

Fall 2007

## Loggerhead Sea Turtle (*Caretta Caretta*) Nesting on a Georgia Barrier Island: Effects of Nest Relocation

Jacob Anthony Tuttle

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# LOGGERHEAD SEA TURTLE (*CARETTA CARETTA*) NESTING ON A GEORGIA BARRIER ISLAND: EFFECTS OF NEST RELOCATION

by

JACOB A. TUTTLE

(Under the Direction of David Rostal)

## ABSTRACT

The purpose of this study was to determine the effects of nest relocation on nest parameters and embryonic development. The nesting biology of the loggerhead sea turtle (*Caretta caretta*) was studied on Blackbeard Island in 2005 and 2006, during the nesting season. Research nests were randomly assigned one of two treatments (*in-situ* or relocated). *In-situ* nests (n=35) were left in the original location, while relocated nests (n=34) were moved above the spring high-tide line and into areas that were considered to be of favorable nesting conditions. Data-loggers were placed in the center of nests to record the temperature during the incubation duration. Incubation durations, nest temperatures, hatch success, and hatchling straight carapace length were compared for all research nests. The observed nests showed similar nest parameters and embryonic development regardless of nest treatment. Differences in nest parameters and embryonic development seemed to be driven by abiotic conditions of the nesting site. This study shows that nest relocation can be used to alleviate nests of extreme abiotic conditions to increase hatch success, without altering embryonic development.

INDEX WORDS: *Caretta caretta*, Temperature Dependent Sex Determination (TSD), Critical Period, Pivotal Temperature, Embryonic Development

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GEORGIA BARRIER ISLAND: EFFECTS OF NEST RELOCATION

by

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B.S., Armstrong Atlantic State University, 2004

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

OF MASTER OF SCIENCE

STATESBORO, GEORGIA

2007

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December 2007

## DEDICATION

I would like to dedicate this thesis to all my family and friends who have supported me throughout the years of this project and throughout my academic career.

Thank you all.

## ACKNOWLEDGMENTS

I would like to acknowledge David Rostal, Lance McBrayer, Sophie George, Ray Chandler, John Robinette, Deb Barnard, Heather Cason, Ian Paige, U.S. Fish and Wildlife Service, Georgia Department of Natural Resources, and all interns and volunteers who assisted with this project.

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## CHAPTER 1

### INTRODUCTION

An estimated 35-40% of global loggerhead nesting occurs in the southeastern United States on sites from North Carolina to Florida (NMFS and USFWS, 1991; TEWG, 2000). This area supports two genetically distinct nesting populations; a southern population which ranges from 29°N (east coast of Florida) to 28°N on (west coast of Florida), and a northern population which ranges from 37.5°N (North Carolina/Virginia border) to 29°N (northeast Florida) (Bowen and Karl, 1997; Ehrhart *et al.*, 2003; NMFS and USFWS, 1991; TEWG, 2000).

Survey efforts (1989-2004) of the southern U.S. population show stable to minimal increase in annual nest production; while the northern population shows an annual decrease in nest production (Dodd and Mackinnon, 2004; Ehrhart *et al.*, 2003; Hopkins-Murphy *et al.*, 2001; TEWG, 2000). Recovery efforts for these populations are implemented through habitat management, conservation law/policy, fisheries management, public education and awareness, and scientific research (NMFS and USFWS, 1991; Margaritoulis *et al.*, 2003). Despite these efforts, recovery of these populations is considered low to non-existent (Ehrhart *et al.*, 2003; TEWG, 2000). The lack of success in nest production raises questions on how effective management and recovery efforts are on loggerhead populations.

Loggerhead nesting sites are primarily open, sandy beaches that are backed by low dunes and are easily accessible from the open ocean (Miller *et al.*, 2003). There are many environmental conditions of nesting sites that influence nest parameters. Various nest parameters directly affect embryonic development (Carthy *et al.*, 2003). Embryonic

development is particularly influenced by moisture, gas exchange, and temperatures during incubation (Miller *et al.*, 2003). Variations of these environmental conditions can alter a large variety of hatchling characteristics, including embryonic growth rates (Kuroyangi and Kamezaki, 1993), hatch success, and sex ratios (Bull, 1980; Carthy, 2003; Mrsofsky and Yntema, 1980).

Temperature is the main environmental factor that affects embryonic development. The sex ratio and growth rates of hatchlings are influenced by nest temperatures during incubation. Loggerhead sex ratios are environmentally determined by a process known as temperature-dependent sex determination (TSD) (Bull, 1980; Mrsofsky and Yntema, 1980). This process occurs during the middle third of the incubation duration, and is known as the critical period (Bull, 1987; Bull and Vogt, 1981; Yntema and Mrsofsky, 1982). During the critical period there is a pivotal temperature that yields a 1:1 sex ratio (Bull, 1980; Mrsofsky and Yntema, 1980). The pivotal temperature for loggerheads is approximately 29°C. Hatchling sex ratio is male-biased when the average critical period temperature begins to drop to temperatures of 28.5°C. Hatchling sex ratio is female-biased when the average critical period temperature begins to reach temperatures of 30°C (Marcovaldi *et al.*, 1997., Mrsofsky, 1988).

The nest temperature during the incubation duration can also influence embryonic growth rate and hatchling size. Nests exposed to warmer temperatures tend to increase the rate of embryonic development and produce larger hatchlings than nests exposed to cooler temperatures (Kuroyanagi and Kamezaki, 1993).

Specific changes in nest site conditions that can potentially alter nest parameters are natural and anthropogenic. Natural occurrences include, but are not limited to

precipitation, tide fluctuations, vegetative growth, and nest depredation. Anthropogenic changes to nest sites are human-related activities; such as coastal armoring, beach nourishment, and coastal development (Carthy, 2003; NMFS and USFWS, 1991). Even some management practices that are intended for the recovery of loggerhead populations could potentially alter nests conditions; in particular nest relocation (Carthy, 2003; Foley, 1998; Foley *et al*, 2000).

Nest relocation is a management tool used in the recovery of loggerhead populations. This type of management involves removing nests from areas with extreme abiotic conditions (i.e. excessive moisture, tidal areas, etc.), and relocating them to areas that are considered to be favorable for hatch success. Nest relocation is intended to aid sea turtle recovery efforts by increasing hatch success; but there are concerns about nest composition and nest dimensions being altered by moving nests from their original location (Carthy, *et al.*, 2003). Changes in nest composition and dimensions can alter nest parameters, such as moisture content (Foley, 1998) and temperature within the nest (Foley *et al*, 2000); therefore any changes in nest parameters attributed to nest relocation could alter embryonic development.

Beaches of coastal GA experience up to nine feet of tidal fluctuation every six hours. These tidal fluctuations expose meters of open beach at high-tide, to hundreds of meters of open beach at low tide. These conditions allow loggerheads to lay nests in a wide range of locations across the beach; including areas below the spring high-tide line. If nests laid below this line were left *in-situ* (remained in their original location where the female deposited the eggs) they would have the potential of being inundated by seawater during the incubation duration. U. S. Fish and Wildlife Service protocol on Blackbeard

Island National Wildlife Refuge requires every nest that is laid below the spring high-tide line to be relocated.

Changes in nest site conditions, and their effects on nest parameters, must be understood for effective management and conservation of sea turtle populations. This study was conducted to answer the question: What are the effects of nest relocation on nest parameters and embryonic development? To answer this question three hypotheses were tested. Hypothesis 1: Nest parameters and embryonic conditions will differ between *in-situ* and relocated nests. Hypothesis 2: Nest parameters and embryonic conditions will differ between *in-situ* nests laid above the spring high-tide line and relocated nests laid above the spring high-tide line. Hypothesis 3: Nest parameters and embryonic conditions will differ between nests above the spring high-tide line (zone 1) and nests below the spring high-tide line (zone 2), regardless of treatment.

## CHAPTER 2

### METHODS

#### **Study Site**

This study took place on Blackbeard Island National Wildlife Refuge (31°87'N, 81°97'W), Liberty County, Georgia, U. S. A. (figure 1). Research was conducted in May through August, 2005 and 2006, during the loggerhead nesting season. The study area consisted of approximately 11km of beach located on the east side of the island.

#### **Experimental Design**

Prior to the start of this study a number set was created to represent the number of nests laid per season. Each nest used in this study was designated one of two treatments, *in-situ* or relocated. *In-situ* nests were left in the original location where the female deposited the eggs. Relocated nests were moved above the spring high-tide line and into areas that do not typically experience erosion or tidal influences. To eliminate human bias on which nests were left *in-situ* or relocated, each nest number was randomly assigned one of these treatments. In order to obtain nests with variable conditions that may occur throughout the nesting season every third nest was targeted to be part of this study.

In order to maintain the original dimensions of the nest chamber, the top of the chamber was measured from the surface (*In-situ* n=35,  $20.85 \pm 1.13$ cm, Relocated n=34,  $23.97 \pm 1.15$ cm), all of the eggs were counted, and removed (*In-situ* n=35,  $118.65 \pm 3.16$  Relocated n=34,  $124.26 \pm 3.21$ ), and then the bottom of the chamber was measured from the surface (*In-situ* n=35,  $47.71 \pm 0.90$ cm, Relocated n=34,  $50.20 \pm 0.91$ cm). All nests were reconstructed to the dimensions of the original nest.

As the clutch was removed from the chamber, the diameters of twenty eggs were measured from each nest (*In-situ* n=35,  $42.12 \pm 0.24$ mm Relocated n=34,  $42.68 \pm 0.24$ mm). To obtain a distribution of eggs from throughout the nest only every sixth egg was measured. After egg diameters were measured, half of the eggs were placed back into the nest, and another measurement was taken from the middle of the nest chamber to the surface (*In-situ* n=35,  $34.88 \pm 0.91$ cm Relocated n=34,  $38.26 \pm 0.92$ cm). A temperature data-logger was then placed in the middle of the nest chamber and covered with the remaining eggs. After all of the eggs were deposited back into the nest they were topped with sand and covered by metal screens to prevent predation.

One out of every three nest that received a data-logger also received a sister data-logger. The sister data-logger was defined as a data-logger put into the ground 1m north of the nest location and placed at the same depth as the nest data-logger. The sister data-loggers were used to observe the temperature of the immediate nesting areas where they were placed; and to compare this temperature with nests' temperatures throughout their incubation. All data-loggers were set to record the temperature every two hours and remained in their locations for the entire incubation duration.

After a mass emergence (a large percent of hatchlings come out of the nest at once) or an extended time period without a mass emergence (which would indicate low hatch success or a failed nest) the nests were excavated. During this excavation data-loggers were retrieved and all data was downloaded. Incubation duration was determined and temperature data was analyzed. Hatch Success (percent of turtles that hatched per clutch) was determined by subtracting the number of eggs that did not hatch by the clutch size.



Twenty hatchlings were targeted to be measured from each nest. Natural incubation durations for loggerhead nests in the southeastern United States average 53-68 days; therefore after 45 days of incubation a cage was placed over the nests to collect hatchlings upon emergence (NMFS and USFWS, 1991). In the event of a mass emergence hatchlings were randomly chosen to be measured. Hatchlings' straight carapace length (SCL) was measured using calipers.

Precipitation was observed throughout the nesting season by the use of rain gauges that were placed at the northern, middle, and southern regions of the nesting beach. This data was used to compare precipitation to beach and nest temperatures.

### **Statistical Analysis**

Two-way analysis of covariance (ANCOVA) was used to test the differences among treatments and among nesting zones as the season progressed. The data for hatch success was not normally distributed, therefore the differences among nest treatments and among nesting zones were tested using Wilcoxon/Kruskal-Wallis tests. Nests and sister data-logger temperatures during embryonic stages 7-27 of development were compared using a t-test. These particular stages of embryonic development were compared because after stage 27 temperature sex determination has already taken place and metabolic heat from growing embryos rapidly increases the temperature of the nest (Godley *et al.*, 2001, Miller, 1985).

There were a total of 73 observed nests in this study. Three of these nests were laid by a female who had duplicate nests in the data-set. To avoid pseudo-replication the duplicate nests were removed for statistical analysis. Final statistical analysis was performed with 35 *in-situ* and 34 relocated nests.

## CHAPTER 3

### RESULTS

Incubation duration has been correlated with sex ratios produced in natural nests (Mrsovsky et al., 1999) and therefore may be altered by nest relocation. No difference was observed in incubation duration for any treatment or zone on the beach (e.g., above or below the spring high-tide line). Overall incubation duration for *in-situ* nests and relocated nests were  $54.34 \pm 0.61$  days and  $54.69 \pm 0.57$  days, respectively (table 1). Incubation duration for *in-situ* nests and relocated nests above the spring high-tide line (zone 1) were  $54.00 \pm 0.93$  days and  $54.69 \pm 0.57$  days, respectively (table 2). Incubation duration based on zone (above or below the spring high-tide line) regardless of treatment (*in-situ* versus relocated) were  $54.62 \pm 0.82$  days (zone 1) and  $54.50 \pm 0.48$  days (zone 2) (table 3).

Nest temperature is also correlated with incubation duration and sex ratio produced in natural nests and provides a good indicator of incubation conditions. No difference was observed in nest temperature for any treatment or zone on the beach (e.g., above or below the spring high-tide line). The overall average nest temperature for *in-situ* nests and relocated nests were  $29.84 \pm 0.11^{\circ}\text{C}$  and  $29.93 \pm 0.11^{\circ}\text{C}$ , respectively (table 1). For nests above the spring high-tide line, average nest temperature for *in-situ* nests and relocated nests were  $30.08 \pm 0.17^{\circ}\text{C}$  and  $29.93 \pm 0.11^{\circ}\text{C}$ , respectively (table 2). The average nest temperature of nests laid below the spring high-tide line ( $29.68 \pm 0.14^{\circ}\text{C}$ ) was significantly lower than the average nest temperature of nests that were laid above the spring high-tide line ( $29.98 \pm 0.09^{\circ}\text{C}$ ) (table 3). The significant difference in average nest temperature in nest above and below the spring high-tide line, and no significant

difference in average nest temperature between *in-situ* and relocated nests above the spring high-tide line, indicates that nest temperature was influenced by nest location and not by nest treatment.

Average critical period nest temperatures displayed similar patterns to average incubation temperatures regardless of treatment but not zone. The average critical period temperature for *in-situ* nests ( $29.96 \pm 0.13^{\circ}\text{C}$ ) and relocated nests ( $30.06 \pm 0.12^{\circ}\text{C}$ ) was not significantly different (table 1). The average critical period temperature for *in-situ* nests above the spring high-tide line ( $30.23 \pm 0.20^{\circ}\text{C}$ ) and relocated nests above the spring high-tide line ( $30.06 \pm 0.12^{\circ}\text{C}$ ) was not significantly different (table 1). The average critical period temperature of nests laid below the spring high-tide line ( $29.74 \pm 0.17^{\circ}\text{C}$ ) was significantly lower than the average critical period temperature of nests that were laid above the spring high-tide line ( $30.11 \pm 0.10^{\circ}\text{C}$ ) (table 3).

Critical period nest temperature provides an accurate estimate of sex ratio produced in natural and relocated nests. All nests, regardless of treatment or zone (above and below the spring high tide line), showed a female-biased sex ratio (figure 3).

Hatchling size is influenced by incubation conditions and provides a good indicator of hatchling condition. Hatchling size indicated by SCL was not affected by treatment or zone. Hatchling SCL was not significantly different between *in-situ* nests ( $44.91 \pm 0.26\text{mm}$ ) and relocated nests ( $45.20 \pm 0.23\text{mm}$ )(table 1). Hatchling SCL between *in-situ* nests above the spring high-tide line ( $45.06 \pm 0.41\text{mm}$ ) and relocated nests above the spring high-tide line ( $45.20 \pm 0.23\text{mm}$ ) was not significantly different (table 2). Hatchling SCL between nests above the spring high-tide line ( $45.16 \pm 0.19\text{mm}$ ) and nests above the spring high-tide line ( $44.78 \pm 0.35\text{mm}$ ) was not significantly different (table 3). No

significant difference in hatchling SCL or incubation duration between nests would indicate that hatchling growth rate was not affected by nest treatment.

Hatch success was not affected by treatment but was affected by zone (above and below the spring high tide line). Hatch success in relocated nests ( $81.21 \pm 5.03\%$ ) was significantly higher than nests that were left *in-situ* ( $61.32 \pm 5.03\%$ ) (table 1). Hatch success in nests above the spring high-tide line (*in-situ*,  $72.27 \pm 6.25\%$ , relocated,  $81.21 \pm 5.03\%$ ), were not statistically different (table 2), regardless of nest treatment. Hatch success in nests below the spring high-tide line ( $53.65 \pm 6.43\%$ ) had significantly lower hatch success than nests above the spring high-tide line ( $78.60 \pm 4.15\%$ )(table 3). Nests laid in zone 2 (below the spring high-tide line) tended to have lower hatching success (figure 2)

Mean temperatures of nests ( $29.23 \pm 0.12$  °C) and sister data-loggers ( $29.02 \pm 0.12$  °C) were not significantly different (t-value = 1.16, DF = 42, P = 0.2514) during embryonic development (figure 4). The consistency between nest temperatures and temperatures in the nesting environment suggest embryonic development will fluctuate as environmental conditions fluctuate independent of treatment. Precipitation was the main environmental factor that influenced the nesting environment on this site. Nest and beach temperature decreased with increased precipitation (figure 4).

## CHAPTER 4

### DISCUSSION

The loggerhead was listed as a threatened species on July 28, 1978, under the Endangered Species Act of 1973 (NMFS and USFWS, 1991). Under this listing a recovery goal was set with three major objectives. The first objective is to have an increase in the adult female population of Florida, and for the populations of North Carolina, South Carolina, and Georgia to return to pre-listing levels (NC = 800 nests/season; SC = 10,000 nests/season; GA = 2,000 nests/season). These conditions must be met with data from standardized surveys which will continue for at least 5 years after delisting. The second objective is for at least 25 percent (560km) of all nesting beaches (2240km) to be in public ownership, distributed over the entire nesting range and encompassing at least 50 percent of the nesting activity within each state. The third objective is that all priority goals have been successfully implemented. The National Marine Fisheries Service and The U.S. Fish and Wildlife Service's "Recovery Plan for U.S. Loggerhead Population" (1991) states that the six major actions needed to achieve this recovery are to provide long-term protection to important nesting beaches, ensure at least 60 percent hatch success on major nesting beaches, implement effective lighting ordinances or lighting plans on all major nesting beaches within each state, determine distribution and seasonal movements for all life stages in marine environment, minimize mortality from commercial fisheries, and reduce threat from marine pollution.

Recovery efforts are implemented to protect nesting and marine habitat and the populations of loggerheads that utilize these areas. This is accomplished through nesting population/habitat management, conservation law/policy, fisheries management, public

education/awareness, scientific research, and international cooperation (NMFS and USFWS, 1991; Margaritoulis et al., 2003).

These management efforts are implemented throughout the range of the northern and southern U.S. populations. Despite these efforts population recovery is considered low to non-existent (Ehrhart *et al.*, 2003; TEWG, 2000). Survey efforts (1989-2004) of the southern U.S. population show stable to minimal increase in annual nest production; while the northern population shows an annual decrease in nest production (Dodd and Mackinnon, 2004; Ehrhart *et al.*, 2003; Hopkins-Murphy *et al.*, 2001; TEWG, 2000). The lack of success in nesting production raises questions about the positive and negative impacts of management and recovery efforts on loggerhead populations.

Loggerhead nesting sites are primarily open, sandy beaches that are backed by low dunes and are easily accessible from the open ocean (Miller *et al.*, 2003). There are many environmental conditions of nesting sites that influence nest parameters. Various nest parameters directly affect embryonic development (Carthy *et al.*, 2003). Embryonic development is particularly influenced by moisture, gas exchange, and temperatures during incubation (Miller *et al.*, 2003). Variations of these environmental conditions can alter a large variety of hatchling characteristics, including embryonic growth rates (Kuroyangi and Kamezaki, 1993), hatch success, and sex ratios (Bull, 1980; Carthy, 2003; Mrsovsky and Yntema, 1980).

Beaches of coastal GA experience up to nine feet of tidal fluctuation every six hours. These tidal fluctuations expose meters of open beach at high-tide, to hundreds of meters of open beach at low tide. These conditions allow loggerheads to lay nests in a wide range of locations across the beach; including areas below the spring high-tide line.

Areas below the spring high-tide line are vulnerable to seawater wash over and inundation. The sand in these areas is higher in moisture content than the sand located above the spring high-tide line (Foley, 1998, Barnard, USFWS, pers. comm., 2002). Higher moisture content within a nest has been found to lower temperature, which would alter embryonic development and hatch success (McGhee, 1990; Foley, 1998). Nests that are above the spring high-tide line are less likely to be influenced by tidal fluctuation, and therefore less likely to alter embryonic development and hatch success.

Nest relocation is used to increase hatch success by alleviating nest of extreme abiotic conditions, such as tidal fluctuation. The use of nest relocation is highly debated because of its potential negative effects on embryonic development, its positive effects on hatch success, and the lack of research of its effects on sea turtle recovery.

It has been suggested by Foley (1998, 2000) that nest relocation has significant detrimental effects on hatch success. These findings are not consistent with data from some long term nest management projects. Nest relocation has been used to aid recovery efforts for sea turtle for decades. Kemp's Ridley nests in Mexico have been actively managed since 1978. Management of this population involves the relocation of almost 100% of all nests (USFWS and NMFS, 1992; USFWS and NMFS, 2007). These efforts have had hatch success up to 79% and has increased the nesting population from 274 nesting females in 1985, to 4,047 nesting females in 2006 (USFWS and NMFS, 1992, 2007). Nest relocation has also been part of nest management in South Carolina, at Cape Romain National Wildlife Refuge since the late 1970's. (Cape Romain NWR, 2007). Since the beginning of its loggerhead management program Cape Romain NWR has produced 2,295,866 hatchlings. It has been estimated that the amount of hatchlings

produced during the same time period, with no nest management, would have been reduced by over 2,000,000 hatchlings (Cape Romain NWR, 2007).

This study indicates that alleviating nests of extreme abiotic conditions, through nest relocation is an effective management tool for increasing hatch success for sea turtle populations. Hatch success in relocated nests ( $81.21 \pm 5.03\%$ ) was significantly higher than nests that were left *in-situ* below the spring high-tide line ( $53.65 \pm 6.43\%$ )(table 1 and 3). Hatch success in nests above the spring high-tide line (*in-situ*,  $72.27 \pm 6.25\%$ ; relocated,  $81.21 \pm 5.03\%$ ), were not statistically different (table 2), regardless of nest treatment. Hatch success in nests that were left below the spring high-tide line ( $53.65 \pm 6.43\%$ ) had significantly lower hatch success than nests that were above the spring high-tide line ( $78.60 \pm 4.15\%$ ) (table 3). The high hatch success of this study, which was achieved with the use of nest relocation, are consistent with the high hatch success of relocated Kemp's Ridley nests in Mexico (USFWS and NMFS, 1992; USFWS and NMFS, 2007) and relocated nests in South Carolina, at Cape Romain National Wildlife Refuge (Cape Romain NWR, 2007). Tidal fluctuations increase the moisture content of the nesting site below the spring high-tide line. The hatch success in nests in these areas are consistent with the findings of McGhee (1990) and Foley (1998), being lower in areas of higher moisture content.

The pivotal temperature for loggerhead populations is approximately  $29^{\circ}\text{C}$ . Hatchling sex ratio is male-biased when the average critical period temperature begins to drop to temperatures of  $28.5^{\circ}\text{C}$ . Hatchling sex ratio is female-biased when the average critical period temperature begins to reach temperatures of  $30^{\circ}\text{C}$  (Marcovaldi *et al.*, 1997., Mrsovsky, 1988). The average critical period temperatures for *in-situ* nests ( $29.96$



$\pm 0.13^{\circ}\text{C}$ ), relocated nests ( $30.06 \pm 0.12^{\circ}\text{C}$ ), and nests below the spring high-tide line ( $29.74 \pm 0.17^{\circ}\text{C}$ ) show a female-biased sex ratio (table 1, table 3, figure 3). This is consistent with many other studies that have found female-biased sex ratios in the northern and southern loggerhead populations of the U.S.: Hutchinson Island, Florida (2.5F:1.0M) (Wibbels et al., 1987a; Wibbels et al., 1991), Chesapeake Bay, Virginia (2.0F:1.0M), Indian River, Florida (1.4F:1.0M) (Wibbels et al., 1987b), Cumberland Island, Georgia (1.9F:1.0M) (Shoop et al., 1998), Virginia (2.1F:1.0M), North Carolina (1.9F:1.0M), South Carolina (2.1F:1.0M), Georgia (1.7F:1.0M), and Florida (1.9F:1.0) (NMFSSFSC, 2001).

It has been suggested that nest relocation can cause changes in nest temperature, which would alter hatchling sex ratios (Foley, 2000). The fact that both nest treatments, *in-situ* and relocated, show no significant difference in average critical period temperatures (table 1, table 2), indicates that nest relocation at this study site has no effect on hatchling sex ratio. The average critical period temperature of nests laid below the spring high-tide line ( $29.74 \pm 0.17^{\circ}\text{C}$ ) was significantly lower than the average critical period temperature of nests that were laid above the spring high-tide line ( $30.11 \pm 0.10^{\circ}\text{C}$ ) (table 3). The nest sites below the spring high-tide line experience tidal wash over, which increases the moisture content of the sand, which decreases sand temperature. Therefore leaving nests in areas of tidal influence will skew the sex ratio by reducing nest temperature, producing more male hatchlings however these nests also display lower overall hatch success.

It has been suggested that incubation duration can be used to predict hatchling sex ratio (Mrsovsky *et al.*, 1999). Nests observed in this study showed no significant

difference in incubation duration for *in-situ* nests ( $54.34 \pm 0.61$  days) (table 1), relocated nests ( $54.69 \pm 0.57$  days)(table 1) or in nests below the spring high-tide line ( $54.62 \pm 0.82$  days)(table 3). The significant difference in average critical period temperature in nests below the spring high-tide line (table 3) would indicate that sex ratio can be influenced without a change in incubation duration. Nest temperature can be influenced by abiotic conditions before or after the critical period, which could slow embryonic development and lengthen incubation duration (figure 4); therefore incubation duration can not be used as a certain index of sex ratio in nesting areas with extreme abiotic conditions.

It has been suggested by Foley (1998) that nest relocation has detrimental effects on hatchling fitness. Hatchling fitness refers to its reproductive success and fecundity throughout its life. Foley (1998) found that cooler nest temperatures produced hatchlings that developed slower than hatchlings in nests with warmer nest temperatures; but hatchlings in cooler nest temperatures grew larger and could swim faster. He suggests that a hatchling's ability to swim faster would increase its fitness by increasing its ability to avoid predation. Although this study did not observe the swimming ability of hatchlings, it did observe hatchling size. Hatchling SCL was not found to be significantly different between *in-situ* nests ( $44.91 \pm 0.26$ mm) and relocated nests ( $45.20 \pm 0.23$ mm) (table 1). Hatchling SCL between *in-situ* nests above the spring high-tide line ( $45.06 \pm 0.41$ mm) and relocated nests above the spring high-tide line ( $45.20 \pm 0.23$ mm) was not significantly different (table 2). Hatchling SCL between nests above the spring high-tide line ( $45.16 \pm 0.19$ mm) and nests above the spring high-tide line ( $44.78 \pm 0.35$ mm) was not significantly different (table 3). No significant differences in hatchling SCL and no significant differences in incubation duration between nests would indicate that hatchling

growth rate was not affected by nest treatment; therefore there is no reason to believe that hatchling mobility would be affected by nest treatment. To accurately assess hatchling fitness a hatchling would have to be observed until it reached sexual maturity. Since the age of sexual maturity of a loggerhead is believed to be between 20 and 30 years, the task of monitoring a hatchling until it reaches sexual maturity is not possible; therefore Foley's (1998) suggestion that hatchling fitness is altered by nest relocation can not accurately be determined.

Mean temperatures of nests ( $29.23 \pm 0.12$  °C) and sister data-loggers ( $29.02 \pm 0.12$  °C) were not significantly different (t-value = 1.16, DF = 42, P = 0.2514) during embryonic development (figure 4). The consistency between nest temperatures and temperatures in the nesting environment suggest embryonic development will fluctuate as environmental conditions fluctuate. Precipitation was the main environmental factor that influenced the nesting environment on this site. Nest and beach temperature decreased with increased precipitation (figure 4). If environmental conditions are the driving factor for nest parameters during embryonic development, than nest treatment should not alter these parameters.

It has been documented that nest relocation can significantly alter hatchling development by changing nest parameters, such as nest dimensions, moisture content, temperature within nests (Foley, 1998; Foley, 2000; Carthy, *et al.*, 2003). The results of this study do not provide any evidence that nest relocation altered any nest parameters or hatchling characteristics. Increased hatch success was achieved by alleviating nests of extreme abiotic conditions, not by nest treatment. On this study site, nest relocation is used to alleviate nest of tidal wash over, tidal inundation, and areas of extreme erosion,

because these areas experience higher moisture content, lower temperature, and lower hatch success. This management tool has achieved its purpose of increasing hatch success without altering any of the observed variables of nest site conditions or embryonic development.

This study site has proven to be a nesting area with consistent beach conditions above the spring high-tide line, providing nesting areas that are favorable for embryonic development and hatch success. If a nesting area has conditions that are highly variable, such as temperature, different grain size, or sand color, than a cautious approach should be taken when relocating nests. Relocating nests to areas with conditions that are not similar to the original nesting conditions could alter embryonic development and hatch success. Beaches within the same geographical region as this study site should have similar nest site conditions; which would allow nest relocation to be utilized. To be certain that nest relocation can be used as an effective management technique for a particular nesting site, temperature trends and areas with extreme abiotic conditions must be located, and nest conditions should be closely monitored.

Table 1: Mean incubation duration, average nest temperature, average critical period temperature, mean hatch success, and mean straight carapace length for hatchlings; and statistical significance for all variables between *in-situ* and relocated nests. (n = number of nests that data was collected)

<b>Measured Variable</b>	<b><i>In-situ</i> Mean ± S.E.</b>	<b>Relocated Mean ± S.E.</b>	<b>Statistics</b>	<b>Significance</b>
<b>Incubation Duration</b>	54.34 ± 0.61days (n=29)	54.69 ± 0.57days (n=33)	DF = 1,59; F =0.53; P = 0.4655	NS
<b>Temperature</b>	29.84 ± 0.11°C (n=35)	29.93 ± 0.11°C (n=34)	DF = 1,66; F = 2.05; P = 0.1563	NS
<b>Critical Period Temperature</b>	29.96 ± 0.13°C (n=29)	30.06 ± 0.12°C (n=33)	DF = 1,59; F = 2.83; P = 0.0976	NS
<b>Hatch Success</b>	61.32 ± 5.03% (n=31)	81.21 ± 5.03% (n=34)	Z = 1.99; P = 0.0455	*
<b>Hatchling SCL</b>	44.91 ± 0.26mm (n=24)	45.20 ± 0.23mm (n=31)	DF = 1,52; F = 0.77; P = 0.3824	NS

Table 2: Mean incubation duration, average nest temperature, average critical period temperature, mean hatch success, and mean straight carapace length for hatchlings; and statistical significance for all variables between *in-situ* and relocated nests that were laid above the spring high-tide line. (n = number of nests that data was collected)

<b>Measured Variable</b>	<b><i>In-situ</i> Mean ± S.E.</b>	<b>Relocated Mean ± S.E.</b>	<b>Statistics</b>	<b>Significance</b>
<b>Incubation Duration</b>	54.00 ± 0.93days (n=13)	54.69 ± 0.57days (n=33)	DF = 1,43; F = 0.0036; P = 0.9527	NS
<b>Temperature</b>	30.08 ± 0.17°C (n=14)	29.93 ± 0.11°C (n=34)	DF = 1,45; F = 0.0006; P = 0.9804	NS
<b>Critical Period Temperature</b>	30.23 ± 0.20°C (n=13)	30.06 ± 0.12°C (n=33)	DF = 1,43; F = 0.0003; P = 0.9511	NS
<b>Hatch Success</b>	72.27 ± 6.25% (n=14)	81.21 ± 5.03% (n=34)	Z = -0.48; P = 0.6258	NS
<b>Hatchling SCL</b>	45.06 ± 0.41mm (n=11)	45.20 ± 0.23mm (n=31)	DF = 1,39; F = 0.13; P = 0.7127	NS

Table 3: Mean incubation duration, average nest temperature, average critical period, mean hatch success, and mean straight carapace length for hatchlings; and statistical significance for all variables between nest laid above the spring high-tide line and nests laid below the spring high-tide line. (n = number of nests that data was collected)

<b>Measured Variable</b>	<b>Above SHTL Mean ± S.E.</b>	<b>Below SHTL Mean ± S.E.</b>	<b>Statistics</b>	<b>Significance</b>
<b>Incubation Duration</b>	54.50 ± 0.48days (n=46)	54.62 ± 0.82days (n=16)	DF = 1,59; F = 7.06; P = 0.2706	NS
<b>Temperature</b>	29.98 ± 0.09°C (n=48)	29.68 ± 0.14°C (n=21)	DF = 1,66; F = 6.28; P = 0.0147	*
<b>Critical Period Temperature</b>	30.11 ± 0.10°C (n=46)	29.74 ± 0.17°C (n=16)	DF = 1,59; F = 9.10; P = 0.0038	*
<b>Hatch Success</b>	78.60 ± 4.15% (n=49)	53.65 ± 6.43% (n=20)	Z = -2.50; P = 0.0123	*
<b>Hatchling SCL</b>	45.16 ± 0.19mm (n=42)	44.78 ± 0.35mm (n=13)	DF = 1,52; F = 0.89; P = 0.3493	NS

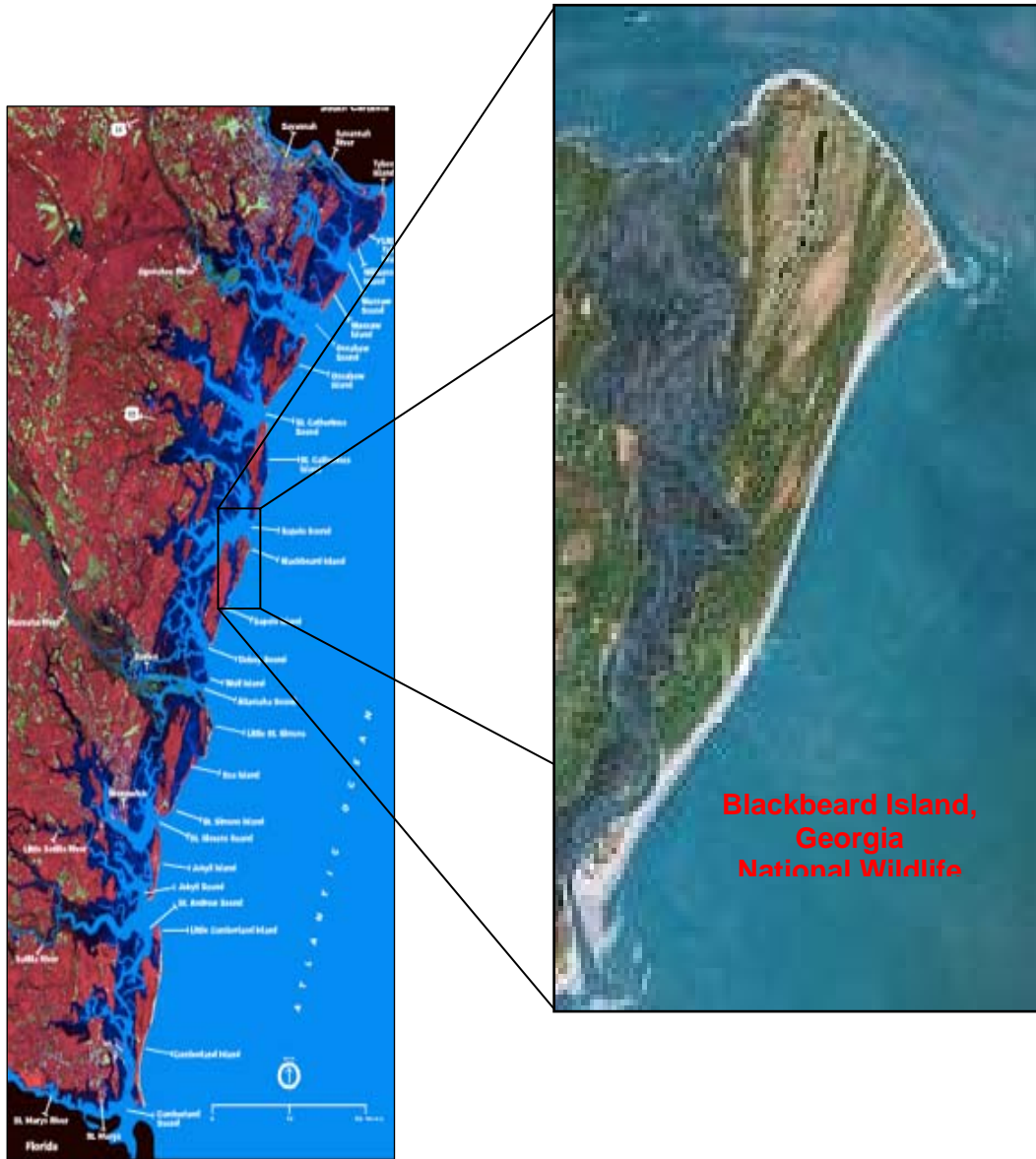


Figure 1: Study Site. Blackbeard Island National Wildlife Refuge, located in coastal Georgia ( $31^{\circ}30'N$ ,  $81^{\circ}12'W$ ). Blackbeard Island has approximately 11 km of nesting beach located on the east side of the island.



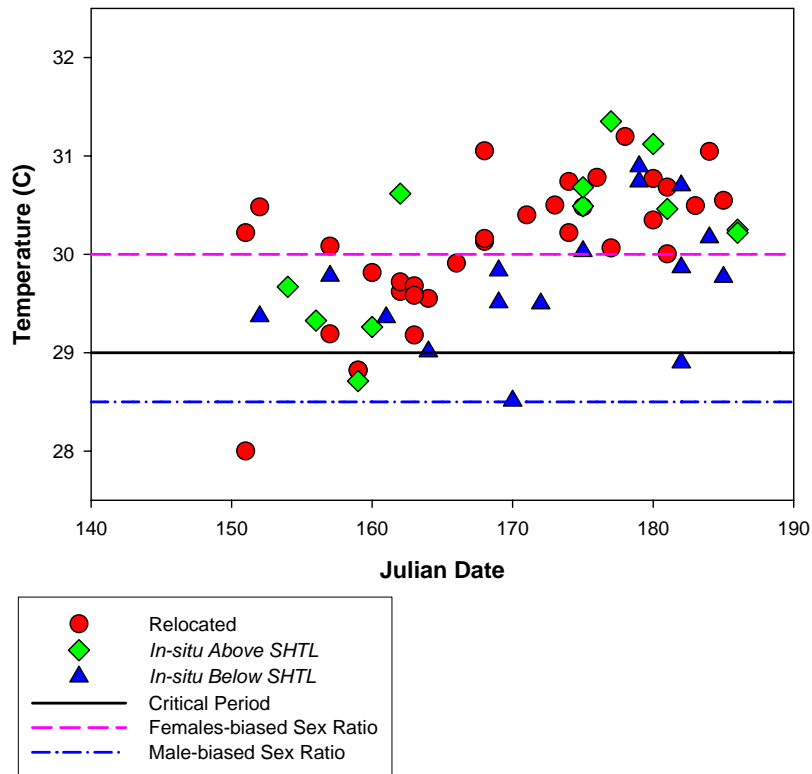


FIGURE 2: Average critical period temperatures for relocated nests, and for *in-situ* nests above and below the spring high-tide line. Hatchling sex ratio is male-biased when the average critical period temperature begins to drop to temperatures around 28.5°C. Hatchling sex ratio is female-biased when the average critical period temperature begins to reach temperatures around 30°C. The pivotal temperature during the critical period is approximately 29°C. The critical period temperatures indicate that a majority of nests that were observed during this study produced a female-biased sex ratio. (SHTL = Spring High-Tide Line).

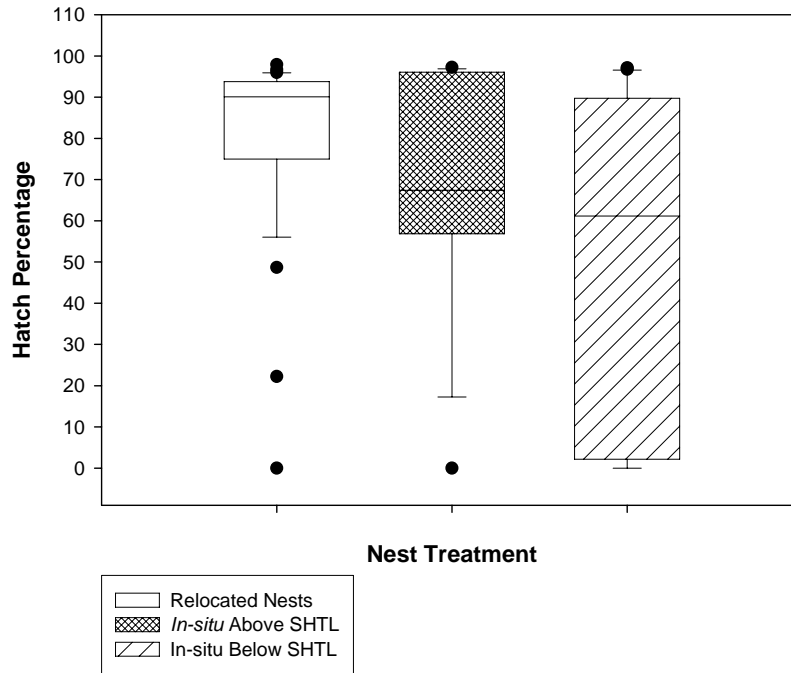


FIGURE 3: Median hatch success for relocated nests (90.10%). Median hatch success for *in-situ* nests above the spring high-tide line (77.07%). Median hatch success for *in-situ* nest below the spring high-tide line (61.86%). (SHTL = Spring High-Tide Line).

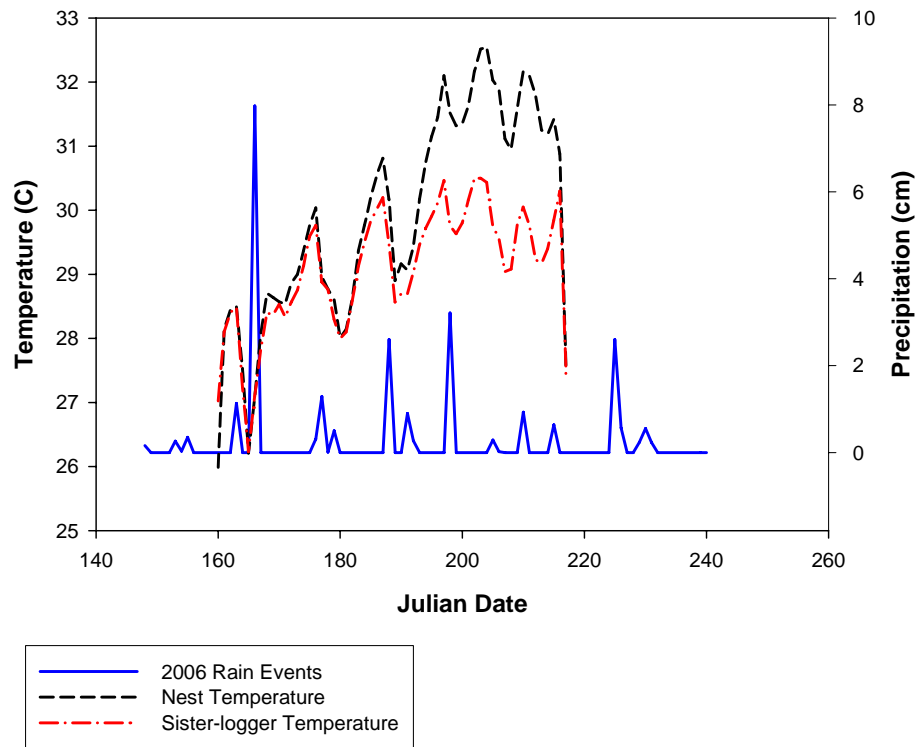


FIGURE 4: This figure shows an example of how nest temperatures and sister-logger temperatures are similar throughout embryonic development. These temperatures will remain the same until later in the incubation duration when metabolic heat is produced in the nest during the hatching growth stage. This figure also shows the influence of rain events on nest and beach temperatures.

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