THE EFFECT OF SCREENING AND RELOCATION ON HATCHING AND EMERGENCE SUCCESS OF LOGGERHEAD SEA TURTLE NESTS AT SAPELO ISLAND, GEORGIA

by

MANDI MCELROY

(Under the direction of Steven B. Castleberry)

ABSTRACT

Loggerhead sea turtle (*Caretta caretta*) nesting beach management is an integral component of population recovery efforts for this internationally threatened species. In Georgia, nests threatened by tidal inundation are commonly relocated to elevated dunes, and screens are placed over nests to prevent depredation. The objective of this study was to examine the effects of nest relocation and nest screening on both hatching success (proportion of successfully hatched eggs) and emergence success (proportion of hatchlings successfully emerging from the egg chamber) at Sapelo Island, Georgia. Results suggest that high hatching and emergence success rates can be maintained on Sapelo Island without nest relocation. Predator screens do not appear to affect hatching or emergence success and should continue to be used to protect nests from depredation.

INDEX WORDS: loggerhead sea turtle, *Caretta caretta*, Sapelo Island, hatching success, emergence success, nest screening, nest relocation, analysis of covariance (ANCOVA).

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CHAPTER 1

INTRODUCTION

Distribution and Conservation Status

The loggerhead sea turtle (*Caretta caretta*) is one of seven extant species of marine turtle. Loggerheads are distributed worldwide, inhabiting open-ocean and near-shore habitats across temperate and tropical latitudes (Bolten 2003). Populations of loggerheads have been identified in the Indian Ocean, eastern Australia, Japan, the southeastern U. S., the Mediterranean, and southern Brazil (Pritchard 1997). In the southeastern U. S., loggerheads nest on beaches along the Atlantic and Gulf coasts, forming five demographically independent sub-populations (Ehrhart et al. 2003, TEWG 1998). The nesting assemblage occurring between North Carolina and northeast Florida is referred to as the "Northern sub-population" (Ehrhart et al. 2003). The nesting beaches of Georgia, which include our study site, are used by the Northern sub-population of loggerheads. The four remaining sub-populations are found in the Yucatan Peninsula of Mexico, southern Florida, the Dry Tortugas, and the Florida panhandle (TEWG 2000).

Loggerhead turtles face multiple threats during all life stages, in both marine and terrestrial habitats. Shrimp trawling, long-line fisheries, and ingestion of anthropogenic marine debris contribute to in-water mortality (Bolten et al. 1996, Carr 1987a, NRC 1990, Witherington 2003). On nesting beaches, eggs are threatened by poaching, mammalian predators, microbial infection, and beach erosion (Lutcavage et al. 1997, Stancyk 1982, Witherington 2003, Wyneken et al. 1988). Widespread population declines prompted the designation of loggerheads as "threatened" by the U. S. Department of the Interior in 1978 (Federal Register 1978). Loggerheads are listed as endangered by the World Conservation Union (MTSG 1996) and are prohibited from commercial trade under Appendix I of CITES.

Life History

The life history of loggerheads typically is divided into four life stages (Bolten 2003). For the purposes of this review, these life stages will be described in reference to the northern subpopulation of the western Atlantic.

The hatchling stage begins when hatchlings emerge from nests on beaches along the coast between North Carolina and northeast Florida. Hatchlings navigate to the ocean, entering a "swim frenzy" once reaching the water (Lohmann and Lohmann 2003, Wyneken and Salmon 1992). Using magnetic cues and wave energy to orient in-water, hatchlings soon locate the North Atlantic gyre (Lohmann and Lohmann 2003). Once associated with this circular ocean current, loggerheads enter the oceanic juvenile stage for 6.5-11.5 years, continuing to feed while rotating along the gyre (Bjorndal et al. 2000, Carr 1987b). The neritic juvenile stage (12-28 years) begins when loggerheads exit the gyre and migrate to foraging grounds along the eastern U. S. continental shelf (Hopkins-Murphy et al. 2003). The final, adult stage begins when loggerheads reach reproductive maturity, at approximately 28-30 years of age (Frazer and Ehrhart 1985).

Nesting Biology

Approximately every 3 years (the "remigration interval", or number of years between nesting seasons, Carr et al. 1978), an adult female loggerhead will migrate from her foraging area to mating grounds, where mating occurs for several weeks (Miller 1997, Richardson et al. 1978).

After mating, females move to nesting areas. Female loggerheads exhibit high nest site fidelity, returning to the region of their natal beaches to nest (Carr 1975). In Georgia, nesting occurs between May and August (Richardson 1980). When ready to nest, a female emerges from the ocean and crawls up the beach to a nesting site (Hendrickson 1982). Nesting females are thought to use sensory clues to select nesting sites that have a high probability of nest survival (Bjorndal and Bolten 1992). She creates a body pit by using her flippers to clear debris from the sand surface, then uses her hind flippers to excavate an egg chamber with a narrow neck and wide bottom (Carthy 1994, Miller et al. 2003). The number of eggs per clutch ranges from 23-198, with a mean of 112 eggs per clutch (Hirth 1980, Van Buskirk and Crowder 1994). After depositing the eggs, the nesting turtle uses her rear flippers to fill the egg chamber with sand, after which she throws more sand over the nest and body pit with her front flippers (Miller et al. 2003). Finally, the female crawls back into the ocean (Hendrickson 1982, Miller et al. 2003). Females deposit clutches every 10-14 days during the nesting season (Caldwell 1962). Frazer and Richardson (1985) reported a mean clutch frequency (number of nests deposited in one season) of 2.81-4.18 clutches per female on Little Cumberland Island, Georgia.

Nest Hatching Success

In Georgia, loggerhead nests hatch 50-70 days post-oviposition (Richardson 1980). Hatching occurs on Georgia's beaches between early July and mid- October (Richardson 1980). The incubation environment (temperature, moisture, and gas exchange, Ackerman 1997) within the egg chamber affects both hatching success (number of hatchlings leaving the eggs, Miller et al. 2003) and hatchling characteristics such as gender and fitness (Carthy et al. 2003). For example, extremes in temperature or water content have been shown to decrease hatching success (Ackerman 1997, Foley 1998, Yntema and Mrosovsky 1980). Variations in temperature, moisture, and gas exchange also can affect hatchling size, growth rate, and activity levels (Carthy et al. 2003, McGehee 1990). Incubation temperature also determines hatchling sex ratios, with cooler temperatures producing more males and warmer temperatures producing more females (Mrosovsky 1988, Yntema and Mrosovsky 1980).

Nest hatching success also can be affected by anthropogenic activities, such as beach armoring, oceanfront development, and sand renourishment (Carthy et al. 2003). These activities can alter the egg incubation environment by shading nests, changing sand density, or forcing the female to lay nests at a low elevation, closer to the tide (Ackerman 1997, Carthy et al. 2003). Furthermore, incubating eggs in Georgia are threatened with predation by mammalian predators such as feral hogs (*Sus scrofa*; Stancyk 1982) and raccoons (*Procyon lotor*; Ratnaswamy et al. 1997). Other common nest predators in Georgia include ghost crabs (*Ocypode quadrata*; Stancyk 1982) and fire ants (*Solenopsis invicta*; Moulis 1997).

Nest Management

Because of the relative convenience of beach access and monitoring, active management and protection of loggerhead nests is common to aid in loggerhead population recovery (Crouse et al. 1987). Although the intent is to maximize hatching success, these efforts could adversely affect hatching success by altering incubation environments (Carthy et al. 2003). Relocation of "doomed" eggs, such as those in nests laid near an incoming tide or those likely to be depredated, is a common conservation practice (Lutcavage et al. 1997, Wyneken et al. 1988). Nests laid low on the beach are susceptible to tidal washovers, which can inundate the egg chamber with sea water and alter the incubation environment, potentially decreasing hatching success (Carthy et al. 2003, Foley 1998). The act of relocation can, however, alter the incubation environment by placement of eggs in a man-made chamber, which may fail to replicate the size and shape of the natural site (Carthy et al. 2003). Additionally, movement-induced mortality has been reported in eggs that are relocated more than 12 hours post-deposition (Limpus et al. 1979)

Screens or cages are often used to cover nests – in-situ and/or relocated - and prevent predator access (Fowler 1979, Irwin et al. 2004). Recently, metal screens have been shown to distort the magnetic field surrounding the egg chamber, which may alter hatchlings' behavior (Irwin et al. 2004). Furthermore, Carthy et al. (2003) suggest that incubation temperature may be altered by excessive solar heat transferred by the screen or cage material.

Thesis Objectives

Georgia's barrier islands are owned and managed by many different groups, with each implementing a variety of nest management protocols. My research sought to determine the effectiveness of nest relocation and nest screening, which are two most common nest management practices in Georgia. In Georgia, nests laid below the high tide line are relocated to the highest point of a nearby primary dune and covered with a screen or cage to prevent nest depredation.

My objective, described in chapter two, was to determine the effects of nest relocation and screening on loggerhead hatching and emergence success. I also examined the relationship between nest elevation and hatching success. In chapter three, I discuss the management implications of my findings, and recommend nest management methods that will effectively maintain high nest success rates on Sapelo Island. By quantitatively assessing these methods, I hope to provide data that will help managers develop a sound management strategy for Sapelo Island.

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CHAPTER 2

THE EFFECT OF SCREENING AND RELOCATION ON HATCHING AND EMERGENCE SUCCESS OF LOGGERHEAD TURTLE NESTS AT SAPELO ISLAND, GEORGIA[1]

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Abstract

Active management of loggerhead sea turtle (*Caretta caretta*) nesting beaches is an integral component of population recovery efforts for this internationally threatened species. Nests threatened by tidal inundation are often relocated to elevated dunes or hatcheries, whereas screens or cages are typically placed over nests to prevent depredation. From 2002-2007, we randomly applied one of five treatments to loggerhead nests (n=382) on Sapelo Island, Georgia to examine treatment effects on both hatching success (proportion of successfully hatched eggs) and emergence success (proportion of hatchlings successfully emerging from the egg chamber). Treatments were 1) locate egg chamber, nest left in-situ, 2) locate egg chamber, nest left in-situ with screen placement, 3) locate egg chamber, relocate without screen placement, 4) locate egg chamber, relocate eggs with screen placement, and 5) control (do not locate egg chamber, do not relocate or place screen). Nest elevation above mean low water was included as a covariate in our analysis. Hatching success (70-80%) and emergence success (66-78%) were high across all treatments for all years. We did not find treatment effects on hatching or emergence success, but both response variables showed significant annual variation. Because nest depredation rates are low, our data suggest that current nest success rates can be maintained on Sapelo Island without relocating nests. Predator screens do not appear to affect hatching success and should be used to protect nests from depredation.

Introduction

In 1978, the loggerhead sea turtle (*Caretta caretta*) was listed as Threatened under the Endangered Species Act of 1973 as a result of widespread population declines (Federal Register 1978). The United States Federal Recovery Plan for the Northwest Atlantic population of the loggerhead turtle lists nest monitoring and control of nest predation as objectives for population recovery (NMFS-USFWS 2008). Many sea turtle nesting beaches have initiated beach monitoring programs and nest protection measures as a component of population recovery efforts for all life stages (Ehrenfeld 1995). When combined with in-water protection of juvenile and adult sea turtles, active monitoring and nest protection can facilitate population growth (Crowder et al. 1994, Dutton et al. 2005, Frazer 1992, Grand and Beissinger 1997).

Hatching success (number of hatchlings leaving the eggs; Miller et al. 2003) and emergence success (number of hatchlings reaching the beach surface, Miller et al. 2003) can be affected by multiple factors, including elevation, slope, predation, moisture, and temperature (Wood and Bjorndal 2000). Nesting females are thought to use sensory clues to select nesting sites that have the highest probability of nest survival (Bjorndal and Bolten 1992). Still, nests laid close to the sea are more susceptible to tidal inundation and have increased potential for erosional damage, whereas nests located farther inland risk higher rates of nest predation (Fowler 1979, Marchand and Litvaitis 2004).

Relocation of nests into hatcheries or corrals is commonly used by beach managers to protect nests from depredation (Marcovaldi 2007). Nest relocation is also used as a conservation tool to reduce tidal inundation risk (Eckert 1990, Dutton 2005). Previous studies on the effects of nest relocation report conflicting results, and most studies have used hatcheries or corrals rather than natural sites for relocation. Wyneken et al. (1988) found lower hatching success in in-situ nests than in nests relocated to natural sites. In their study, however, nests selected for relocation were only those considered to be at risk of tidal inundation, and data were analyzed under the assumption that each relocated nest would have failed (hatching success=0) if left in-situ. Additionally, the sample of nests relocated to natural sites was limited to five nests. Of the 20 remaining in-situ nests, Wyneken et al. (1988) reported a high hatching success rate of 87 percent. In an analysis of results compiled from multiple nesting beach studies, Grand and Beissinger (1997) found hatching success of non-depredated in-situ nests significantly higher than those relocated to corrals. Grand and Beissinger (1997) concluded that relocation to protected areas would be likely to increase hatching success only on beaches experiencing poaching and predation, and otherwise recommended in-situ nest protection to avoid movement-induced mortality as described by Limpus et al. (1979). Other reported adverse effects of nest relocation include altered sex ratios (Mrosovsky and Yntema 1980) and compromised egg hatchability (Parmenter 1980). Relocation also has been shown to affect hatchling emergence patterns (Adams et al. 2007) and rates (Glen et al. 2005) by altering the original incubation environment.

Wire or plastic cages and screens are often used to protect nests from predators (Antworth et al. 2006, Irwin et al. 2004, Mroziak et al. 2000, Ratnaswamy et al. 1997). Screening significantly improves hatching success by reducing nest depredation (Antworth et al. 2006, Ratnaswamy et al. 1997); however, potential effects of installation and presence of screens have not been investigated. Wire screens have been shown to alter local magnetic fields, possibly affecting hatchlings' ability to navigate (Irwin et al. 2004). This potential negative effect has prompted some sea turtle nesting beaches in Georgia to use plastic protective screens (MD *pers. obs.*).

Although several studies have reported success rates of nests reared in hatcheries, few studies to date have investigated hatching or emergence success in relocated, hand-excavated nests in natural dunes. Furthermore, characteristics of Georgia's barrier island beaches have not been independently evaluated with respect to loggerhead nest management strategies. In this study, we measured the effects of nest relocation and nest screening on loggerhead hatching and emergence success. Sapelo Island, with limited human access and a low incidence of sea turtle nest depredation, was selected as an optimal location for isolating the mechanical effects of both nest relocation and nest screening. Based on preliminary data and observations from preceding years, we hypothesized that hatching and emergence success on Sapelo would not be affected by presence of plastic screens and would not differ between in-situ and relocated nests.

Methods

Study area:

We conducted our study on Sapelo Island, a barrier island located in McIntosh County, Georgia. The ocean shoreline of the island totals 9.9 km of contiguous beach. A wooden pavilion is the only permanent structure on the beach. Anthropogenic activity is low, as the island has few permanent residents and limited visitor access.

Beach monitoring:

We patrolled the entire length of both beaches daily at dawn. We used four-wheel drive vehicles for surveys and restricted driving below the previous night's tide line to avoid disturbance of beach-nesting birds and turtle nests and to ensure that all sea turtle emergences were detected. We conducted daily patrols for the duration of Georgia's sea turtle nesting season (May 15-October 1) in 2002-2007.

When evidence of a loggerhead nest was detected, we applied one of five treatments including: 1) locate egg chamber, nest left in-situ, 2) locate egg chamber, nest left in-situ with screen placement, 3) locate egg chamber, relocate nest without screen placement, 4) locate egg chamber, relocate eggs with screen placement, and 5) a control (do not locate egg chamber, do not relocate or place screen). When locating eggs, we removed sand from directly over the egg chamber and used caution to minimize the likelihood of puncturing an egg.

Treatment protocols:

Treatment 1: We removed sand by hand from the area above the egg chamber until egg location was visually confirmed. We replaced sand removed during the nest search and smoothed the nest area by hand.

Treatment 2: We confirmed egg location and sand was replaced over eggs as in treatment 1. We placed a flat, white, plastic 4.1 cm x 4.1 cm mesh screen on top of the sand, with the center of the screen aligned above the egg chamber location. Screens were approximately 1.22 m x 1.22 m and were secured with a bent steel rod at each corner.

Treatment 3: We located the nest chamber, then carefully removed and placed the eggs in a five-gallon plastic bucket. We maintained the vertical orientation of eggs as accurately as possible. When all eggs were excavated from the in-situ chamber, we constructed a new egg chamber by hand or with a small shovel on a nearby, ocean-facing primary dune, following the standard procedure used on Georgia beaches. We attempted to reproduce the dimensions of the original egg chamber as closely as possible. We replaced the sand and smoothed over the nesting site by hand.

Treatment 4: We conducted nest relocation as in treatment 3. After sand was smoothed over, we installed a plastic mesh screen as in treatment 2.

Treatment 5: We identified the emergence as a nest based on the presence of a body pit with disturbed sand and evidence of thrown sand and uprooted vegetation. We estimated the location of the egg chamber by the boundaries of the body pit and direction of thrown sand.

Nest monitoring:

We marked all nests with a wooden stake placed approximately 1 m inland of the egg chamber location. We monitored nests daily for the duration of incubation (55-70 days). We assessed predator activity by daily track counts, estimated within a 2 m radius of each egg chamber location. We recorded attempted, partial, and complete nest depredations.

We excavated nests on the fifth day following the first sign of hatchling emergence. We excavated nests without sign of hatching at 70 days after deposition. We recorded total hatched eggs, un-hatched eggs, and dead hatchlings. For in-situ nests (in which the initial number of eggs was unknown), we estimated the total number of eggs by counting eggshell fragments $\geq$50% intact as one egg. Although the exact number of eggs in relocated nests was recorded at the time of relocation, we used a $\geq$50% estimation method to calculate total eggs in relocated nests during excavation. We used the estimated nest totals for all nests in the data set to account for subjectivity and error inherent in eggshell fragment counts. After hatching, we hired land survey crews (Wilder & Stone Land Surveyors, Inc., Rincon, GA) to measure height (m) above mean low water of each nest.

Data analysis:

We included five years of nesting data (2002, 2003, and 2005-2007; n=382 in our analysis. Data from 2004 were excluded after a majority of nests were lost to mid-season storms. We used arcsin transformation to transform hatching and emergence success values from percentages to degrees for analysis. Calculations used were:

$$\text{Hatching success} = (\text{Hatched eggs}/\text{Total eggs})*100$$

$$\text{Emergence success} = (\text{Hatched eggs} - (\text{Dead hatchlings} + \text{Live hatchlings}))/\text{Total eggs})$$

We used an analysis of covariance (ANCOVA) in a randomized complete block design to examine treatment effects on hatching success and emergence success ($\alpha = 0.05$). We included nesting year as a block to account for annual variation. We included nest elevation measurements as a covariate. Because our investigation of nest elevation was confounded by the intentional placement of relocated nests at higher elevations, we conducted a regression analysis to further examine the relationship between in-situ nest elevation and hatching success with relocated nests removed from the data set. To test the assumption of heterogeneous slopes for ANCOVA, we included the interaction between treatment and elevation in the model. SAS Statistical Analysis Software (Version 9.1) was used to perform all analyses.

Results

Of 382 total treated nests, 213 were left in-situ (treatments 1, 2, 5) and 169 nests were relocated (treatments 3, 4). Adjusted mean success rates across all treatments ranged from 70-80% hatching success and 66-79% emergence success (Figure 1). Complete nest failure (hatching success=0) occurred in 44 in-situ nests and 13 relocated nests during the course of the study. Of the failed nests, two relocated nests and 28 in-situ nests were washed over more than one time. Raccoons completely depredated nine nests, four in 2002 and five in 2003; raccoon depredations did not occur in any other years of the study. Of the nests completely depredated by raccoons, five were in-situ without a protective screen (treatments 1 and 5) and four were relocated without a screen (treatment 3). We assume ghost crab depredations occurred throughout the study; however, crabs appeared to destroy or remove single eggs. Because individual egg losses were difficult to monitor and attribute to ghost crabs with certainty, these losses were not considered in our assessment of nest depredation.

We did not find a treatment effect on hatching success (p=0.09) or emergence success (p=0.26) when adjusted for elevation. Nesting year approached significance when accounting for annual variation in hatching success (p=0.07) whereas emergence success rates showed a significant year effect (p=0.02). Elevation was a significant covariate in each ANCOVA (p=<0.0001); however, regression analysis showed elevation to explain only a small amount of variation in in-situ nest hatching success rates (r^2=0.08; Figure 2). Neither hatching success (p=0.06) nor emergence success (p=0.11) differed when ANCOVA was performed on only in-situ nests (n=213). Interaction between treatment and elevation was not significant for hatching success (p=0.08) or emergence success (p=0.30), suggesting that the slopes of the regressions within treatments were not significantly different.

Discussion

We did not find a difference in hatching and emergence success rates between in-situ and relocated nests on Sapelo Island, which supports a similar result found at a loggerhead nesting beach in South Carolina (Stancyk et al. 1980). In the absence of nest predation, hatching success of in-situ nests is greater than relocated nests across a range of international loggerhead nesting beaches (Grand and Beissinger 1997). In the U. S. Virgin Islands, relocation was found to significantly reduce hatching success in leatherback nests on a beach with minimal predator activity (Eckert and Eckert 1990). To avoid movement-induced mortality, Grand and Beissinger (1997) support protection of in-situ nests rather than nest relocation on beaches with minimal nest predation.

Installation and presence of plastic screens do not appear to significantly affect hatching or emergence success on Sapelo Island. Wire screening has been shown to reduce nest depredation, thereby increasing hatching success rates on beaches with high levels of predator activity (Antworth 2006, Baskale 2005, Ratnaswamy 1997); however, we are unaware of studies to date that have investigated the effect of screens on nest success rates in the absence of predators, nor have plastic screens been evaluated. Plastic screens used in our study did not have a discernable effect on nest success and could continue to be used as a precautionary measure on all nests on Sapelo Island. Further investigation of the effectiveness of plastic screens against heavy nest predation is warranted, as replacement of wire screens with plastic mesh screens could avoid potential disruption of magnetic fields around the egg chamber (Irwin et al. 2004).

Elevation did not appear to explain much of the variation in our estimates of hatching success; however, elevation has influenced nest success of hawksbill turtles (Horrocks and Scott 1991). In an ever-changing beachscape, considering elevation for use in beach management protocols is a challenge. Although a primary dune may provide a well-elevated nest site, its proximity to the incoming tide is an important consideration. Anecdotal observations suggest distance to tide line also has some influence on nest fate at Sapelo Island (MD, *pers. obs.*). Elevation could potentially be used as an index of nest fate when combined with measurements of nest distance-to-tide. Such measurements would depict the location of each nest more accurately, providing a more reliable indicator of nest fate.

The observed differences in block (year) effect could be caused by environmental and anthropogenic factors that vary annually. Rain and vegetative growth can create barriers to emergence, such as hardened sand and heavy root growth above the egg chamber (Kraemer and Bell 1980). Such barriers could be more likely to affect emergence success than egg hatchability. Also, personnel conducting nest surveys and relocations tend to vary annually (MD *pers. obs.*). Although nest treatment protocols are standardized, relocation techniques are subject to individual variation in digging methods and nest site selection. These annual shifts in technician methodology could contribute to annual differences in hatching or emergence success.

Apart from confirmed depredation events and tidal inundation of clutches, the causes of many of our in-situ and relocated nest losses are uncertain. Although a number of our failed relocated and in-situ nests were washed over more than once, the extent of inundation in these nests is not known. Tidal wash-overs increase embryonic mortality and decrease hatching success (McGehee 1990, Peters et al. 1994, Whitmore and Dutton 1985). Recently, loggerhead nests withstood multiple tidal wash-overs, dependent on the extent of inundation of the egg chamber (Foley et al. 2006). Several environmental factors may have contributed to decreased success rates in nests that were not depredated or washed over in our study. Eggs are sometimes ruptured by ghost crabs, roots, or ants, which lowers hatching success and may contribute to further mortality by introducing fungus or bacteria (Fowler 1979, Whitmore and Dutton 1985). Microbial pathogens also significantly affect hatching success (Wyneken et.al. 1988). Invasion of plant roots may also create sand compaction above and around the egg chamber, hindering hatchling emergence (Lohmann et al. 1996). The impact of root growth on emergence success may be more prevalent in nests located in the dunes, where vegetation is more abundant. Sand compression, which may occur when sand accretes above the egg chamber, negatively impacts emergence success (Peters et al. 1994) and may have affected some of the nests in our sample.

Based on high mean success rates across treatments, paired with low levels of human disturbance and predator activity, current hatching and emergence success rates on Sapelo Island could be maintained through a less manipulative nest relocation strategy. Although some low-lying nests are inevitably washed-over, similar pressures on hatching and emergence success appear to be exerted on both relocated and in-situ nests at various elevations. The absence of a treatment effect in our study could be interpreted to advocate nest relocation; however, several potential negative effects of nest relocation have been reported, such as increased embryo and hatchling mortality (Blanck and Sawyer 1981, Eckert and Eckert 1990, Limpus 1979, Stancyk 1980), sex ratio alteration (Mrosovsky and Yntema 1980), gene pool alteration (Mrosovsky

2006), increased hatchling disorientation (Godfrey and Barreto 1995, Kamel and Mrosovsky 2005), increased risk of vegetative root invasion of the egg chamber (Whitmore and Dutton 1985), and increased exposure time to predators upon emergence (Mrosovsky 2006). Such risks were not quantified in this study and should be strongly considered when determining management protocols for loggerhead nesting beaches.

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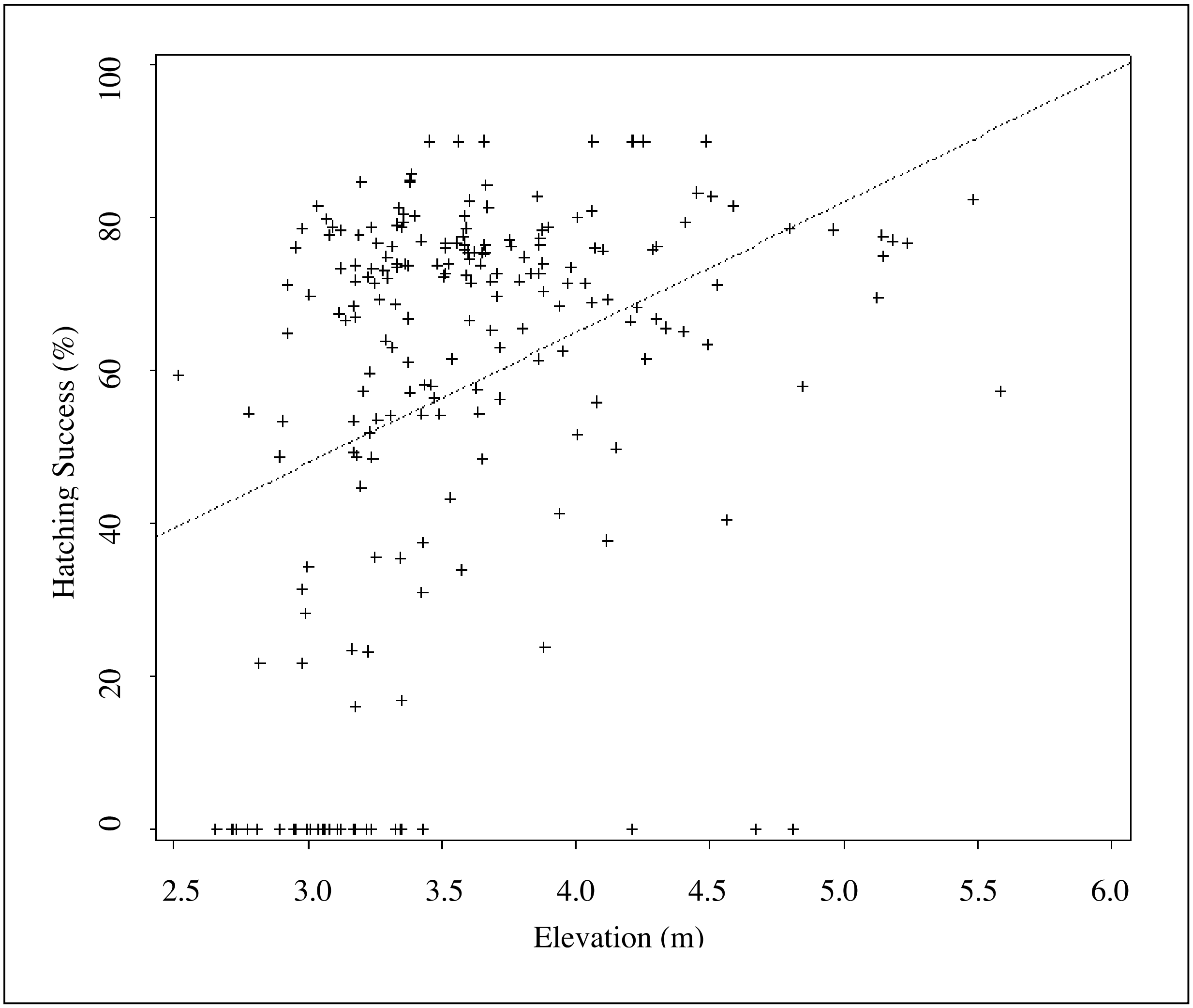

Figure 1. Regression of percent hatching success of in-situ nests (n=213) against nest elevation (m); r^2=0.08.

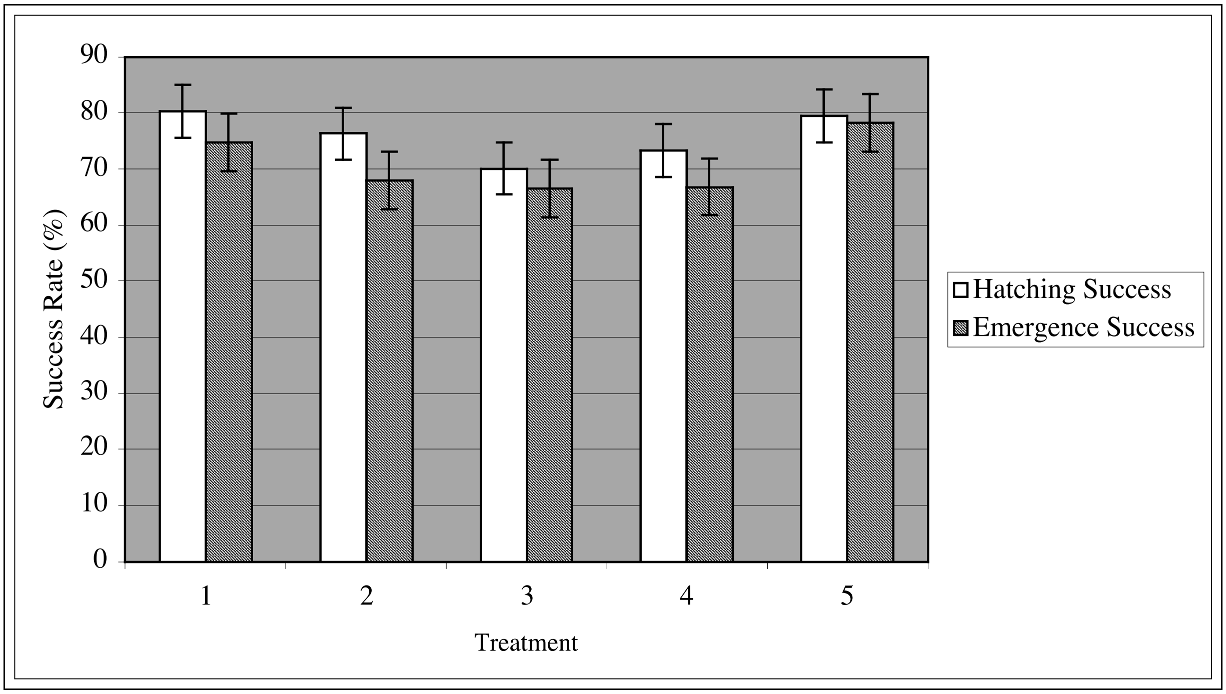

Figure 2. Mean loggerhead turtle hatching and emergence success rates (%) and standard error of 5 treatments used to examine the effect of nest relocation and screening on Sapelo Island, Georgia, 2002-2007. Treatments were 1) locate egg chamber in-situ, 2) locate egg chamber in-situ with screen placement, 3) relocate eggs without screen placement, 4) relocate eggs with screen placement, and 5) a control (do not locate egg chamber, relocate, or place screen).

CHAPTER 3

CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

Long-term trend analysis indicates that the Northern subpopulation of loggerhead sea turtles has been experiencing a population decline of 1.3% per year since 1983 (NMFS-USFWS 2008). When combined with in-water protection of juvenile and adult turtles, nesting beach protection has been shown to benefit sea turtle population recovery (Dutton et al. 2005). My research was initiated to support the need for informed loggerhead nest management specific to Georgia's beaches. As threats to nesting habitat continue to emerge and shift (levels of predation, ocean-front development, sea-level rise), careful evaluation of nest management methods is essential.

Previous studies reporting the effects of nest relocation used small sample sizes of nests relocated to "natural" sites (Wyneken et al. 1988), or used hatcheries or corrals as nest relocation sites (Blanck and Sawyer 1981, Eckert and Eckert 1990, Grand and Beissinger 1997, Wyneken et al. 1988). Some relocation studies also suffered from selective bias by labeling low-lying nests as "doomed" and relocating only those eggs (Eckert and Eckert 1990, Whitmore and Dutton 1985, Wyneken et al. 1988). These studies advocate relocation based on a "net gain" of hatchlings, by assuming the relocated clutches would have been lost (hatching success=0) if left in-situ. Although increased moisture in the egg chamber can inhibit hatching and emergence success (Kraemer and Bell 1980, McGehee 1990), nests can withstand a number of tidal wash-overs, and low-lying nests can produce hatchlings despite being inundated "at least two" times (Foley et al. 2006).

Because I did not find a significant difference in hatching or emergence success between relocated and in-situ treatments, and because the in-situ success rates are relatively high, I advocate leaving nests in-situ on Sapelo Island. Several other studies support this management strategy. Mrosovsky (2008) argued that relocation of nests laid low on the beach might interfere with natural selection and that the effects of relocation need further investigation. By leaving nests in-situ, natural variation in nest site selection is retained. Maintaining in-situ nests also avoids any movement-induced mortality risks associated with nest relocation (Grand and Beissinger 1997, Limpus et al. 1979). Miller (1997) suggests relocation only for beaches that lose a significant number of nests to erosion or inundation. As suggested by the high hatching and emergence success rates reported in our study, routine nest relocation is not warranted on Sapelo Island.

I was able to investigate the effects of installation and presence of screen hardware on hatching and emergence success because of the low occurrence of predator activity on Sapelo Island. I did not find a significant effect on hatching or emergence success from the use of flat plastic mesh screens. Previous investigations supporting the use of screens or cages occurred only on beaches experiencing significant predator activity. Antworth et al. (2006) observed a long-term, significant decrease in raccoon predation on nests covered with flat screens for the duration of incubation. When comparing the effectiveness of three predator control methods (nest screening, predator deterrents, and predator removal), Ratnaswamy et al. (1997) found only nest screening to significantly decrease nest depredation. Yerli et al. (1997) also found higher hatching success in screened nests than in those unprotected or treated with deterrents, and recommended installation of mesh screens as a routine conservation measure. I support the continued use of flat plastic screens on Sapelo Island, as predator activity may occur unexpectedly, or increase in the future. Use of plastic mesh in place of wire mesh has begun only recently to avoid disruption of magnetic fields around nests (Irwin et al. 2004), and this study supports the continued use of this magnetically-inert material on Sapelo. In some cases, nests covered with flat wire screens have higher depredation rates than nests covered with wire cages (Addison 1997). For this reason, designing and testing the effectiveness of plastic mesh cages on Georgia beaches with significant predator activity would be useful. During the 2009 loggerhead nesting season, all nests on Ossabaw Island, Georgia will be screened with flat plastic mesh and left in-situ. Because Ossabaw typically experiences heavy nest losses to predators and tidal inundation, this data will provide an interesting contrast to the relative lack of disturbance on Sapelo Island, as well as a valuable assessment of hatching and emergence success rates in the absence of nest relocation.

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Appendix A. Occurrence of tidal inundation, erosion, depredation, and hatchling misorientation and disorientation, average nest elevation above mean low water (MLW), and average sand accretion/erosion for in-situ nests (treatments 1, 2, 5) and relocated nests (treatments 3, 4) on Sapelo Island, Georgia (2002-2007).

	In-Situ			Relocated	
	Control (5)	No Predator Screen (1)	Predator Screen (2)	No Predator Screen (3)	Predator Screen (4)
Number of nests	58	79	75	83	86
Number of nests inundated < 1 time	47 (81.0%)	57 (72.2%)	53 (70.7%)	81 (97.6%)	81 (94.2%)
Number of nests inundated 1-3 times	7 (12.1%)	10 (12.7%)	7 (9.3%)	1 (1.2%)	4 (4.7%)
Number of nests inundated >3 times	4 (6.9%)	12 (15.2%)	15 (20.0%)	1 (1.2%)	1 (1.2%)
Nests lost to storm erosion	1 (1.7%)	2 (2.5%)	1 (1.3%)	0	2 (2.3%)
Nests partially depredated by raccoons	1	4	1	1	2
Nests completely depredated by raccoons	1	4	0	4	0
Average nest elevation above MLW (m)	3.66	3.55	3.57	4.12	4.11
Average sand accretion/erosion at nest (cm)	+6.45	+6.54	+6.88	+5.15	+4.91
Number of nests with disoriented hatchlings	3	1	4	5	4
Number of nests with misoriented hatchlings	2	4	5	6	3