Out-foxing the red fox: how best to protect the nests of the Endangered loggerhead marine turtle *Caretta caretta* from mammalian predation?

David J. Kurz, Katherine M. Straley and Brett A. DeGregorio

Abstract Recovery plans for the Endangered loggerhead marine turtle *Caretta caretta* cite mammalian predation as a major threat, and recommend nest protection efforts, already present at many rookery beaches, to protect eggs and hatchlings. Nest protection techniques vary but wire box cages and plastic mesh screens are two common tools used to deter predation by a host of beach-foraging, opportunistic mammalian predators. We empirically tested the efficacy of wire cages and plastic mesh screens in preventing red fox *Vulpes vulpes* predation on artificial nests. Both techniques averted fox predation (0%), whereas unprotected control nests suffered 33% predation under conditions of normal predator motivation, or a level of motivation stimulated by loggerhead turtle egg scent. However, in side-by-side comparisons under conditions of presumed high predator motivation, 25% of mesh screens were breached whereas no cage-protected nests were successfully predated. In addition to effectiveness at preventing predation, factors such as cost, ease of use, deployment time, and magnetic disturbance were evaluated. Our study suggests that the efficacy of plastic screens and the potential disadvantages associated with galvanized wire should influence selection of mechanical barriers on beaches where fox predation threatens loggerhead nests.

Keywords Artificial nests, Bald Head Island, *Caretta caretta*, loggerhead, marine turtle, nest protection, predation, *Vulpes vulpes*

Introduction

Predation by mammals is perhaps the most significant biotic threat to the hatching success of the loggerhead marine turtle *Caretta caretta*. The devastating impact of predators such as raccoons *Procyon lotor*, red foxes *Vulpes vulpes*, feral pigs *Sus scrofa*, coyotes *Canis latrans* and armadillos *Dasypus novemcinctus* on loggerhead turtle nests is well-documented (Stancyk, 1982; Erk'akan, 1993; Mroziak et al., 2000). On some beaches predation by mammals has partially or fully destroyed up to 97% of nests annually (Hopkins & Murphy, 1980; Talbert et al., 1980; Schroeder, 1981). Although population models for loggerhead turtles show that eggs and hatchlings are generally the least-responsive life stage to decreases in mortality, they also show that significant decreases (e.g. 50%) in first-year survival cause populations to decline more swiftly (Crouse et al., 1987; Crowder et al., 1994). Furthermore, all life stages of threatened or declining populations merit consideration for conservation efforts (Marchand & Litvaitis, 2004). The reduction of nest predation is also one of 13 goals cited in the Northwest Atlantic Loggerhead Sea Turtle Recovery Plan, with the specific target of reducing the annual rate of mammalian predation on nests to < 10% (NMFS & USFWS, 2008).

Several mechanical nest protection methods have been proposed: wire cages (Addison & Henricy, 1994; Jordan, 1994; Ratnaswamy et al., 1997), wire screens (Yerli et al., 1997), flags (Longo et al., 2009), and relocation of nests to fenced hatcheries (Stancyk et al., 1980; Talbert et al., 1980). Each method has proved successful in preventing nest predation in relation to unguarded nests. However, some of these methods may be site-specific (e.g. flags require windy beaches) or cost and labour prohibitive (e.g. relocation to hatcheries). Cages and screens are often the most popular choices in the south-eastern USA. In 2002 > 90% of loggerhead turtle nests in North Carolina and Georgia were protected with a plastic or wire cage or screen (NMFS & USFWS, 2008). However, the widespread use of galvanized metal screen or wire to protect loggerhead turtle nests is cause for concern, as recent research indicates that galvanized wire cages may disorient marine turtle hatchlings (Irwin et al., 2004). The potential risk posed by galvanized wire to the magnetic compass of hatchlings necessitates re-evaluation of this common management strategy. If other mechanical barriers prove as effective in protecting nests as wire cages, large-scale implementation of these new designs could eliminate concern about hatchling disorientation while still increasing annual hatchling emergence success.

Although wire cages have been successful in preventing predation (Addison & Henricy, 1994; Adamany et al., 1997; Ratnaswamy et al., 1997) and have been implemented on many nesting beaches, no published study has empirically tested their effectiveness in comparison to plastic mesh

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screens. The objectives of our study were to (1) compare the rates of predation among unprotected nests and nests protected with wire cages or plastic mesh screens, (2) compare the effectiveness of wire cages and mesh screens in preventing predation when predator motivation was high because of attractive baiting, and (3) make management recommendations based on the efficacy, cost, ease of implementation and potential risk of hatchling disorientation for each of the competing methods.

Study area

Bald Head Island is a forested barrier island in south-eastern North Carolina at the confluence of the Cape Fear River and the Atlantic Ocean (Fig. 1). Available nesting habitat consists of 15.3 km of sandy beach on the west, south, and east sides of the island (Hawkes et al., 2005). Marine turtle monitoring and nest protection have been ongoing at Bald Head since 1983, with a mean of 89 ± SE 8.2 (range 36–198; 1983–2009) loggerhead turtle nests deposited annually. Galvanized metal cages (122 cm long × 61 cm wide × 61 cm high, with 30-cm flaps on each side) are deployed at each nest location immediately following egg deposition and nest covering. Nest predation on the island is predominantly by red foxes (BAD, pers. obs.).

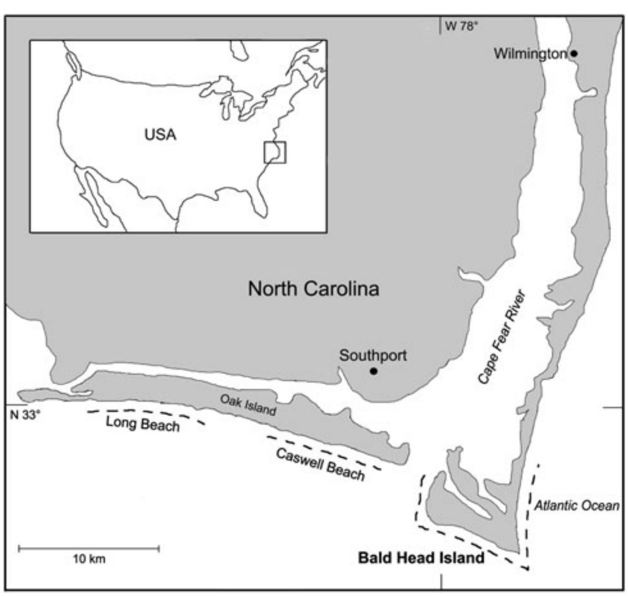

FIG. 1 Bald Head Island, North Carolina, USA (map modified with permission from Hawkes et al., 2005). Approximately 15 km of beach on the west, south and east of Bald Head Island provide nesting habitat for loggerhead *Caretta caretta* marine turtles annually. Broken lines represent nesting beaches on Bald Head Island and nearby Oak Island (not included in our study). Bald Head Island is located at the confluence of the Cape Fear River and Atlantic Ocean. The rectangle on the inset indicates the location of the main map on the east coast of the USA.

Methods

Experiment 1

Two trials were conducted to compare fox predation on unprotected (control), cage-protected, and screen-protected artificial nests; chicken eggs were placed inside each artificial nest and covered with sand to mimic loggerhead turtle nests. We prepared six nests of each treatment and six control nests along a 4.25-km transect that ran 5 m from the edge of dune habitat (a typical nesting area for *C. caretta* on Bald Head Island). Wire cages were made from galvanized wire fencing (Red Brand Welded Wire Fence, Peoria, USA). Cages were 122 cm long × 61 cm wide × 61 cm high, with 30-cm flaps extending horizontally from the bottom in all four directions. Sides were fastened with 20-cm plastic cable ties and the cages were buried 30 cm into the sand.

Mesh screens were made of 5 × 5 cm mesh plastic fencing (Tenax Plastic Home Fence, Baltimore, USA). Two 2.44 × 1.22 m sections were cut and connected with 20-cm cable ties to make a square screen with side lengths of 2.44 m. Screens were centred over the nests, staked down using 12 15-cm wire stakes (16-gauge wire coil) per screen, and covered with 1–2 cm of sand both for aesthetic reasons and to avoid providing foxes with visual cues. Control nests were marked discreetly with a plain stake 5 m from the nest.

Based on our knowledge of fox foraging habits on Bald Head Island (BAD, pers. obs.), we spaced nests 250 m apart from one another to ensure that multiple beach-foraging foxes had access to at least one nest. We placed nests in a regular alternating pattern (cage, screen, unprotected) to avoid bias. The second trial, although identical in design, was conducted 8 km from the first, as individual foxes and family groups patrol distinct areas of beach (DJK, pers. obs.). In each nest, we buried five chicken eggs to a depth of 29 cm from ground level to the top of the eggs (Tiwari & Bjorndal, 2000) to replicate the distance from the surface to the top of the egg chamber in a real loggerhead turtle nest. This experiment was intended to incite fox predation efforts similar to those on loggerhead turtle eggs in the first few days after deposition.

We scented chicken eggs by pouring 15 ml of a dilute loggerhead egg yolk solution on the eggs as well as on top of the filled-in nest. The solution was prepared by vigorously mixing one loggerhead turtle egg yolk (already sacrificed for a genetics project; Shamblin, 2007) with 300 ml of water. Nests were checked daily for signs of predator activity, and each nest was classified according to the following categories: predation (some or all eggs removed), attempted predation (visible effort exerted by predator to breach egg chamber), fox presence (footprints or scat present within 30 cm of cage or screen), or no interest (no visible signs of fox presence). Each day signs of fox activity were cleared. When substantial predation attempts disturbed the area near nests (e.g. via holes next to cages), we smoothed the sand to simulate the daily efforts of a real marine turtle nest protection programme. Every 2 days 15 ml of egg yolk mixture was re-applied to keep the scent fresh, and daily checks halted when attempted predation events ceased (6–7 days after the start of the trials). Differences in predator attendance, predation attempts, and successful predation events were compared between protected and unprotected nests, and then between caged and screen-protected nests. Because of the non-parametric nature of the data sets we used a 2×2 contingency table test. All trials took place during the summer of 2010.

Experiment 2

Two trials were conducted to compare empirically the performance of wire cages and mesh screens placed side by side under conditions of attractive baiting and therefore presumed high predator motivation. The two nest protection techniques were deployed in the same way as those in the first two trials; however, in this experiment we placed nests in pairs to ensure equal predation pressure. Thus, each cage-protected nest was placed 5 m from a mesh-protected nest, allowing the same individual foxes to attempt predation on each paired treatment. Four pairs of nests were scattered along 9 km of beach in areas with resident foxes (DJK, pers. obs.), with at least 1 km between each pair to increase the likelihood of independent sampling.

To test the effectiveness of each mechanical barrier we selected bait with a high probability of stimulating vigorous fox predation attempts. In the first trial, we used high-fat bacon and rotten eggs. We placed 0.25 kg of bacon and ten rotten chicken eggs in each nest. Bacon grease was used to scent the sand on top of the nest, and for re-scenting the top of the nest every 3 days.

The second trial was constructed the same way, using different areas of beach. For this trial we placed 0.35 kg of chicken breast and leftover bacon scraps (< 0.05 kg) in each nest. Chicken grease was used to scent the sand on top of the nest, and nests were re-scented after 3 days. Both trials were continued for a minimum of 5 days and were removed after 24 hours with no new predation attempts (each trial happened to run for 6 days). Because of the paired nature of the data we used McNemar's test to compare the predation rates of foxes on caged and screen-protected nests.

Additional analysis

In addition to testing for protection success we evaluated the drawbacks of each technique in terms of installation time and the financial cost of each individual barrier. For all cages and screens (four of each) in the second trial of Experiment 2 we used a stopwatch to record the time required for two people to deploy the mechanical barrier while working at a moderate pace. Cost was assessed by summing the aggregate price of all materials required to make a cage or screen. Finally, we considered the qualitative features of each technique, including aesthetics, portability and potential disorientation of hatchlings.

Results

Experiment 1

During trials one and two of Experiment 1 predators were motivated by loggerhead turtle egg scent. No difference in predator attendance was detected between control and protected nests ($\chi^2 = 1.04$, $P = 0.31$), with fox attendance (footprints or scat) at all 12 (100%) control nests and 11 of 12 (92%) nests of each treatment (Table 1). Predation attempts were more successful at control nests (four of eight attempts) than at protected nests ($\chi^2 = 5.0$, $P = 0.03$), as attempted predation at four caged and four screen-covered nests was unsuccessful. Overall predation rate was higher for control nests than for protected nests ($\chi^2 = 8.75$, $P = 0.003$); however, no direct comparisons between caged and screen-protected nests were possible as each type of barrier deterred all predation attempts.

Experiment 2

In Experiment 2 predator motivation to breach nests was assumed to be high because of baiting and scenting with attractive lures. This assumption is supported by the more vigorous response of foxes in comparison to Experiment 1. Two of eight (25%) screen-protected nests were successfully predated whereas zero of eight caged nests were predated (Plate 1). Foxes predated screened nests by tearing through the plastic mesh and reaching the egg

TABLE 1 Number of artificial marine turtle nests in Experiment 1 that red foxes *Vulpes vulpes* attended, attempted to predate, or successfully predated on Bald Head Island (Fig. 1). Each nest was assigned to one of 3 treatments: control (unprotected), protection with a wire cage surrounding the nest, or protection with a plastic mesh screen placed on top of the nest and buried under 1–2 cm of sand.

Treatment	n	No. of nests attended	No. of nests with predation attempts	No. of nests predated
Control (unprotected)	12	12	8	4
Wire cage	12	11	4	0
Mesh screen	12	11	4	0

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(a)

(b)

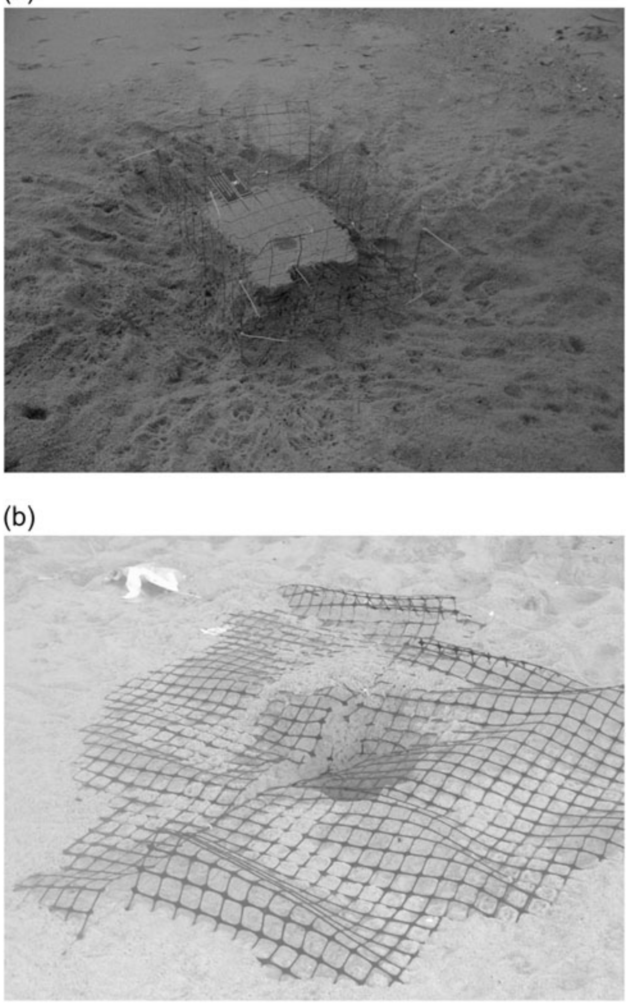

PLATE 1 (a) An unsuccessful predation attempt on a wire box cage-protected artificial nest (the fox, or foxes, attempted to dig at the nest from all sides of the cage but was/were unable to reach the egg chamber), and (b) a successful predation event by one or more red foxes on a screen-protected artificial nest.

chamber from above. Foxes attended every nest in each trial, regardless of treatment type. Six predation attempts were made on caged nests, and predation was attempted on all eight screen-protected nests. Successful predation rates at caged vs screen-protected nests were not significantly different ($\chi^2 = 2.50$, $P = 0.11$).

Assessment of additional costs

Plastic screens could be deployed substantially faster than wire cages: on average, screens took 48% less time to install than cages under the same conditions. The cost per unit difference was less dramatic, but a screen still cost slightly less than a cage. A summary of the advantages and weaknesses of each nest protection measure is presented in Table 2.

TABLE 2 Relative strengths and weaknesses of two mechanical barriers (galvanized wire cage and plastic mesh screen) to red fox predation of artificial loggerhead marine turtle nests (++ and – – indicate qualitative assessments).

	Galvanized wire cage	Plastic mesh screen
Effectiveness at preventing predation (normal motivation)	100%	100%
Effectiveness at preventing predation (high motivation)	100%	75%
Cost per unit (USD)	10.96	9.35
Mean ± SE time (range) to deploy (seconds)	461 ± 62.3 (285–572)	238 ± 27.4 (175–308)
Predator attendance at nests	95%	95%
Aesthetics	– –	+ +
Portability	– –	+ +
Hatchlings free from magnetic disturbance	? ?	+ +

Discussion

Both wire box cages and plastic mesh screens proved effective at preventing fox predation of artificial loggerhead nests. Although we did not compare mechanical barriers using genuine loggerhead turtle nests, our findings seem to parallel high levels of fox and raccoon predation documented on real, unprotected loggerhead turtle nests (Stancyk et al., 1980; Davis & Whiting, 1997; Yerli et al., 1997) and protection rates of 96–100% of nests guarded by metal cages or screens (Addison & Henricy, 1994; Jordan, 1994; Yerli et al., 1997). However, our study aimed to prevent fox predation specifically and may not be applicable to beaches with other mammalian predators. On some beaches nest caging may condition raccoons to the presence of a nest, making mechanical barriers more likely to attract predators than an uncaged nest (Mroziak et al., 2000).

Results from our second experiment may imply that wire box cages are more effective than plastic mesh screens at protecting artificial marine turtle nests under conditions of high predator motivation, although the difference was not statistically significant. For this experiment we used bait assumed to be attractive to foxes to test the strength of each type of mechanical barrier. This comparison was important, as stochasticity in predator population, prey availability and environmental conditions inevitably create conditions of food scarcity and thus high-effort predation attempts (BAD, pers. obs.). In addition to the quantitative differences in protection success (100% for cages, 75% for screens) our qualitative observations indicated that foxes may expend less energy penetrating screens than tunnelling under cages. Further research into nest protection materials could support use of a stronger mesh screen than the type we used.

Because our results show that mechanical barriers are effective at reducing predation of artificial loggerhead turtle

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nests, we recommend that efforts be made to protect (using an effective screen or cage) loggerhead turtle nests on beaches where fox predation is a threat. For example, foxes were by far the most destructive mammalian predator of marine turtle eggs in North Carolina in 2010 (M. Godfrey, pers. comm.) and are the dominant predator on some Mediterranean beaches (Erk'akan, 1993; Yerli et al., 1997). The scope of our study does not allow us to suggest how other mammalian predators would react to wire cages or plastic screens but it is possible that the implementation of mechanical barriers would also be efficacious against other predators. Despite the demonstrated effectiveness of mechanical barriers in protecting loggerhead nests from foxes and raccoons (Jordan, 1994; Ratnaswamy et al., 1997; Yerli et al., 1997), in some parts of the south-east USA $< 50\%$ of loggerhead turtle nests are protected with cages or screens (NMFS & USFWS, 2008). Documented mammalian depredation rates of up to 97% of unprotected nests suggest that nest protection is an essential component of long-term loggerhead conservation (Davis & Whiting, 1977; Talbert et al., 1980; Schroeder, 1981).

Although wire cages are the most established option for nest protection (Addison & Henricy, 1994; Ratnaswamy et al., 1997; Kinsella et al., 1998), many programmes may lack the resources necessary to purchase and deploy hundreds or thousands of cages. Our mesh screens took 48% less time to deploy and cost c. 15% less than cages. Furthermore, because no foxes attempted to predate the screen-protected nests by tunnelling from the side, we think that reducing the size of screens to 1.8×1.8 m could be an equally effective and substantially cheaper way to prevent red fox predation. Using the same materials this version would only cost c. USD 5.80, which is c. 47% less than the cost of our wire box cages. That plastic mesh screens are cheaper to construct and faster to deploy suggests that mesh screens may be particularly practical for beaches that support large numbers of turtle nests each year and suffer from fox predation. However, management measures must also be beach-specific, taking into account predation threats, resources for protection, and nesting turtle densities. Use of mechanical barriers may not be appropriate on beaches with high-density nesting because the presence of cages or screens could deter nesting females.

Marine turtle hatchlings use the earth's magnetic field to orient and are thought to begin using this ability as they swim offshore following hatching (Lohmann, 1991; Lohmann & Lohmann, 1998; Irwin & Lohmann, 2003). As a result, galvanized wire poses a possible risk to the navigational abilities of hatchlings. Irwin et al. (2004) found that galvanized wire cages alter magnetic intensity in the area of the egg chamber by 5–26% and field inclination by 4–20% (however, there is no experimental evidence demonstrating whether an altered magnetic field is detrimental to turtle hatchlings). While the extent to which marine turtles may be harmed remains unknown, an altered magnetic environment during development could negatively affect hatchlings: (1) as they migrate post-hatching; (2) as they respond to regional magnetic markers throughout their lives; and (3) as they attempt to relocate their natal beaches as adults (Irwin et al., 2004). Although these possible effects have not yet been studied, alternatives to galvanized wire should be sought until wire cages and screens can be exonerated from potentially disorienting effects on developing hatchlings.

Little in the literature points to a nest protection measure that is effective, affordable and free of the potential dangers associated with galvanized wire. Although other studies have independently assessed the performance of wire cages (Addison & Henricy, 1994; Jordan, 1994) and wire screens (Yerli et al., 1997), to the best of our knowledge our study is the first to use artificial nests to compare the efficacy of two mechanical barriers to marine turtle nest predation. There is probably no single solution appropriate for reducing mammalian predation of marine turtle nests on every beach. Rather, our study suggests that continued research will help identify multiple potent mechanical barriers to nest predation, each suited to distinct conservation needs.

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Biographical sketches

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