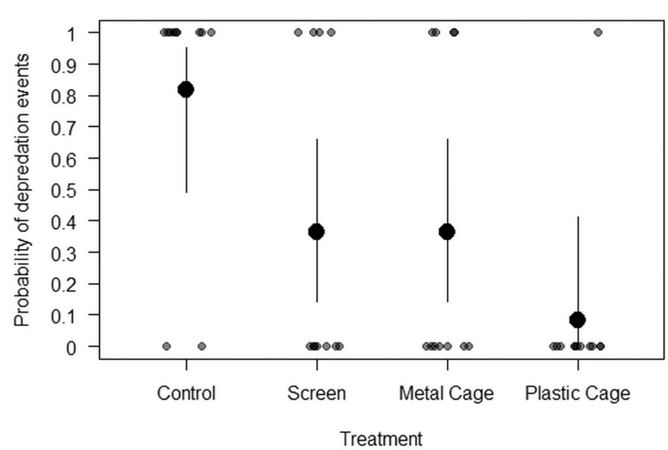

Fig. 3. Binomial Generalized-Linear Model (Model 1) for depredation events with asymptotic 95% confidence limits showing the probability of a depredation event occurring on an individual nest with respect to each treatment.

Table 2
Predicted probabilities, estimated marginal means (EMMS), standard error, asymptotic 95% confidence limits (CL) for model 1 and *P* value when compared to against the control.

	Probability	SE	EMMs	SE	CL	CL	P value
Control	0.81	0.11	1.50	0.78	−0.02	3.036	
Metal cage	0.36	0.14	−0.56	0.62	−1.78	0.669	0.16
Plastic cage	0.08	0.08	−2.40	1.04	−4.44	−0.351	0.01
Metal screen	0.36	0.14	−0.56	0.62	−1.78	0.669	0.16

egg chamber without actively depredating nests. Of the 11 nests with surrounding coyote activity, only 2 nests with cameras recorded depredation attempts and events (a self-releasing metal screened nest and a self-releasing plastic caged nest). Four depredation attempts, and two depredation events occurred (Supplementary Fig. 2A-D) on these nests. Three of the four attempts as well as both depredation event occurred on the self-releasing metal screened nest, and the fourth depredation attempt occurred on the self-releasing plastic caged nest.

During the depredation attempts, coyotes were only seen sniffing and scratching around the treatment without forcefully attempting to get through the protection strategies. During both depredation events, the nest was breached, and eggs were removed from the chamber individually. The first depredation event occurred approximately 9:37 pm when the coyote took 8 min to breach the chamber (Supplementary Fig. 2D) by digging underneath the flat seaward-facing side of the self-releasing metal screen. Once breached, it proceeded to take eggs out of the chamber individually. The initial depredation event lasted approximately 20 min. Two hours later, a second coyote (based on its lighter fur color, smaller body size and darker shade in the tip of its tail) was documented examining the broken eggs, scratching around the nest and further exposing the egg chamber. The second depredation event occurred on the same nest approximately five hours after the second coyote had left the scene. Based on the shade of the coyote's fur, we believe it to be the coyote that originally breached the chamber earlier that same evening.

4. Discussion

The protection strategies trialed here were found to reduce depredation of sea turtle nests by coyotes, but they did not eliminate the problem as some nests were still depredated. Self-releasing plastic cages were the most effective protection strategy trialed when compared to controls. Importantly, the effectiveness of plastic cages suggests the use of protection strategies made entirely of plastic should be further considered to address concerns of the effects of metal cage/screens on hatchlings. We encourage future studies to replicate our approach and determine the effectiveness of predation reduction strategies more systematically and to determine the effectiveness of strategies made of a variety of materials (e.g., plastic, bamboo, aluminum). Indeed, to date, most studies determining the effectiveness of nest protection strategies explore only one individual approach/method (e.g. metal screens compared to nests with no protection against red foxes at Dalyan beach, Turkey (Yerli et al., 1997), and metal cages against raccoons and invasive feral swine (*Sus scrofa*) at Keewaydin Island (Engeman et al., 2016)) while only a few studies compare multiple protection approaches within a nesting site (Addison, 1997; Kurz et al., 2012; Lei and Booth, 2017; Pheasey et al., 2018). However, to date, only one study has compared different predation mitigation strategies against coyotes, where metal screens and habanero powder were tested against coyote depredation at Sand Island, South Carolina, with results showing the survival rates for sea turtle nests significantly varied for each method (Lamarre-DeJesus and Griffin, 2013).

Regardless of the strategy trialed, several studies have indicated that protected nests are often depredated (Engeman et al., 2016; Engeman et al., 2005, 2006; Engeman and Smith, 2007; Eskew, 2012; Lamont et al., 1998; Mroziak et al., 2000), implying the effectiveness of the method is potentially influenced by an array of factors such as predator type (density and distribution), and their ability to identify nests and learn (adapt) during the nesting season. It is known that certain predators (e.g., racoons) use nest cages as landmarks when searching for sea turtle nests (Mroziak et al., 2000). Thus, further studies should explore whether coyotes also use nest markers as a search tool. Further, the deployment and placement of the protection strategies may also affect their effectiveness (Addison, 1997; Mroziak et al., 2000). The correct placement of screen/cages on the nest is particularly important because incorrect installation/placement allows for predators to reach the egg chamber more easily. For example, screens should be fixed in place with tent stakes and covered with about 5 cm of sand (Addison, 1997), and self-releasing cages should be buried approximately 30 cm deep in the sand and secured in place by the surrounding 15 cm flanges. These guidelines exist to make the strategies more efficient and to prevent predators digging around the protection. Adhering to these guidelines requires a considerable time investment by sea turtle patrol staff but it is essential to the success of predation reduction measures. Importantly, a critical step to properly placing protection strategies is to identify the approximate clutch location prior to deployment. This is necessary for centering the protection strategy over the nest correctly (Addison, 1997) and particularly important if screen/cages are smaller than 4 × 4 feet (FWC, 2016). All procedures, if not deployed correctly, would not protect the nest adequately and can potentially allow predators to breach the protection.

When placing protection strategies, consideration should also be given to potential modifications in the morphology of the beach (i.e. from storms and wave activity) and consequent exposure of the nest or modifications to the nest environment, which could potentially increase nest susceptibility to depredation (Addison, 1997). Indeed, depredation events in our study caught on the infrared camera surveillance showed a coyote digging under a metal screened nest relatively easily. This occurred in a location previously eroded by waves, making it easier for the coyote to gain access to the nest. Since nesting beaches are dynamic and their morphology has the potential to change during the nesting season displacing protection strategies, it is important to monitor protected nests consistently, especially after storm activities, as protection structures (cages/screens) might need to be adjusted throughout the nesting season or removed, in case of a major climatic events (e.g. storm, hurricane, typhoon), to avoid beach and ocean littering.

Since the effectiveness of nest protection is dependent on a series of factors, often nest protection by itself is not completely effective. It has been suggested that removal of predators and possibly even night patrol surveys should occur concurrently with nest protection to completely mitigate predation of sea turtle nests (Engeman et al., 2006; Engeman and Smith, 2007; Engeman et al., 2016). For example, a study conducted in the Archie Carr National Wildlife Refuge indicated a 54.8% reduction in depredation of sea turtle nests by coyotes after four coyotes were removed from the beach (Cope, 2016). On South Island beach (South Carolina), the implementation of night patrol surveys reduced coyote predation rate from 52% to 15%; predation rate was further reduced to 2.6% by coyote trapping and removal (Eskew, 2012). Predator removal is recommended during late spring (in the northern hemisphere) as young coyotes are dispersing which allows for predators to be removed prior to the start of shorebird and sea turtle nesting seasons (Eskew, 2012; FDEP, 2014). However, the removal of a top predator can be challenging since it can be costly, requires considerable logistics, resources and public support, may alter local level population dynamics and increase depredation from secondary predators (Barton and Roth, 2007; Barton and Roth, 2008; Fuentes et al., 2015). Further, removal strategies need to be undertaken often and across several years to completely eliminate predators, as single removal events will only reduce predation but not eradicate it (Engeman et al., 2006; Fuentes et al., 2015). Indeed, at the beginning of the 2018 nesting season, three coyotes were removed from SJPSP as part of an eradication program;

however, as the eradication did not continue throughout the nesting season or eliminated all coyotes, nests were still depredated.

A multitude of factors need to be considered when designing a robust strategy to eliminate and mitigate depredation of sea turtle nests. Cost-benefit analysis may prove useful to identify and prioritize the best set of strategies to reduce depredation. For this to occur, information on the effectiveness, logistical and financial constraints, and level of depredation is needed (Eckert et al., 1999; Engeman et al., 2002a, 2002b; Fuentes et al., 2015). However, the incorporation of knowledge on the effectiveness and potential success of strategies is often not available and, hence, often not included into optimization frameworks (Dunkin et al., 2016; Engeman et al., 2002a; Engeman et al., 2002b; Engeman et al., 2012; Fuentes et al., 2015). Therefore, future studies quantifying spatial-temporal depredation levels at nesting beaches, should also determine the effectiveness of different strategies and consider the social, cultural, political, and logistical factors involved to increase support and implementation success (Fuentes et al., 2015; Marsh et al., 2007).

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jembe.2020.151470.

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