Sea Turtle Nest Management: Examining the Use of Relocation as a Management Tool on Three South Carolina Beaches

An internship report submitted in partial satisfaction of the requirements for the degree of

MASTER OF SCIENCE

in

ENVIRONMENTAL STUDIES

by

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May 2010

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Sea Turtle Nest Management: Examining the Use of Relocation as a Management Tool on Three South Carolina Beaches

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Abstract

One management tool utilized by nest management projects in South Carolina is relocation of presumed doomed nests. The objective of this project was to examine nest relocation as a sea turtle nest management tool on three South Carolina beaches: Edisto Beach State Park, Fripp Island, and Folly Beach. The project involved daily monitoring of initial nest sites of relocated nests for wash-over and washed away events, analysis of data collection during nest surveys and inventories, and the design of Geographic Information System maps as nest management guides for volunteers and project leaders. Generally, the three project beaches follow South Carolina Department of Natural Resources guidelines and only relocate nests laid below the spring high tide line. A number of initial sites, *in situ*, and relocated nests were impacted by tidal events. Hatch and emergence success were similar between *in situ* and relocated nests for all project beaches combined and for Edisto Beach State Park and Folly Beach. Hatch and emergence success were significantly higher in relocated nests on Fripp Island. Analysis of statewide data found hatch and emergence success of nests with four or more wash-overs was significantly lower than nests with zero wash-overs. Four or more wash-overs were used to evaluate nest management outcomes for project beaches. A majority of the nests on each project beach were correctly managed with a small percentage unnecessarily relocated or needing further management. This study suggests that the use of relocation, when employed correctly, is still an important nest management tool, especially for beaches that suffer from severe erosion and tidal inundation.

Acknowledgements

I would first like to thank my committee members DuBose Griffin, David Owens, Martin Jones, and Norm Levine. All members offered support, encouragement, and advice throughout my internship process. I want to thank fellow Master of Environmental Studies students Melissa Bimbi and Kelly Sloan for generously sharing their sea turtle knowledge. Thank you to Mark McConnel, Master of Environmental Studies Program Coordinator, for knowing everything there is to know about the MES Program.

I would especially like to thank all the project leaders, volunteers, and interns who made this project possible. Thank you to Andrea Grabman, her two interns Corinne Campi and Mary McCumber, and the Edisto Beach State Park sea turtle volunteers for all their hard work and dedication. Thanks to Judi Beahn and the Folly Beach sea turtle volunteers for diligently covering their entire beach while having fun at the same time. Thank you Janie Lackman and her crew of Fripp Island sea turtle volunteers for making me feel part of the team and offering constructive criticism and advice. Thank you all for your commitment and assistance with my project.

Finally, thank you to all my friends and family for supporting me through this process. Special thanks to Ryan Bollinger for keeping me focused, distracting me when I felt overwhelmed, and always lending a hand in the lab or the field.

Introduction and Literature Review

Distribution and Conservation Status

South Carolina's barrier islands provide nesting habitat for several species of sea turtles, including the loggerhead (*Caretta caretta*) and infrequently the Kemp's ridley (*Lepidochelys kempii*), green (*Chelonia mydas*) and leatherback (*Dermochelys coriacea*). In South Carolina, loggerheads account for the majority of sea turtle nesting (SCDNR unpublished data). Loggerheads are found worldwide and inhabit open-ocean and near shore habitats across both temperate and tropical latitudes (Bolten 2003). Within the United States, loggerheads commonly nest from Virginia to Louisiana with major nesting concentrations occurring in North Carolina, South Carolina, Georgia, and Florida (NMFS and USFWS 2008). There are five recovery units of loggerheads in the Northwest Atlantic. These five recovery units are: the Northern Recovery Unit (includes South Carolina), Peninsular Florida Recovery Unit, Dry Tortugas Recovery Unit, Northern Gulf of Mexico Recovery Unit, and Greater Caribbean Recovery Unit (NMFS & USFWS 2008). In each of these five recovery units, mtDNA haplotype frequencies and geopolitical boundaries have established distinct genetic differences between nesting females (Encalada et al. 1998; Pearce 2001; NMFS & USFWS 2008). The nest protection projects in South Carolina are particularly important for loggerhead turtles since females nesting in this state make up approximately 66% of the Northern Recovery Unit (NMFS & USFWS 2008).

Loggerheads face many threats throughout their life. On nesting beaches, threats include poaching, nest predators both native and non-native, storm and tidal inundation, microbial infection, beach erosion, and artificial lighting due to coastal development (Lutcavage et al. 1997; Stancyk 1982; Witherington 1999). In-water mortality is often caused by shrimp trawling, long-line fisheries, boat strikes, and intake of human debris (Bolten et al. 1996; Witherington 2003). Due to declining numbers, loggerheads were listed as “threatened” on July 28, 1978 under the Endangered Species Act of 1973 (USFWS and NMFS 1978) and are currently being considered for reclassification to endangered status (USFWS and NMFS 2010). Loggerheads are also listed as endangered under the International Union for the Conservation of Nature (IUCN) Red List (MTSG 1996).

Life Stages

The life history of loggerheads comprises four life stages: hatchling stage, oceanic juvenile stage, neritic juvenile stage, and the adult stage (Bolten 2003). Hatchlings emerge at night and enter the ocean where they have a brief, 1 to 3 day swimming frenzy before entering ocean currents (Bolton et al. 1994). Hatchlings use wave energy and magnetic cues to find the North Atlantic gyre (Lohmann & Lohmann 2003). Once in the North Atlantic gyre, loggerheads enter the oceanic juvenile stage for 6.5-11.5 years (Bjorndal et al. 2000, Carr 1987). The neritic juvenile stage (12-28 years) begins when loggerheads leave the North Atlantic gyre and travel to foraging grounds along the coast (Hopkins-Murphy et al. 2003). Finally, loggerheads reach reproductive maturity and the adult stage at 28-30 years of age (Frazer and Erhardt 1985).

Nesting

An individual loggerhead turtle nests approximately every 2.5 years (Richardson & Richardson 1982). Female loggerheads display high nest site fidelity and will return to the region of their natal beaches to nest (Carr 1975). The nesting (laying and hatching) season in South Carolina is from May 1 to October 31. Nests are laid approximately May through August while hatching occurs July through October. Once prepared to nest, the female loggerhead leaves the water and crawls on the beach to find a nesting site (Hendrickson 1982). Using her flippers, the female loggerhead creates a body pit and then uses her hind flippers to dig an egg chamber with a narrow neck and wide bottom (Carthy 1994, Miller et al. 2003). After deposition, the female loggerhead fills the egg chamber with sand using her rear flippers and then throws sand over the nest and body pit with her front flippers (Miller et al. 2003). She then crawls back to the ocean (Miller et al. 2003). During the nesting season, females lay 3 to 5.5 nests per female per season with approximate clutch count of 100 to 126 eggs (USFWS & NMFS 2008). Incubation lasts approximately 60 days depending on the temperature and moisture conditions of the sand (Mrosovsky & Yntema; Limpus et al. 1983). Nests are laid at approximately 14-day intervals (Hopkins-Murphy et al. 1999).

Though South Carolina barrier islands provide suitable nesting habitat for loggerhead turtles, nests at sites selected by nesting females are not always successful. Turtles may nest in areas vulnerable to inundation and erosion (Janzen & Paukstis 1991). The nest site selected by females determines the physical and chemical characteristics of the nest environment. The physical and chemical characteristics influence hatch and emergence success, incubation temperature, incubation duration, sex ratio, and hatchling fitness

(Packard & Packard 1988; Janzen 1994; Matsuzawa et al. 2002; Zbinden et al. 2006). For example, extremes in either temperature or water content have led to a decrease in hatch success (Ackerman 1997, Foley 1998, Yntema & Mrosovsky 1980). Other studies have shown that changes in incubation temperature, moisture content, and gas exchange can affect the size, growth rate, and activity levels of hatchlings (Carthy et al. 2003, McGehee 1990). Tidal inundation, seaward orientation of hatchlings, and the risk of predation of eggs and/or hatchlings can be positively or negatively affected by the nest site selection (Fowler 1979; Janzen & Paukstis 1991; Shine 1999).

Nest Relocation

Standardized aerial survey data collected since 1980 in South Carolina indicate loggerhead nesting is declining 1.3% per year (NMFS & USFWS 2008). Many beaches in the southeast use relocation as a nest management tool to increase productivity to offset this decline. Nest relocation occurs when clutches of doomed eggs (a nest laid where eggs and hatchlings are vulnerable to erosion and/or tidal inundation and may not survive) are moved from their original nest site to an area considered safer and less vulnerable for the eggs and hatchlings (Pfaller et al. 2008). The outcome of such nest site selection (i.e., areas of erosion or tidal inundation) is a substantial reduction in hatchling production (Mrosovsky 1983). Studies have shown that relocation of these presumed doomed eggs increased nest productivity (Hopkins & Murphy 1983, Stancyk et al. 1980, Eckert & Eckert 1990).

There are several concerns about the use of relocation as a sea turtle nest management tool. Relocation disturbs eggs during the incubation period (often measured from the time of deposition to hatchling emergence). Unnecessary disturbance or incorrectly performed relocations could lead to embryo mortality or the alteration of the nest environment, which could affect sex ratio and hatchling fitness (Limpus et al. 1979, Mrosovsky 2006, 2008, Pike 2008). Relocation of eggs 12 hours after deposition may cause movement-induced mortality of embryos (Limpus et al. 1979). Relocation can alter the incubation environment by the placement of eggs in a new chamber that may not replicate the original egg chamber (Carthy et al. 2003).

In the Loggerhead Recovery Plan, one recovery goal is to assess the impact of nest management activities on sex ratios, hatchling fitness, and nest productivity (NMFS & USFWS 2008). Several studies have attempted to determine the impact of relocation on incubation temperature and hatch success. Some studies on hatch success reported higher hatch success rates in relocated than *in situ* nests, lower hatch success rates in relocated than *in situ* nests and no difference in hatch success between relocated and *in situ* nests (Bimbi 2009, Hoekert et al. 1998, Moody 1998, Pintus et al. 2009, Tuttle 2007, Wyneken et al. 1988). These studies suggest that local variations in the use of relocation may play a part in establishing hatch success (Bimbi 2009).

Internship Objectives

In South Carolina, nest relocation is considered a management tool of last resort and only if the likelihood of the nest surviving to hatch is nil. The most desirable alternative is to eliminate problems that prompt relocation of the nest. Normally, the only situation that justifies nest relocation is when a nest is laid seaward of the spring high tide line (SHTL; SCDNR Guidelines for Marine Turtle Permit Holders 2007). The following objectives in this study examined the use of relocation on Edisto Beach State Park, Folly Beach, and Fripp Island:

1. Quantify the number and percent of nests relocated and the number of wash-overs on original nest sites, *in situ*, and relocated nests on project beaches.
2. Map locations of wash-over and washed away events using Geographic Information System (GIS) on project beaches.
3. Compare hatch and emergence success between *in situ* and relocated nests on project beaches.
4. Analyze the impact of wash-over events on hatch and emergence success for statewide data.
5. Determine the outcome of nest management decisions and whether management decisions are warranted on project beaches.
6. Calculate potential costs (i.e., the number of eggs unnecessarily relocated and number of eggs that needed relocation) and benefits (i.e., the number of eggs that hatch and the number of hatchlings that emerge from relocated nests) of relocation on project beaches.

Methods

Project Study Beaches

The three beaches chosen for this project were: Edisto Beach State Park, Folly Beach, and Fripp Island (Figure 1). Beaches were chosen for their consistently high percentage of nests relocated year after year. Edisto Beach State Park is a steep, narrow beach approximately 2.3 km in length. Along several areas, the beach is backed by campsites for recreational vehicles. Other areas of the beach are backed by salt marsh. Folly Beach is approximately 11.0 km in length. Due to erosion, Folly Beach placed rock groins perpendicular to the beach beginning in the 1940's and renourished their beach most recently in 2007. Placement of the Charleston Harbor jetties in the 1890's altered coastal sediment supply and has caused Folly's beach to erode (Levine et al. 2009). Fripp Island has approximately 3.2 km of beach but very little is suitable for sea turtle nesting. The construction of rock revetments in the mid 1970's led to erosion of suitable nesting habitat. Currently, almost the entire length of Fripp Island is a rock wall. The only suitable nesting habitat left is a section on the northern part of the island where a sand bar has attached.

Project Supplies and Equipment

Each project beach used personal handheld GPS devices to record the coordinates for original nest site locations, *in situ*, and relocated nests. Participants marked original nests sites with a stake 36 inches (91.5 cm) tall with an attached SCDNR nesting sign and used smaller 12-inch (30.5 cm) tall stakes and surveyors tape to rope off the nest to prevent disturbance (Figure 2). Participants measured the distance between the previous night's high tide line and the SHTL with the provided soft measuring tape 60 inches (152.4 cm) in length. Project leaders used the provided relocation data collection sheets to compile data (Appendix A).

Nest Surveys by Nest Protection Projects

During the nesting season, project participants monitored the beach daily around day break. They walked the previous night's high tide line looking for turtle crawls. After finding a crawl, the participant determined if it was a false crawl or nest. False crawls are non-nesting emergences (Hopkins-Murphy et al. 1999). False crawls may occur due to artificial lighting, presence of predators or humans on beach, or inability for nesting females to find a suitable nesting site. If a nest was laid, the observer probed the nest to find the egg chamber. After finding the egg chamber, the participant decided whether to leave the nest *in situ* or to relocate it. Participants monitored nests until emergence approximately 55 - 60 days later.

Project Protocol

After relocation, the participant placed the above mentioned wooden stake near the original *in situ* nest site referred to as the "initial site" from this point forward. Each stake has a black line drawn 20 inches (50.9 cm) from the bottom of the stake (referred to as the "sand line" from this point forward) which is used as a reference point when determining if a majority of the stake is exposed (Figure 2). Participants did not place stakes in the initial nest cavity; instead they dug a hole 20 inches (50.9 cm) deep and 6 inches (15.3 cm) to the right or left of the *in situ* nest site. Participants placed the stake in the hole with 20 inches (50.9 cm) of its length below the sand level. Participants labeled the initial site stakes with the nest number and date laid. Participants recorded the following information: longitude and latitude (decimal degrees; WGS 1984), distance (inches) landward or seaward of the SHTL, and sand profile (options: slope, flat, and/or trough). Participants completed initial site monitoring when: 1) the initial site washed away, 2) hatchlings in the relocated nest showed signs of emergence, or 3) the nest had been incubating for a minimum of 60 days. See Relocation Data Sheet and Protocol in Appendices A and B, respectively.

Project participants monitored the initial nest site location during their daily nest surveys for wash-over or wash away events. Wash-over was defined as nests that were washed over during the previous high tide. Observers recorded wash-over dates and distance (inches) from the initial site to the highest landward tide line from the previous night (Figure 3). An initial site was considered washed away if a stake (1) fell over, (2) completely washed away, or (3) was significantly exposed (12 inches or more; 30.5 cm or more) below the sand line (Figure 4). The observer recorded the date the initial nest site washed away.

Project participants also monitored *in situ* and relocated nest sites for wash-over events and washed away occurrences, noting the number of times the nest was washed over.

Nest Inventories by Nest Protection Projects

Nest protection projects conducted nest inventories three days after hatchlings emerged. Participants noted hatchling emergence by a depression in the sand directly above the nest or tracks coming from the nest. During the inventory, the contents of the nest were divided into the following categories: hatched eggs (defined as eggshells with at least 50% of shell intact), live hatchlings, dead hatchlings, and unhatched eggs. Pipped eggs are considered unhatched eggs. Project participants divided and counted the contents within each of the above listed categories. The data collected were used to determine the hatch and emergence success for each nest. We defined hatch success (HS) as the number of hatchlings that hatch out of shells from the total number of eggs deposited (HS = [Hatched Eggs ÷ Clutch Size]*100 percent) (Miller 1999). We defined emergence success (ES) as the total number of hatchlings that emerge from the nest out of the total number of eggs deposited (ES = {[Hatched Eggs – (Live Hatchlings + Dead Hatchlings)] ÷ [Clutch Size]}*100 percent) (Miller 1999).

Data Analysis

Nest Survey Data on Project Beaches

SCDNR database and project data sheets were used to quantify the number of: nests laid, *in situ* nests, relocated nests, and relocated nests laid below SHTL. The datasheets also provided how many initial sites were washed over, how many washed away, and the total wash-over inches for each initial site. Total wash-over inches were calculated by adding all wash-over measurements together at each initial site. The information was used to calculate the number and percentage of initial sites washed over and washed away. The SCDNR nesting database was used to determine the number and percentage of *in situ* and relocated nests washed over and/or washed away. Binary logistic regression was used to predict whether or not an initial site washed away based on two predictors: number of times washed over and total wash-over inches.

Nest Inventory Data on Project Beaches

Hatch and Emergence Success

Nest inventories occurred three days after the emergence of the first hatchlings. The SCDNR nesting database calculated hatch and emergence success for each nest. We did not include nests with loss events such as root invasion, fire ants, or due to probing. All data were exported into Minitab 15 (Minitab, Inc. State College, PA) for analysis. I used the Anderson-Darling test to examine normality of hatch and emergence success. Since data were determined to be approximately normally distributed, two sample T-tests were used to determine differences between *in situ* and relocated hatch and emergence success ($\alpha = 0.05$) for all beaches and for individual beaches.

Impact of Wash-over Events Using Statewide Data

SCDNR database was used to calculate the number of: nests laid, false crawls, *in situ*, relocated, and nests relocated to hatcheries for all data from 2009. Data were also analyzed to examine the impact of the number of wash-over events on hatch and emergence success. Nests included in the wash-over analysis were both *in situ* and relocated nests with undetected nests excluded. Undetected nests were nests not located after laying but discovered either because the nest was predated or the nest hatched. Only nests with an inventory date no more than 70 days after the date the nest was laid were included to guard against counting wash-overs after nest emergence. Nests with loss events such as probing, depredation, and washed away events were not included in the analysis. All data were exported into Minitab 15 for analysis. Arcsin transformation was used to transform hatch and emergence success values from percentages to degrees for analysis and to make variances more similar. The Kolmogorov-Smirnov test was used to examine normality of hatch and emergence success. Since hatch and emergence success were determined to not be normally distributed a Mann-Whitney rank sum test was used to determine differences between hatch and emergence success of non-event nests and washed over nests ($\alpha = 0.05$).

Outcome of Nest Management Decisions

The analysis of statewide data from the 2009 nesting season provided an assumption as to the minimum number of wash-overs that may impact hatch and emergence success. I used this minimum number of wash-overs and washed away occurrences at actual and initial nest sites to determine whether the nest management decision was correct. Nest management outcomes were categorized as managed correctly, needed further management, relocation was not justified, or relocation was necessary but a poor relocation site was chosen.

For each beach, we examined the potential cost and benefit of nest relocation. Cost was defined as the number of eggs disturbed by unnecessary relocations (nest relocation was not justified) and the estimated number of eggs that needed relocation (needed further management). Unnecessary relocations were defined as nests that could have been left *in situ* based on the nest management outcome analysis. We could only estimate the number of eggs for some nests that needed relocation because these nests were *in situ* nests that completely washed away. For unknown clutch counts, we assigned a clutch count of 120 eggs, the mean number of eggs found in a nest. We defined the benefit of using relocation as the number of eggs that hatched and the number of hatchlings that emerged from relocated nests that were managed correctly. Nests were considered managed correctly if the initial site was washed-over too many times or washed away. The SCDNR nesting database was used to determine the number of eggs relocated, number of eggs that needed relocation, number of eggs that hatched, and number of hatchlings that emerged.

Spatial Analysis of Nests on Project Beaches

ArcGIS 9.3 (ESRI, Redlands, CA) was used to create maps for each project beach using remotely sensed and field collected data (Environmental Systems Research Institute 2008). National Wetlands Inventory (Land Use/Land Cover data for James Island, Rockville, Edisto Island, and Edisto Beach 7.5 Minute Quadrangle) from SCDNR GIS Data Clearinghouse were used to visualize each beach. I also used World Imagery Basemaps downloaded from the ArcGIS website to visualize each beach. Roads were visualized using Charleston County Roads from the College of Charleston GIS database. Project participants used various hand held GPS receivers to fill out information on the datasheets. Information from the datasheets was input manually into a GIS database and linked to the simplified beach layer.

For each project beach, two maps were designed. The first set of maps depicts the location of the initial sites, *in situ*, and relocated nests and the frequency of wash-overs at each location. The second map depicts the location of any initial sites, *in situ* and relocated nests that were washed away. On each map, beaches were oriented based on the preference of the project leader.

Results

Nest Survey Data – Individual Project Beaches

Edisto Beach State Park

From 2001 to 2009, 558 nests were laid on Edisto Beach State Park with 203 nests left *in situ* and 355 nests relocated. Number of nests laid per year ranges from 20 nests in 2004 to 94 nests in 2005. The mean number of nests laid per year equals 62.0 (SE±7.5) nests (SE is the standard error of the means). The number of nests relocated ranges from 7 of 66 nests (10.6%) to 18 of 20 nests (90.0%). For the 2009 nesting season, 23 of the 61 nests (37.7%) were relocated. See Figure 5 for number of nests relocated for each year from 2001 to 2009.

Edisto Beach State Park had a total of 23 initial sites. Most initial sites were laid below the SHTL. See Table 1 for the number of *in situ* and relocated nests washed over and washed away. Of the four initial sites laid above the SHTL, three of the four were washed over or washed away. See Table 2 for the number of initial sites laid below the SHTL, the number of initial sites washed over, and the number of initial sites washed away. See Figure 6 for the frequency of wash-over events on initial sites on Edisto Beach State Park.

Based on Binary Logistic Regression neither the number of wash-overs ($z = 1.09$, $p = 0.274$) nor the total wash-over inches ($z = -1.62$, $p = 0.105$) were significant predictors for initial sites washing away.

Folly Beach

From 2001 to 2009, 366 nests were laid on Folly Beach with 119 nests left *in situ* and 247 nests relocated. Number of nests laid per year ranges from 19 nests in 2007 to 63 nests in 2008. The mean number of nests laid per year equals 40.6 (SE±4.8) nests. The number of nests relocated ranges from 24 of 46 nests (52.2%) to 31 of 37 nests

(83.8%). For the 2009 nesting season, 21 of 35 nests (60.0%) were relocated. See Figure 7 for number of nests relocated for each year from 2001 to 2009.

Folly Beach had a total of 18 initial sites. See Table 1 for the number of *in situ* and relocated nests washed over and washed away. A majority (11) of the initial sites were laid above the SHTL. However, 10 of these initial sites were washed over. See Table 2 for the number of initial sites laid below the SHTL, the number of initial sites washed over, and the number of initial sites washed away. See Figure 8 for the frequency of wash-over events on initial sites on Folly Beach.

Based on Binary Logistic Regression neither the number of wash-overs ($z = 0.55$, $p = 0.580$) nor the total wash-over inches ($z = -0.68$, $p = 0.497$) were significant predictors for initial sites washing away.

Fripp Island

From 2001 to 2009, 278 nests were laid on Fripp Island with 94 nests left *in situ* and 184 nests relocated. Number of nests laid per year ranges from 9 nests in 2004 to 54 nests in 2003. The mean number of nests laid per year equals 30.8 (SE±4.7) nests. The number of nests relocated ranges from 9 of 31 nests (29.0%) to 8 of 9 nests (88.9%). For the 2009 nesting season, 18 of 27 nests (66.7%) were relocated. See Figure 9 for number of nests relocated for each year from 2001 to 2009.

Fripp Island had a total of 13 initial sites. See Table 1 for the number of *in situ* and relocated nests washed over and washed away. Most initial sites were laid below the SHTL. Of the three initial sites laid above the SHTL, one of the three was washed over. See Table 2 for the number of initial sites laid below the SHTL, the number of initial sites washed over, and the number of initial sites washed away. See Figure 10 for the frequency of wash-over events on initial sites on Edisto Beach State Park.

Based on Binary Logistic Regression neither the number of wash-overs ($z = 0.93$, $p = 0.353$) nor the total wash-over inches ($z = -1.04$, $p = 0.299$) were significant predictors for initial sites washing away.

Nest Inventory Data

Hatch and Emergence Success – Project Beaches Combined

No significant differences were detected between *in situ* ($n = 64$) and relocated ($n = 63$) hatch success (2 Sample T test, $T = -0.38$, $p = 0.702$) or emergence success (2 Sample T test, $T = 0.07$, $p = 0.944$) for all beaches. Mean hatch success for *in situ* and relocated nests was 62.7% (SE± 4.1) and 65.0% (SE± 4.3), respectively. Mean emergence success for *in situ* and relocated nests was 58.7% (SE± 4.3) and 58.2% (SE± 4.5), respectively.

Hatch and Emergence Success – Individual Project Beaches

Edisto Beach State Park

No significant differences were detected between *in situ* and relocated nest hatch (2 Sample T test, $T =1.40$, $p = 0.169$) and emergence success (2 Sample T test, $T = 1.44$, $p = 0.155$). Mean hatch success for *in situ* and relocated nests was 69.3% (SE± 4.0) and 57.6% (SE± 8.7), respectively. Mean emergence success for *in situ* and relocated nests was 64.8% (SE± 4.9) and 51.4% (SE± 8.8), respectively.

Folly Beach

No significant differences were detected between *in situ* and relocated nest hatch (2 Sample T test, T = 0.45, p = 0.658) and emergence success (2 Sample T test, T = 0.60, p = 0.553). Mean hatch success for *in situ* and relocated nests was 75.8% (SE± 12) and 71.1% (SE± 4.6), respectively. Mean emergence success for *in situ* and relocated nests was 74.0% (SE± 12) and 67.4% (SE± 5.0), respectively.

Fripp Island

Relocated nests had significantly higher hatch (2 Sample T test, T = -3.16, p = 0.004) and emergence success (2 Sample T test, T = -2.13, p = 0.044) than *in situ* nests. Mean hatch success for *in situ* and relocated nests was 49.5% (SE± 13) and 84.3% (SE± 4.3), respectively. Mean emergence success for *in situ* and relocated nests was 44.0% (SE± 12) and 71.9% (SE± 7.0), respectively.

Nest Inventory Data

Impact of Wash-over Events Using Statewide Data

In 2009, there were 3,372 false crawls and 2,154 loggerhead nests (excluding undetected) with 1,000 nests left *in situ*, 877 nests relocated, and 277 nests relocated to hatcheries from 33 nest protection projects in South Carolina. A total of 276 nests were washed over (*in situ* = 198, relocated = 78). Mean number of wash-overs for all nests was 2.84 (SE± 0.11). Mean number of wash-overs for *in situ* nests was 2.98 (SE± 0.14). Mean number of wash-overs for relocated nests was 2.47 (SE ± 0.15). Nests with zero wash-overs (n = 544) had significantly higher hatch (Mann-Whitney U-Test; W = 175985.0, p = 0.0001) and emergence success (Mann-Whitney U-Test; W = 175425.0, p = 0.0003) than nests with three wash-overs (n = 80). Nests with four or more wash-overs (n = 63) had a hatch (Mann-Whitney U-Test; W = 173055.5, p = 0.0000) and emergence success (Mann-Whitney U-Test; W = 172907.5, p = 0.0000) significantly lower than nests with zero wash-overs. See Table 3 and Figure 11 for median hatch and emergence success of nests with wash-over events ranging from zero to four or more wash-overs in South Carolina.

Outcome of Nest Management Decisions

In determining whether nest management decisions were justified, I used four or more wash-overs as the number of wash-overs that may significantly impact nest success. Though significant differences were seen between zero wash-overs and three wash-overs hatch and emergence success, I chose four or more wash-overs because the 2009 statewide data found hatch success dropped below 60% after four or more wash-overs. The first edition of the Recovery Plan for U.S. Population of the Loggerhead Turtle recommends at least a 60% hatch success on nesting beaches (NMFS & USFWS 1991). See Figure 11 for comparison of median hatch and emergence success between nests with zero, one, two, three, and four or more wash-overs.

Edisto Beach State Park

For Edisto Beach State Park's *in situ* nests (n = 38), 33 nests were managed correctly and five nests should have been relocated because the site experienced four or more wash-overs or the nest washed away. See Table 4 for nest management outcomes for *in situ* nests on Edisto Beach State Park. For relocated nests (n = 19), eight nests were correctly relocated, seven nests were not justified because the initial site was not washed over at least four times or did not wash away, and four nests were appropriately relocated but poor relocation site selection led to four or more wash-overs occurring at the relocation site or the site washed away. See Table 5 for nest management outcomes for relocated nests on Edisto Beach State Park.

For cost and benefit of relocation, Edisto Beach State Park had seven initial sites that had fewer than four wash-overs and did not wash away and 12 sites with four or more wash-overs and/or the sites washed away. The cost of relocation was defined as the number of eggs relocated unnecessarily and the estimated number of eggs that needed relocation. A total of 874 eggs were unnecessarily relocated. An estimated 532 eggs needed relocation. The benefit of relocation was defined as the number of eggs that hatched and the number of hatchlings that emerged from relocated nests where the initial site was washed over four or more times or the initial site washed away. A total of 659 eggs hatched from relocated nests with four or more wash-overs at initial sites and/or initial site washed away. A total of 535 hatchlings emerged from relocated nests with four or more wash-overs at initial sites and/or initial site washed away.

Folly Beach

For Folly Beach's *in situ* nests (n = 13), 11 nests were managed correctly and two nests should have been relocated because the site experienced four or more wash-overs or the nest washed away. See Table 6 for nest management outcomes for *in situ* nests on Folly Beach. For relocated nests (n = 18), 13 nests were correctly relocated, four nests were not justified because the initial site was not washed over at least four times or did not wash away, and one nest was appropriately relocated but poor relocation site selection led to the site washing away. See Table 7 for nest management outcomes for relocated nests on Folly Beach.

For the cost and benefit of relocation, Folly Beach had four initial sites that had fewer than four wash-overs and did not wash away and 14 sites with four or more wash-overs and/or the sites washed away. The cost of relocation was defined as the number of eggs relocated unnecessarily and the estimated number of eggs that needed relocation. A total of 483 eggs were unnecessarily relocated. An estimated 248 eggs needed relocation. The benefit of relocation was defined as the number of eggs that hatched and the number of hatchlings that emerged from relocated nests where the initial site was washed over four or more times and/or initial site washed away. A total of 1071 eggs hatched from relocated nests with four or more wash-overs at initial sites and/or initial site washed away. A total of 1057 hatchlings emerged from relocated nests with four or more wash-overs at initial sites and/or initial site washed away.

Fripp Island

For Fripp Island's *in situ* nests (n = 9), all nests were managed correctly. See Table 8 for nest management outcomes for *in situ* nests on Fripp Island. For relocated nests (n = 13), 10 nests were correctly relocated and three nests were not justified because the initial site was not washed over at least four times. See Table 9 for nest management outcomes for relocated nests on Fripp Island.

For the cost and benefit of relocation, Fripp Island had three initial sites that had fewer than four wash-overs and did not wash away and 10 sites with four or more wash-overs and/or the sites washed away. The cost of relocation was defined as the number of eggs relocated unnecessarily and the estimated number of eggs that needed relocation. A total of 358 eggs were unnecessarily relocated. An estimated zero eggs needed relocation. The benefit of relocation was defined as the number of eggs that hatched and the number of hatchlings that emerged from relocated nests where the initial site was washed over four or more times and/or initial site washed away. A total of 985 eggs hatched from relocated nests with four or more wash-overs at initial sites and/or initial site washed away. A total of 764 hatchlings emerged from relocated nests with four or more wash-overs at initial sites and/or initial site washed away.

Spatial Analysis of Nests on Project Beaches

Edisto Beach State Park

Edisto Beach State Park had 20 initial sites, four *in situ*, and five relocated nests impacted by tidal inundation during the 2009 nesting season. Initial sites appear to be located lower on the beach closer to tidal influences. The southern end of Edisto Beach State Park fared worst, in regards to *in situ* and relocated nest wash-overs. The southern end of Edisto Beach State Park also had the majority (10 of the 14) nest sites washed away. See Figures 12 - 15.

Folly Beach

Initial sites appear to be located on the ends of the beach and lower on the beach closer to tidal influences. Initial sites located on the ends were often washed over four or more times. Wash-over of *in situ* and relocated nests seems to be spread out along beach. The southern end of Folly Beach had the majority (3 of the 5) nest sites washed away. Offshore currents off the coast tend to remove sand from the northern end of barrier islands and deposit the sand on the southern end (Pilkey et al. 1984). This coastal process may be the reason wash-overs are concentrated on the ends of Folly Beach. See Figures 16 - 19.

Fripp Island

A majority of the initial sites (8 of the 13) are located on or near the sand bar that is attaching on the middle of the beach. These locations may be closely situated to tidal influences. For initial sites, wash-overs seem most extreme on the northern end of the island. Only one *in situ* nest was washed over during the 2009 nesting season but GPS points were not collected. For relocated nests, wash-overs occurred on the northern end of the island. Washed away events of initial sites occurred most often on the northern part of the island or on the sand bar. See Figures 20 - 23.

Discussion

In the past ten years, Edisto Beach State Park, Folly Beach, and Fripp Island have relocated a combined 786 nests out of 1200 nests laid. Approximately 60% of nests laid were relocated. Though the number relocated is high, Figures 5, 7, and 9 show that the range of nests relocated each year fluctuates. Beaches and nesting circumstances change from year to year making it impossible to judge whether the use of relocation has increased due to chronic erosion, loss of suitable nesting habitat, and/or "top-down" or "bottom-up" tidal inundation or for unjustified reasons. The data collected from the 2009 nesting season shows the majority of relocated nests were laid below the SHTL (70.0%). Also, 15 of the 18 initial nest sites laid above the SHTL were washed over at least once. However, neither the number of wash-overs nor the inches washed over could predict if an initial site washed away. The degree and duration of the wash-over events is variable. This study found it impossible to predict when an initial site might wash away. In addition to initial sites, approximately 25% of *in situ* and relocated nests were washed over at some point during the 2009 nesting season. Tidal inundation could be a serious threat to nests on these project beaches. Additional research similar to this study is needed to determine whether the use of relocation does guard against wash-overs or washed away events.

In 2009, the use of nest relocation on Edisto Beach State Park, Folly Beach, and Fripp Island combined did not alter the overall hatch or emergence success compared to *in situ* nests. Recent studies have also found no difference between *in situ* and relocated nest hatch and emergence success on beaches in South Carolina and Georgia, which is consistent with our results (Bimbi 2009, McElroy 2009). Although my results are consistent with these studies, this project did not use random selection of nests, which may lead to biased results.

For individual beaches, nest relocation on Edisto Beach State Park and Folly Beach did not impact overall hatch and emergence success, however, on Fripp Island hatch and emergence success was significantly higher in relocated nests than *in situ* nests. Relocation did not significantly alter hatch and emergence success on Edisto Beach State Park or Folly Beach perhaps due to relocation site choice. It is possible that relocation nest sites on Edisto Beach State Park and Folly Beach mimic the nest environment of the initial nest site location on these beaches. It is unclear why *in situ* nests had lower hatch and emergence success on Fripp Island. Some of the *in situ* nests were impacted by tidal inundation while other environmental factors may have contributed. Studies have found that eggs are sometimes broken by ghost crabs, roots, or ants, which can lower nest success and may contribute to later mortality by introducing fungus or bacterial growth (Fowler 1979, Whitmore & Dutton 1985). Though we removed nests with loss events, some loss events could have occurred without project participants' knowledge.

Surprisingly, the percentage of relocated nests (31.0%) that were washed over was similar to the percentage of *in situ* nests (36.7%) washed over. A number of *in situ* nests, relocated nests, and initial sites were possibly impacted by storm tides and sea level anomalies during the 2009 nesting season. The National Oceanic and Atmospheric Association (NOAA) recorded higher than normal sea levels along the East Coast during the months of June and July, coinciding with spring tides (Sweet et al. 2009). NOAA found that throughout these months water levels were between 0.6 inches to 2.0 ft above normal depending on location (Sweet et al. 2009). In addition, Hurricane Bill possibly caused a number of wash-overs on several beaches during the latter part of August. Not all project beaches recorded the dates of wash-over or washed away events on relocated or *in situ* nests. We were unable to determine which exact nests were impacted by the storm and tide anomalies. On Edisto Beach State Park, all washed away nests occurred during the month of July and all washed over nests were incubating during the time of the sea level anomalies or Tropical Storm Bill. For Folly Beach, three nests were washed over during the month of June and one nest washed away during the month of July. Also on Folly Beach, Hurricane Bill possibly impacted the following locations: three initial sites (all washed away), one washed away nest, and 10 washed over nests. On Fripp

Island, all but two of the initial sites that washed away occurred during the months of June and July and all washed over nests were incubating during the time of the sea level anomalies or Hurricane Bill.

The statewide data for the 2009 nesting season showed 42.3% of *in situ* nests washed over and 22.2% of relocated nests washed over. Nests with three wash-overs had significantly lower hatch and emergence success than nests with zero wash-overs. However, hatch and emergence success dropped below 60% after four or more wash-overs. For the 2009 nesting season, one to three wash-overs did not decrease hatch and emergence success to a level that is counterproductive to population recovery (NMFS & USFWS 1991). However, four or more wash-overs did greatly impact hatch and emergence success.

It should be noted that the date (stage of egg development), magnitude (amount of water) or the duration (length of time nest contained water) was not measured during this study. Additionally, beach elevation was not considered which may play a significant role in how a nest fares with tidal inundation. However, it appears that four or more wash-overs could cause sand compaction, asphyxiation of embryos, or drowning of hatchlings (Kraemer & Bell, Foley et al. 2006). It is possible that the timing of the wash-over event is more important than the number of times washed over; however, this project was unable to investigate this issue. The sea level anomalies and their subsequent impact on spring tides may have increased the duration and degree of wash-over leading to a lower nest success for washed over nests during the 2009 nesting season. Since only one year of wash-over data were available for this study, additional years are needed to further examine the relationship between the number of wash-overs and hatch and emergence success.

The project beaches correctly managed 84 of 110 nests (76.4%). These nests were either correctly left *in situ* or the use of relocation was justified. The remaining 26 were either unnecessarily relocated, *in situ* nests that should have been relocated, or relocation sites were poorly chosen. For the 2009 nesting season, a majority of the nests laid on the three project beaches were managed correctly. However, additional study years are recommended since 2009 was an unusual year because of sea level anomalies and Hurricane Bill. Further research is also needed on the unique issues hindering these beaches, such as, inundation from below, severe erosion, and limited, suitable nesting habitat.

Spatial analysis of project beaches provided insight into location and frequency of wash-overs on initial sites, *in situ* nests, and relocated nests. All beaches seem to experience a high number of wash-overs on the northern (eastern) and southern (western) ends of the beaches. Washed away events also tend to occur on the ends. Additional years are needed to determine which locations are more susceptible to wash-overs. It does appear that nests with few wash-overs are located further from tidal influences. However, additional years are needed to determine if washed over nests are situated lower on the beach or if the number of wash-overs is influenced by the timing of spring tides or sea level anomalies.

Conclusion

Generally, the three project beaches follow SCDNR guidelines and only relocate nests laid below the SHTL. A number of initial sites, *in situ* nests, and relocated nests were impacted by tidal events. Hatch and emergence success were similar between *in situ* and relocated nests for all project beaches combined and for two individual beaches, Edisto Beach State Park and Folly Beach. Hatch and emergence success were significantly higher in relocated nests on Fripp Island. Statewide data found that hatch and emergence success of nests with four or more wash-overs was significantly lower than nests with zero wash-overs. Due to its low hatch and emergence success, four or more wash-overs were used to measure nest management outcomes for project beaches. A majority of the nests on each project beach were correctly managed with a small percentage unnecessarily relocated or needing further management. This project suggests that the use of relocation, when employed correctly, is still an important nest management tool, especially for beaches that suffer from severe erosion and tidal inundation.

Management Recommendations

Relocation is a nest management tool containing both the potential to benefit or possibly impair the recovery of sea turtle populations. This project suggests that relocation is an important conservation practice when employed properly. As a nest management tool, relocation is particularly important given that the Northern Recovery Unit of loggerheads has been experiencing a population decline of 1.3% a year since 1983 (NMFS-USFWS 2008). Protection efforts on nesting beaches, including the use of relocation, when combined with in-water protection of juveniles and adults has been shown to benefit sea turtle population recovery (Dutton et al. 2005). In contrast to the potential benefits, unnecessary or incorrectly performed relocations could lead to distortion of the gene pool, embryo mortality, or the alteration of the nest environment which could affect sex ratio and hatchling fitness (Mrosovsky 2006, 2008; Limpus et al. 1979, Pike 2008).

Nest relocation is only an effective conservation method when relocation sites are chosen carefully and eggs are handled cautiously during the process (Wyneken et al. 1988). For the three project beaches combined, hatch and emergence success did not significantly differ between *in situ* and relocated nests. Fripp Island did have significant differences when looking at individual beaches. Due to these conflicting conclusions, it is recommended that relocation sites be chosen only after careful consideration of environmental characteristics. Sites selected for relocated nests should mimic the initial nest site location as closely as possible.

Generally, the three project beaches followed SCDNR guidelines by only relocating nests laid below the SHTL or from areas known to be frequently inundated. Several nests on project beaches were relocated for issues besides tidal inundation. Therefore, it is still important to record the reason nests are relocated. It is recommended that SCDNR guidelines for nest relocation be followed because reasons for relocation other than tidal inundation, such as lighting or heavy foot traffic, either need to be addressed or have not shown to negatively affect hatchling productivity.

Several studies advocate the use of relocation by assuming that doomed clutches if left *in situ* would have been lost, meaning a hatch success of zero (McElroy, 2009).

This project found that a majority of initial nest site locations were washed over or washed away during the 2009 nesting season. Statewide data showed that four or more wash-overs seem detrimental to hatch and emergence success. I do advocate the continued use of relocation on Edisto Beach State Park, Folly Beach, and Fripp Island because of their issues with tidal inundation and the assumption that at some point wash-over events are detrimental to nest success. I do not recommend project leaders try to predict the number of wash-overs that may occur at a nest site. Beach characteristics and weather conditions change from year to year making it impossible to predict how well certain nesting areas will fare. I recommend that relocation only be used as a last resort for nests laid above and below the SHTL. Foley et al. (2006) suggests that nests laid lower on the beach may produce males, the rarer sex, and should be left *in situ* since these nests produce some hatchlings. It is possible that some wash-overs are good for the nest and I do not recommend relocating nests that may have some form of tidal inundation.

Finally, every year it is important for project leaders to adjust their decisions based on what should and what should not be relocated. It is not recommended that relocation decisions be based on past years storm or spring tides. As with 2009, spring tides were much higher than normal and very unpredictable. By following SCDNR guidelines, project leaders and volunteers can ensure that the use of relocation continues to be a powerful tool for conservation.

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Appendix A: Relocation Data Sheet

1. Nest Number: ______________________ Date Laid (*mm-dd*): _____________2009

2. *In Situ* Nest Location (*original nest location*): Latitude (*dd.ddd*) _____________

Longitude (*-dd.ddd*) ____________

3. What is the distance above (*landward*) or below (*seaward*) the spring high tide line?

Above (*landward*): _______ Below (*seaward*): __________ Distance: _________ inches

4. *In Situ* Nest Location Sand Profile (*check all that apply*): Slope ______ Flat _ Trough__________

5. *In Situ* Nest Location – Was it washed out (*refer to protocol*)? Yes _____No______

If you answered Yes it was washed out, what was the washout date (*mm-dd*): __________2009

6. *In Situ* Nest Location - Wash-over(s)

Date (*mm-dd*)	Distance from Stake to Wash-over Tide Line	Date (*mm-dd*)	Distance from Stake to Wash-over Tide Line
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)
	(inches)		(inches)

7. Comments

Appendix B: Relocation Protocol

PROTOCOL FOR MONITORING *IN SITU* NEST LOCATIONS

1. Once a nest is relocated, place a stake at the original *in situ* nest site location. DO NOT place stake in nest cavity. Dig a hole that is 20 inches deep and 6 inches to the right or left of the nest cavity. This hole should not be closer to or farther from the ocean than the original nest cavity. Place stake in the 20 inch hole that you have dug. The stake has a black line denoting 20 inches for reference.

2. Mark this *in situ* nest location as you would if this was a true nest. Write the nest number and date the nest was laid on the stake, which should match information on the project nest data card and nest relocation project data sheet. It is important to write this information on the stake so that other project members patrolling the beach will be able to record data from this site and place it on the corresponding nest relocation project data sheet.

3. Complete all information on nest relocation project data sheet regarding *in situ* nest location information. Please make sure that your GPS unit is collecting the latitude and longitude in decimal degrees. If you are not sure, please contact either your project leader or Gretchen Coll (678-525-0585) for assistance with this. This is very important.

4. Monitor *in situ* nest location on a daily basis during your normal patrols and note on the nest relocation project data sheet if the nest is washed over or washed out. Washed out nests are defined as any nest with a stake falling over, significantly leaning, or a majority of the stake exposed. Use the 20 inch line as a reference when determining if a majority of the stake is exposed. If there is 12 inches or more of stake exposed below the 20 inch line then consider the nest washed away. If a stake is missing and you do not believe it is due to wash out please replace with new stake.

5. After monitoring is complete, attach the nest relocation project data sheet to the project nest data card.

WHEN TO STOP MONITORING THE *IN SITU* NEST LOCATIONS

1. If the stake falls, is washed away, or if a significant amount of the stake is exposed (12 inches of stake or more below the 20 inch line) then the nest is considered washed away. Note the date on the project data sheet.

2. If the relocated nest emerges (hatchlings must emerge), then you can stop monitoring the *in situ* nest location.

3. After 60 days from the date the nest was laid, you no longer need to monitor the *in situ* nest location.

INSTRUCTIONS AND DEFINITIONS FOR NEST RELOCATION PROJECT DATA SHEET

Nest Number - nest number for the season Date Laid - date nest was laid

Latitude/Longitude – latitude and longitude in decimal degrees where the nest was laid

Distance Above/Below Spring High Tide Line – Note whether the nest was above (landward) or below (seaward) of the spring high tide line. Measure (in inches) the distance from the stake (that is placed at the *in situ* nest location) to the spring high tide line.

Sand Profile – Check all that apply to the *in situ* nest location sand profile.

(a)Slope – incline or steepness; (b) Flat – no slope; (c) Trough – depression or dip

Wash Outs – If at any time the stake falls over, leans significantly, or a large amount of the stake becomes exposed (12 inches or more below the 20 inch line) then mark the *in situ* nest relocation as washed out. On the data card, note whether or not this occurs during the monitoring period and the date.

Wash-over(s) – If at any time, the stake (*in situ* nest location) is washed over, note the following:

(a) Date – Date that stake was washed over;

(b) Distance from stake to wash-over tide line – Measure (in inches) from the stake to the wash-over tide line directly landward of the stake. Keep measuring tape perpendicular to the ocean, i.e. directly in line with stake, and measure to the previous high tide line. This previous high tide line should be obvious.

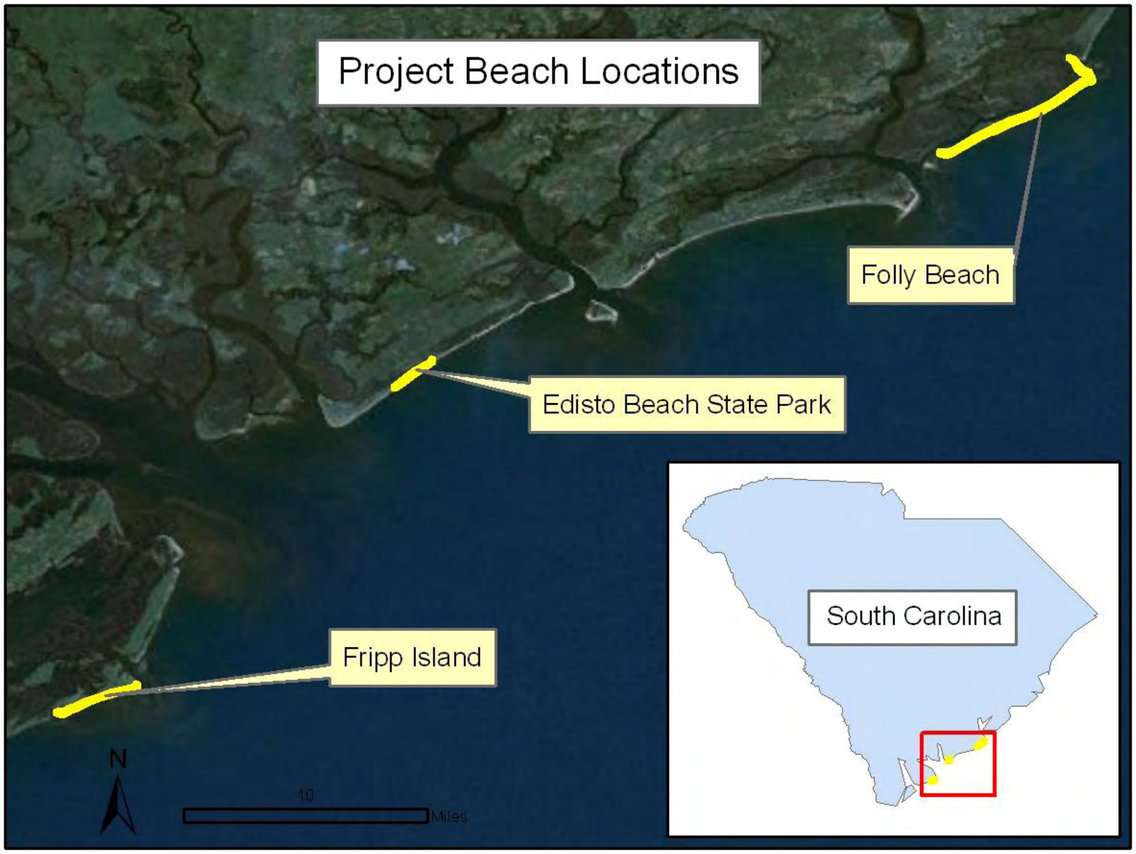

Figure 1. Location of Project Beaches.

Figure 2. Project Stake.

Figure 3. Washed over event.

Figure 4. Washed away event on Edisto Beach State Park (2009).

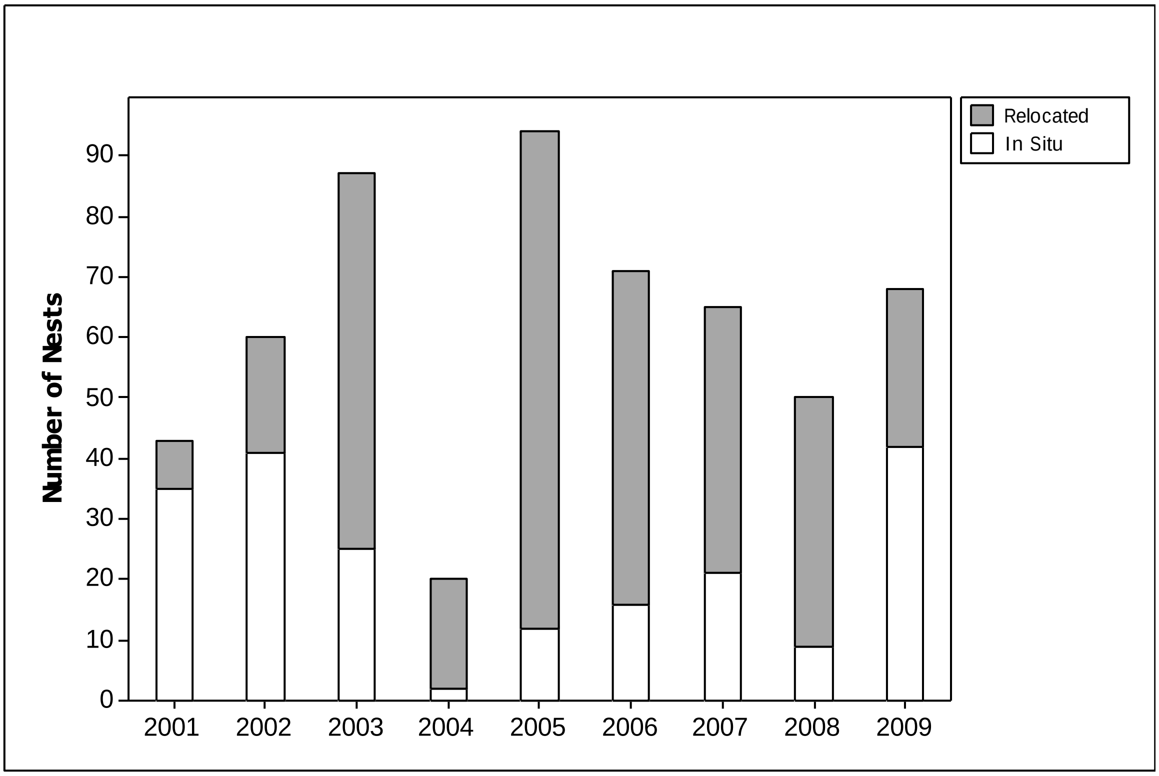

Figure 5. Edisto Beach State Park sea turtle nests from 2001 to 2009.

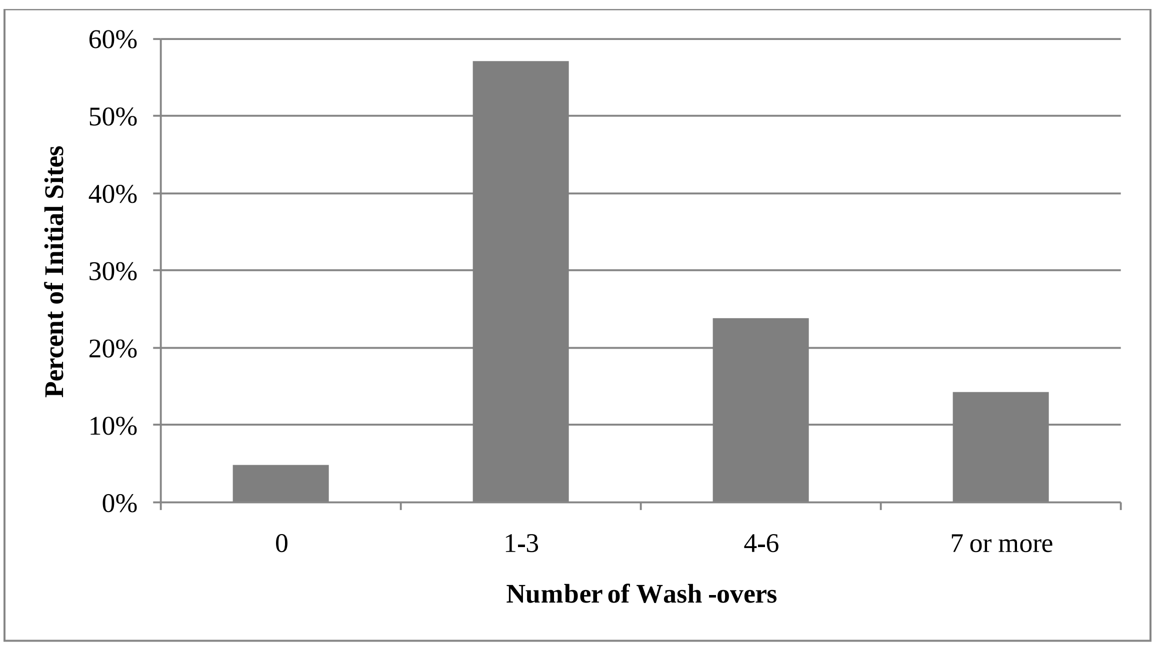

Figure 6. Frequency of wash-over events at initial sites on Edisto Beach State Park, South Carolina during 2009 nesting season.

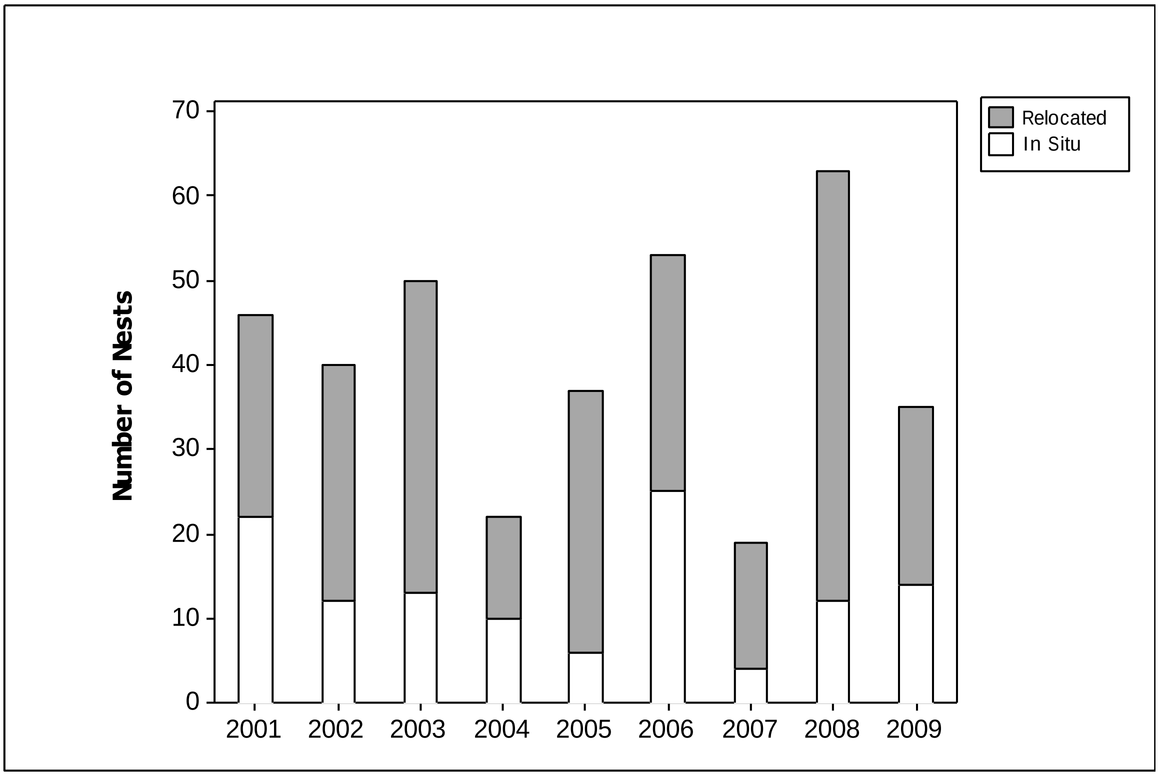

Figure 7. Folly Beach sea turtle nests from 2001 to 2009.

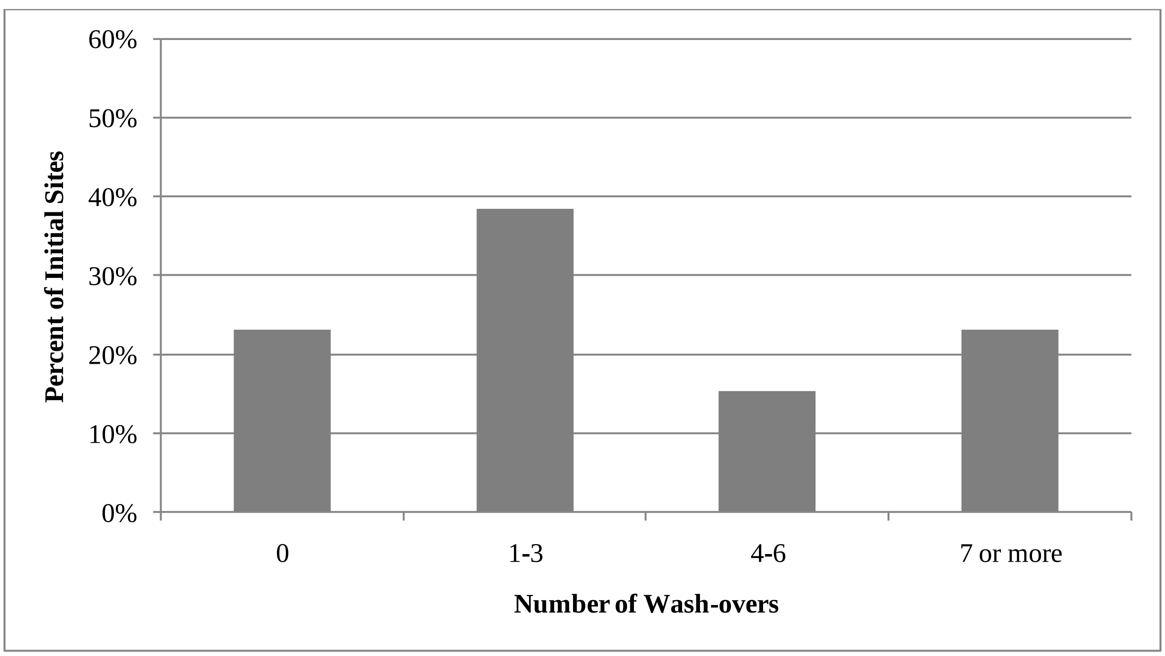

Figure 8. Frequency of wash-over events on initial sites on Folly Beach, South Carolina during 2009 nesting season.

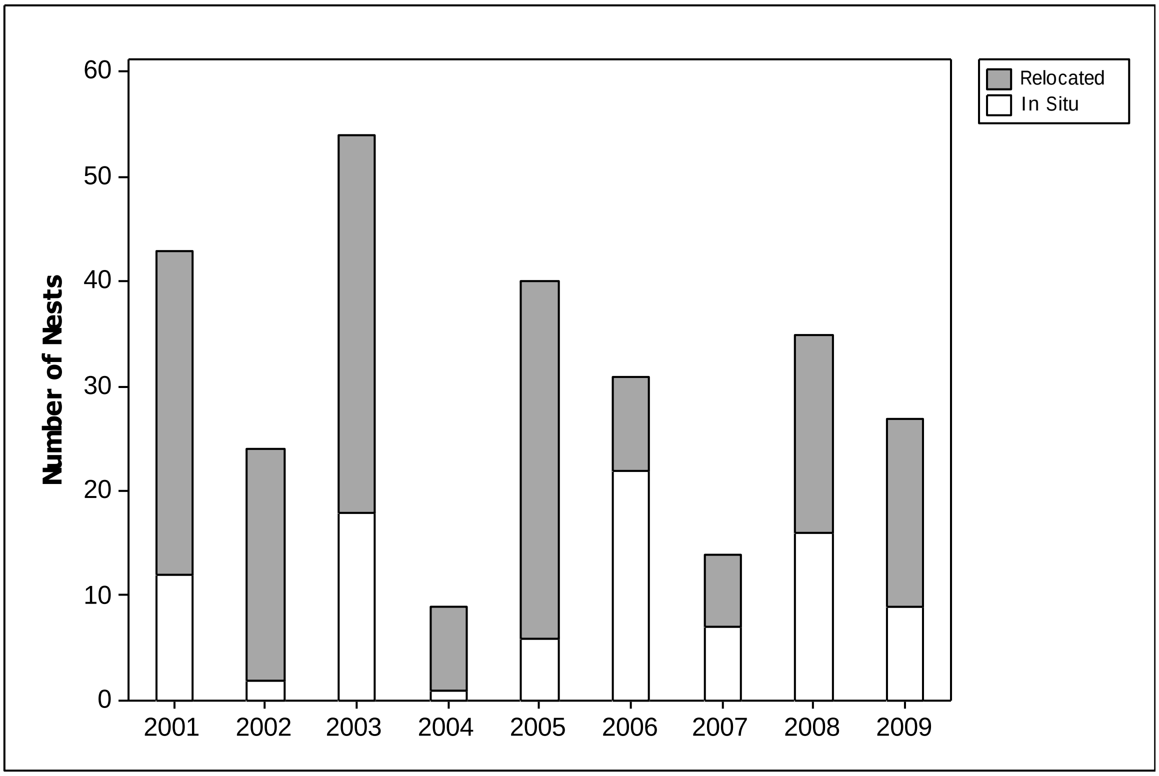

Figure 9. Fripp Island sea turtle nests from 2001 to 2009.

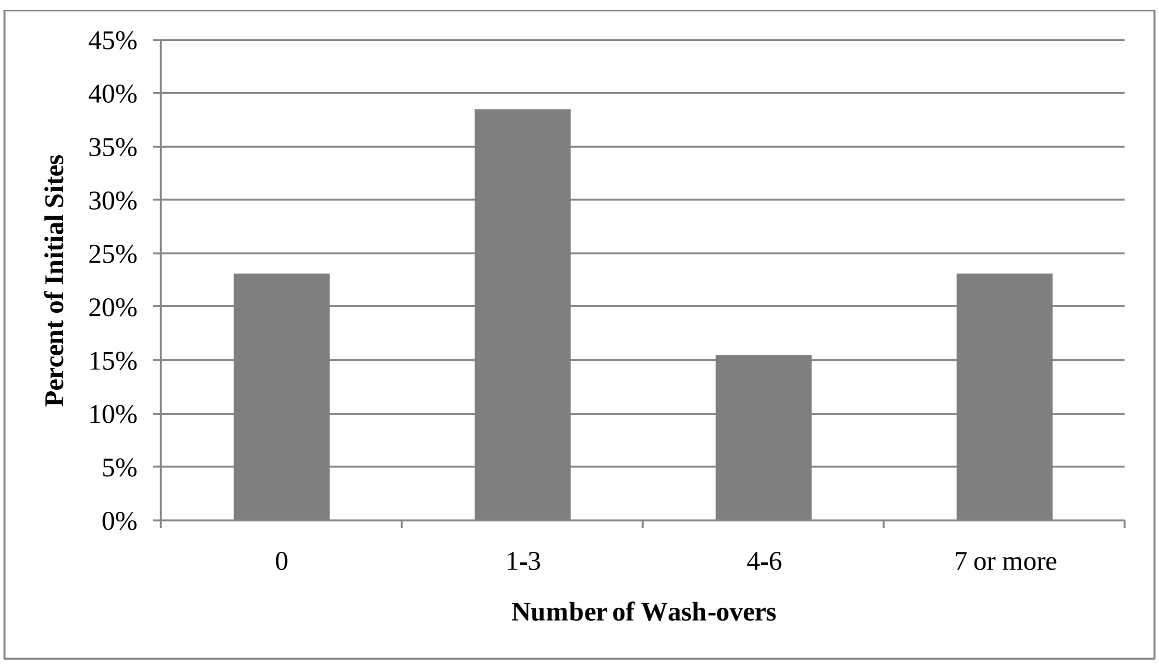

Figure 10. Frequency of wash-over events on initial sites on Fripp Island, South Carolina during 2009 nesting season.

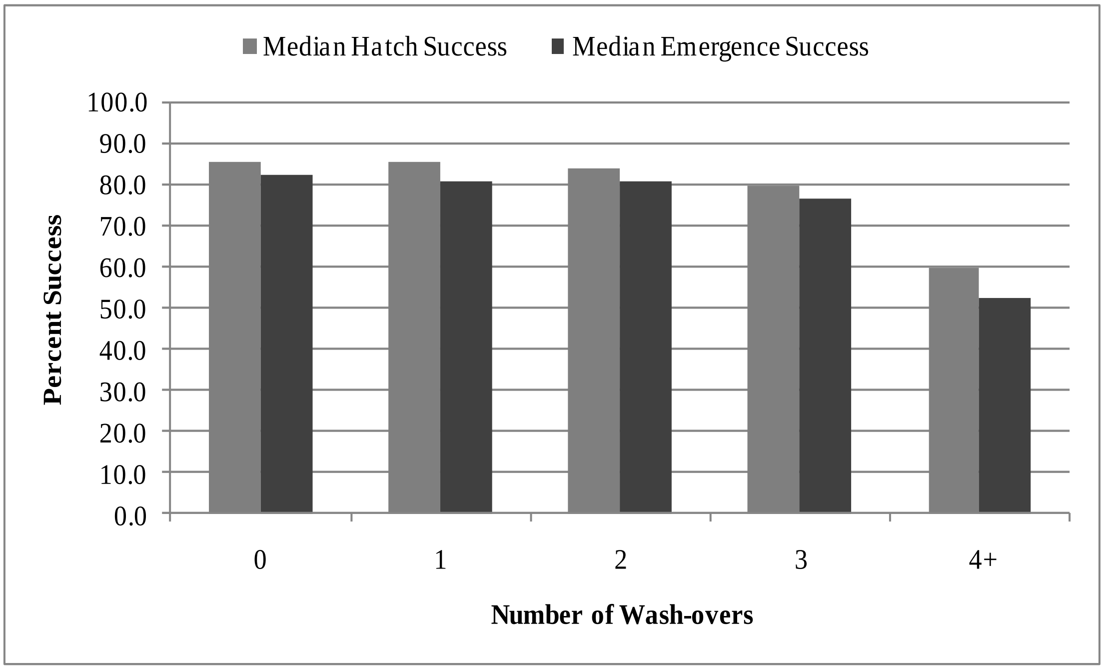

Figure 11. Comparison of median hatch and emergence success percentages between nests with zero, one, two, three, and four or more wash-overs for South Carolina statewide data (2009).

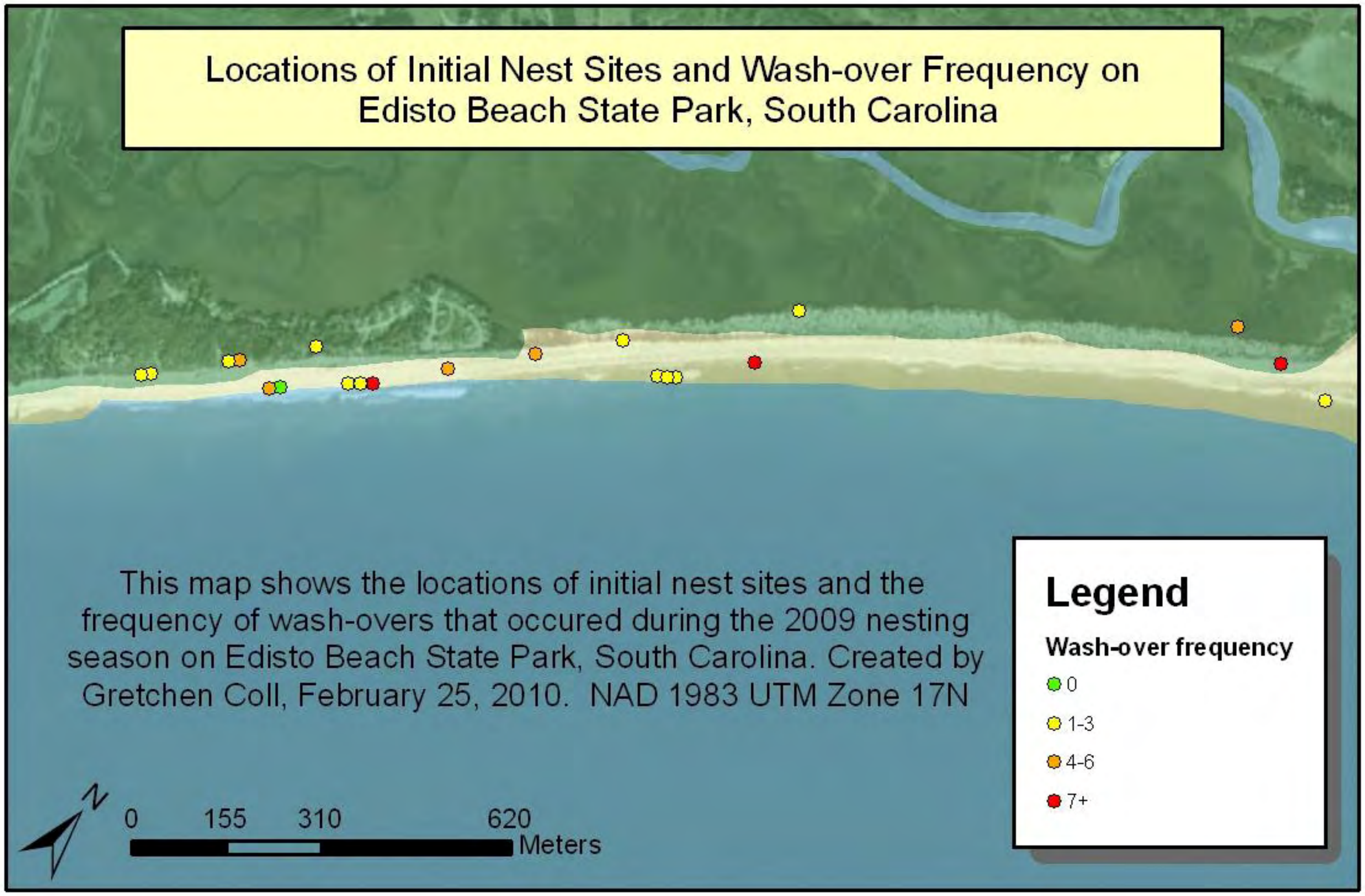

Figure 12. Locations of initial nest sites and wash-over frequency on Edisto Beach State Park, South Carolina.

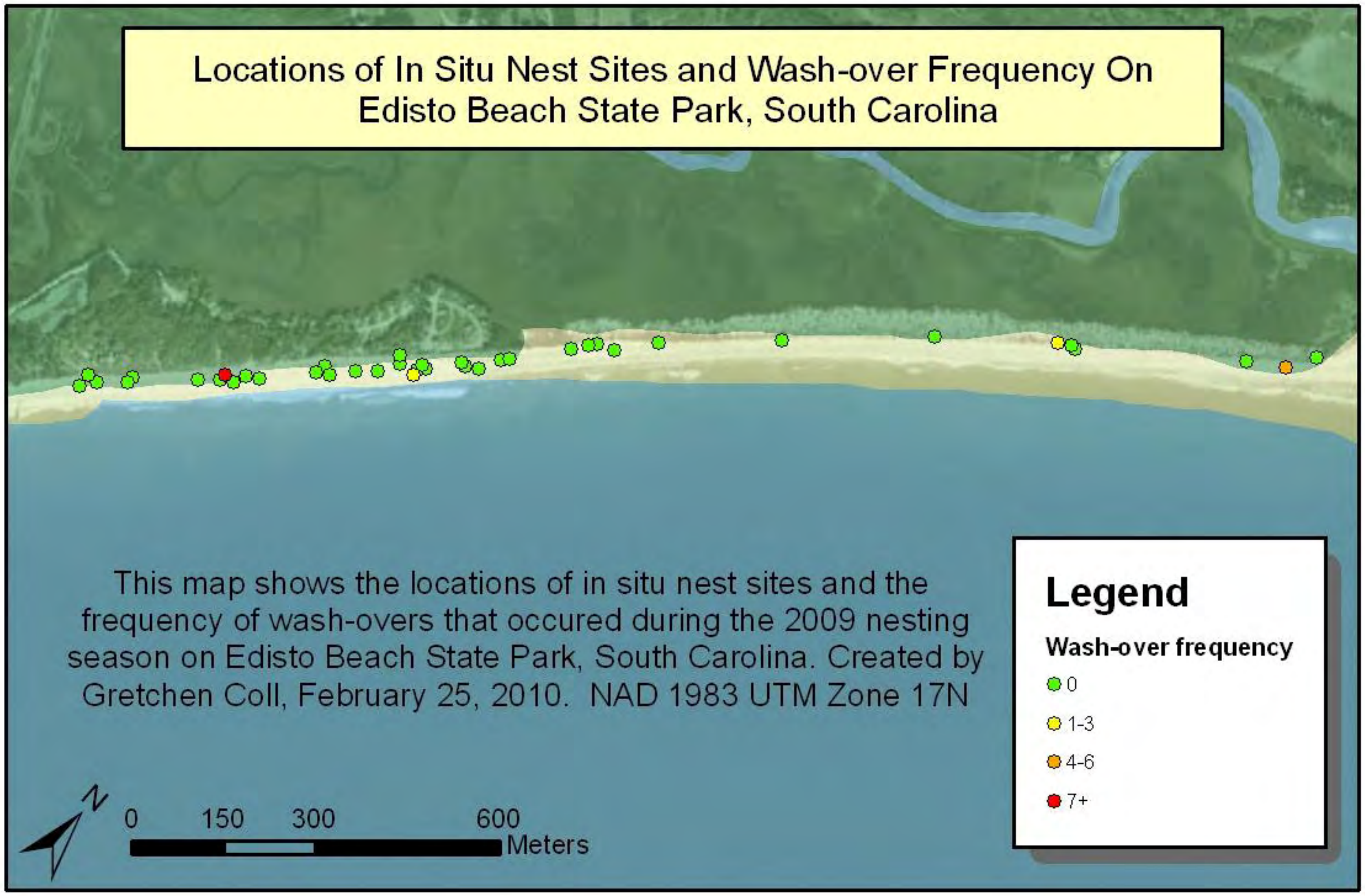

Figure 13. Locations of in situ nest sites and wash-over frequency on Edisto Beach State Park, South Carolina.

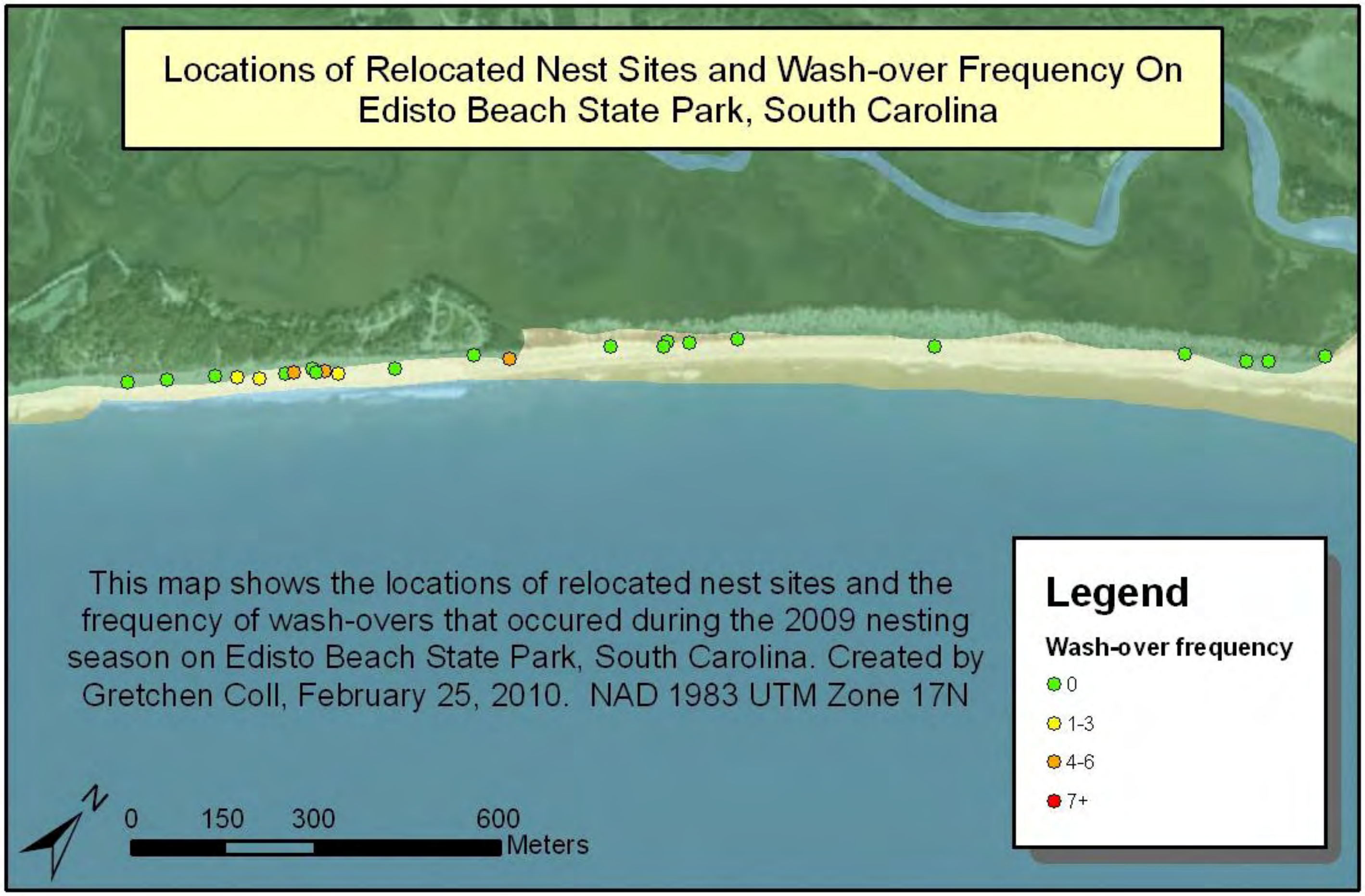

Figure 14. Locations of relocated nest sites and wash-over frequency on Edisto Beach State Park, South Carolina.

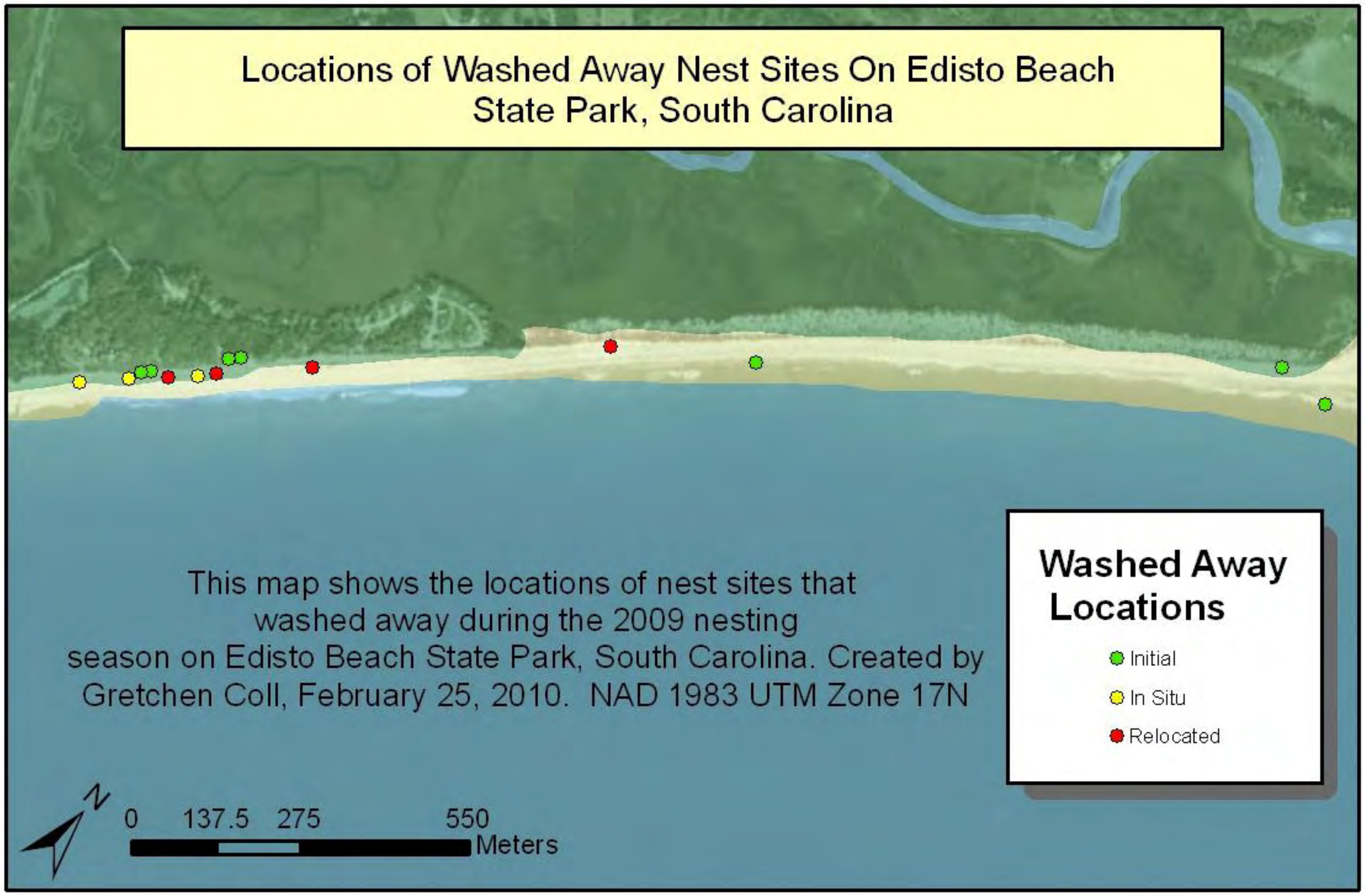

Figure 15. Locations of washed away nest sites on Edisto Beach State Park, South Carolina

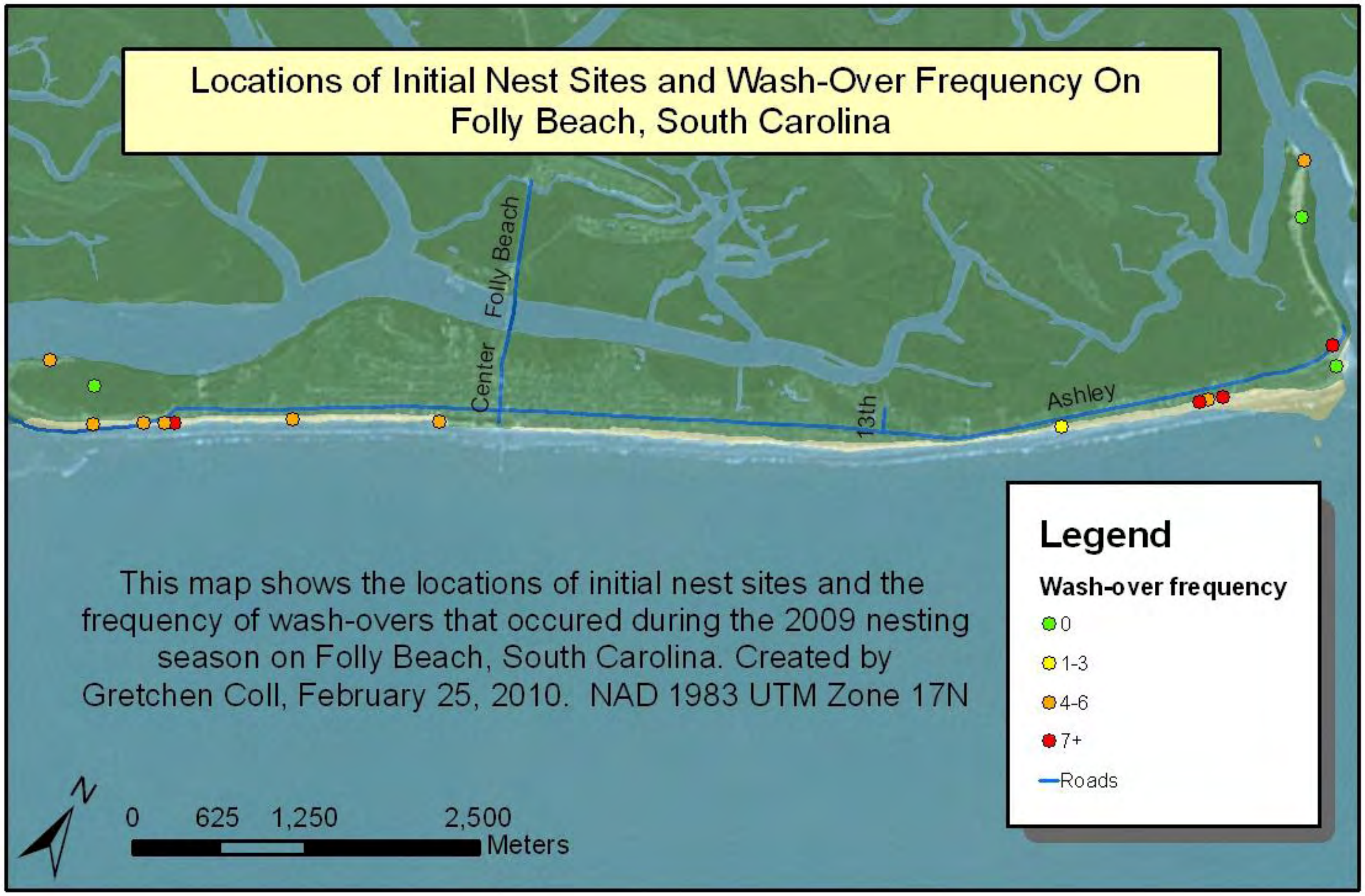

Figure 16. Locations of initial nest sites and wash-over frequency on Folly Beach, South Carolina

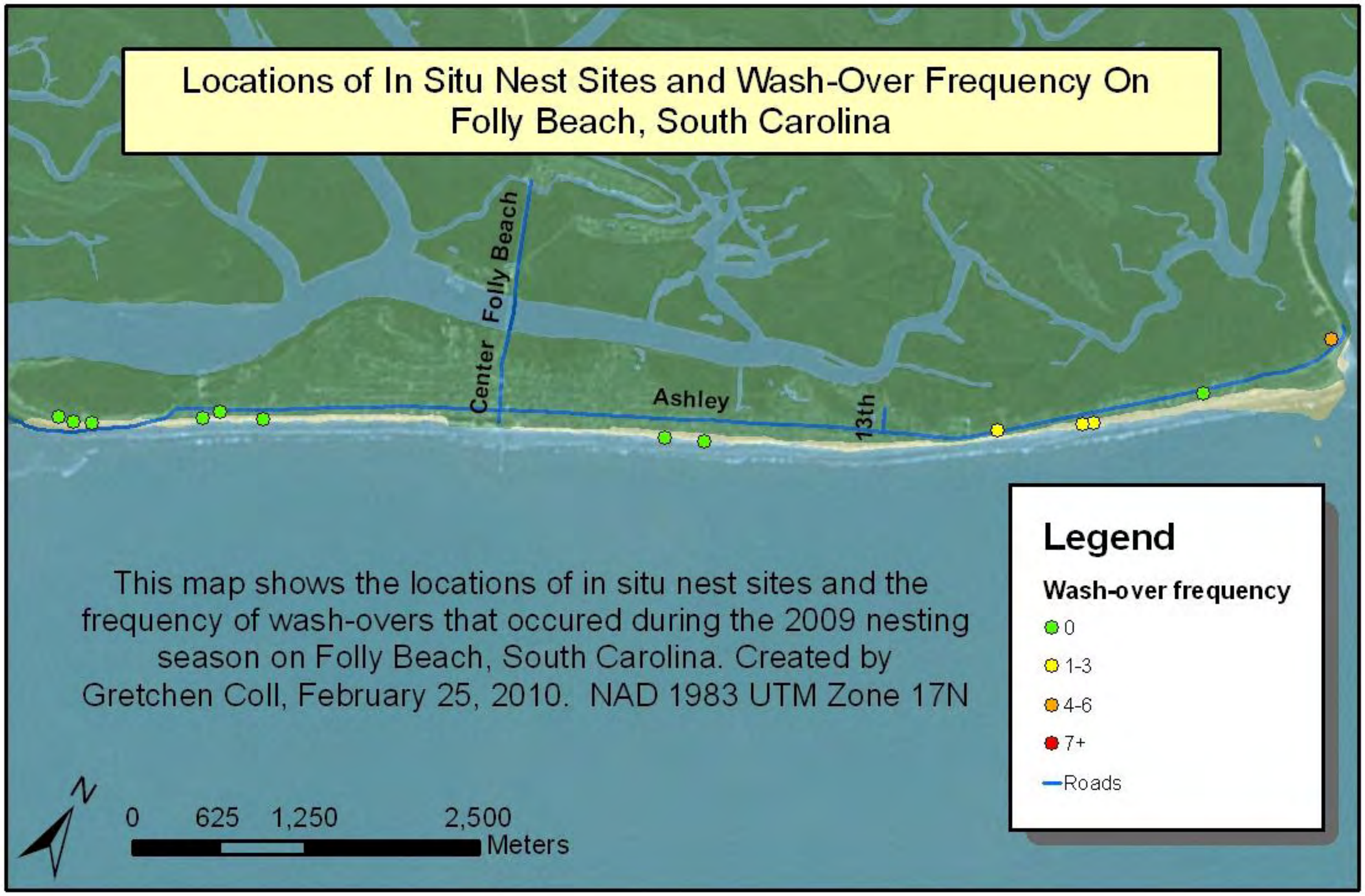

Figure 17. Locations of in situ nest sites and wash-over frequency on Folly Beach, South Carolina

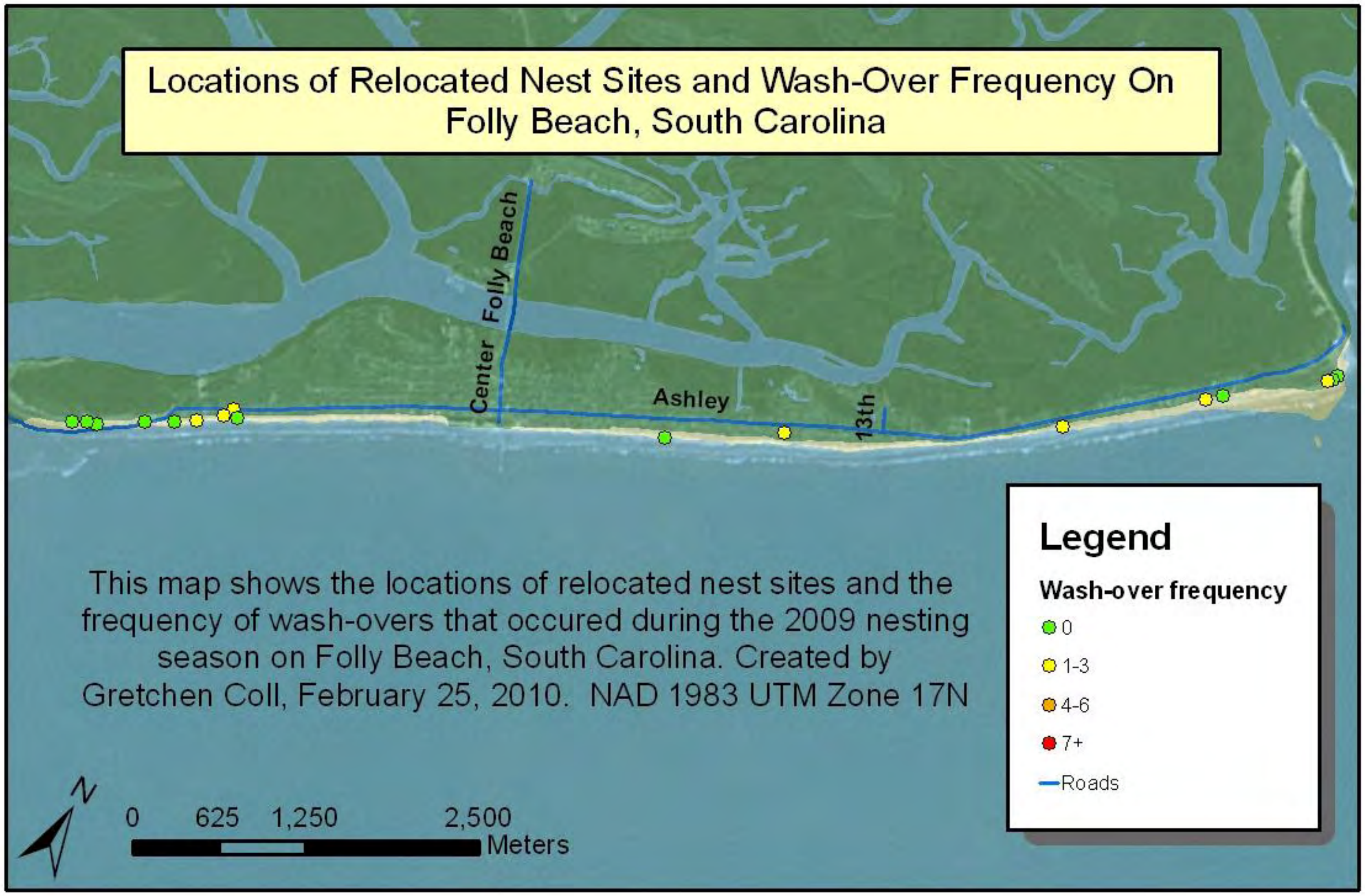

Figure 18. Locations of relocated nest sites and wash-over frequency on Folly Beach, South Carolina

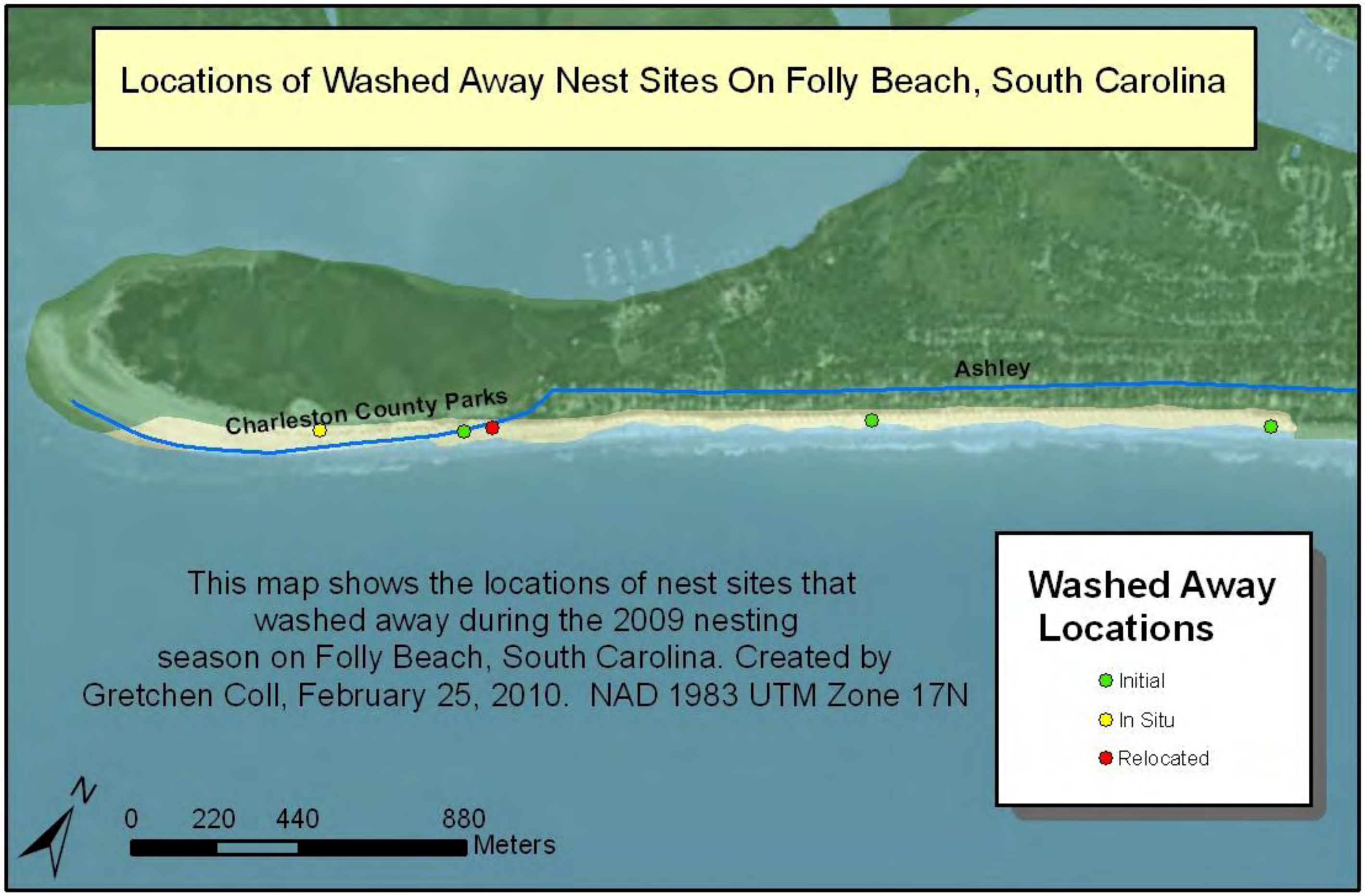

Figure 19. Locations of washed away nest sites on Folly Beach, South Carolina

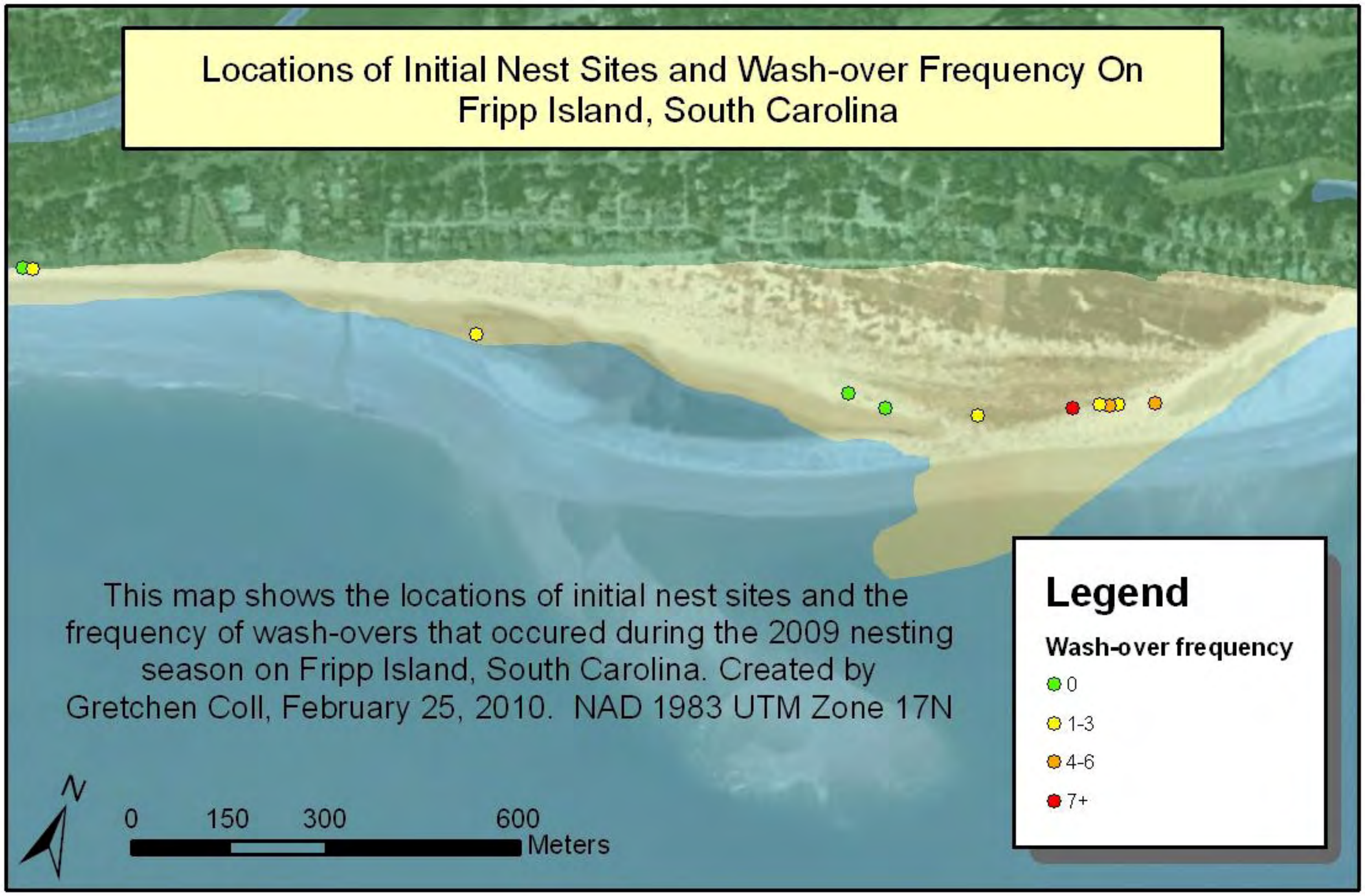

Figure 20. Locations of initial nest sites and wash-over frequency on Fripp Island, South Carolina

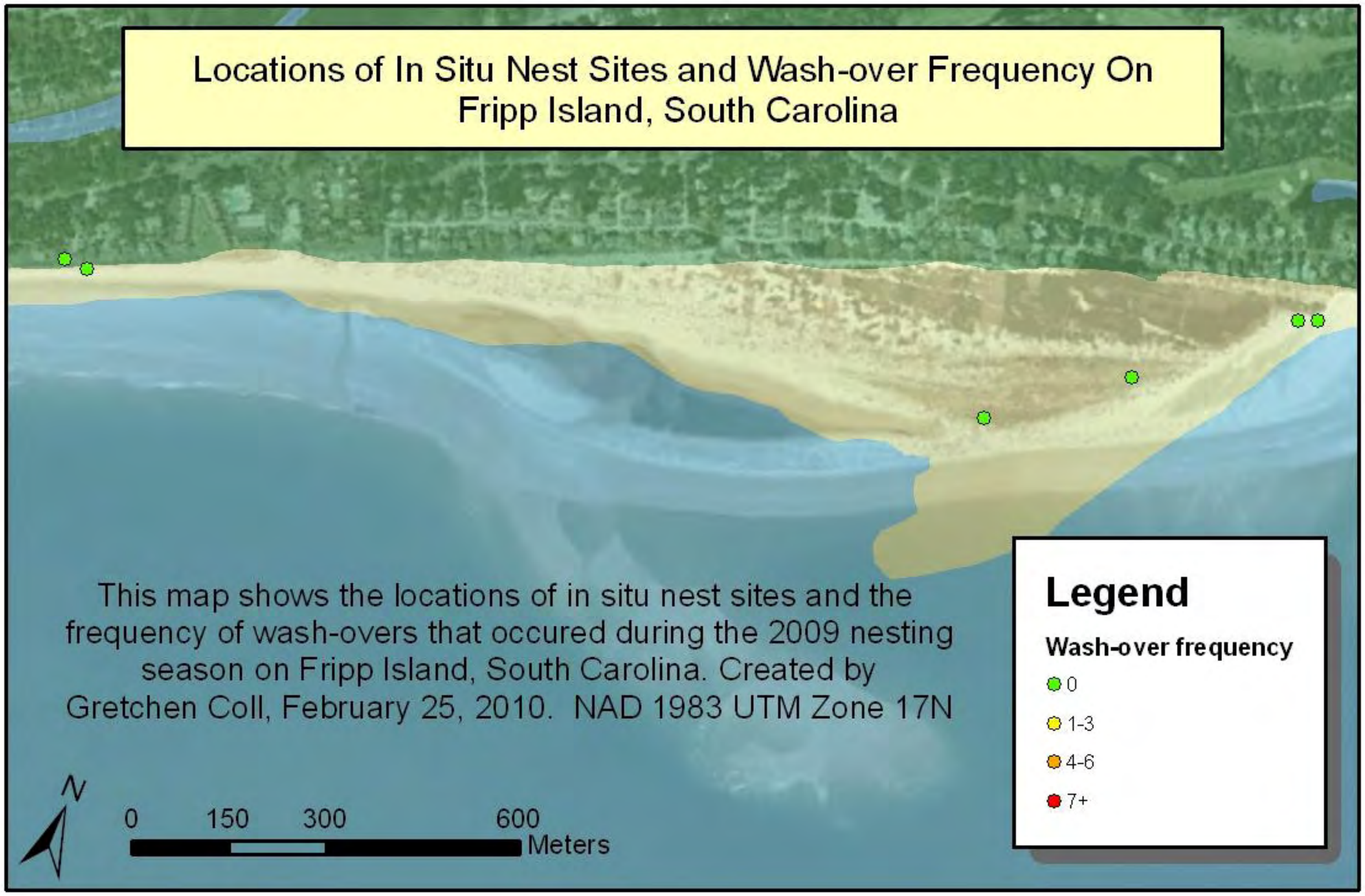

Figure 21. Locations of in situ nest sites and wash-over frequency on Fripp Island, South Carolina

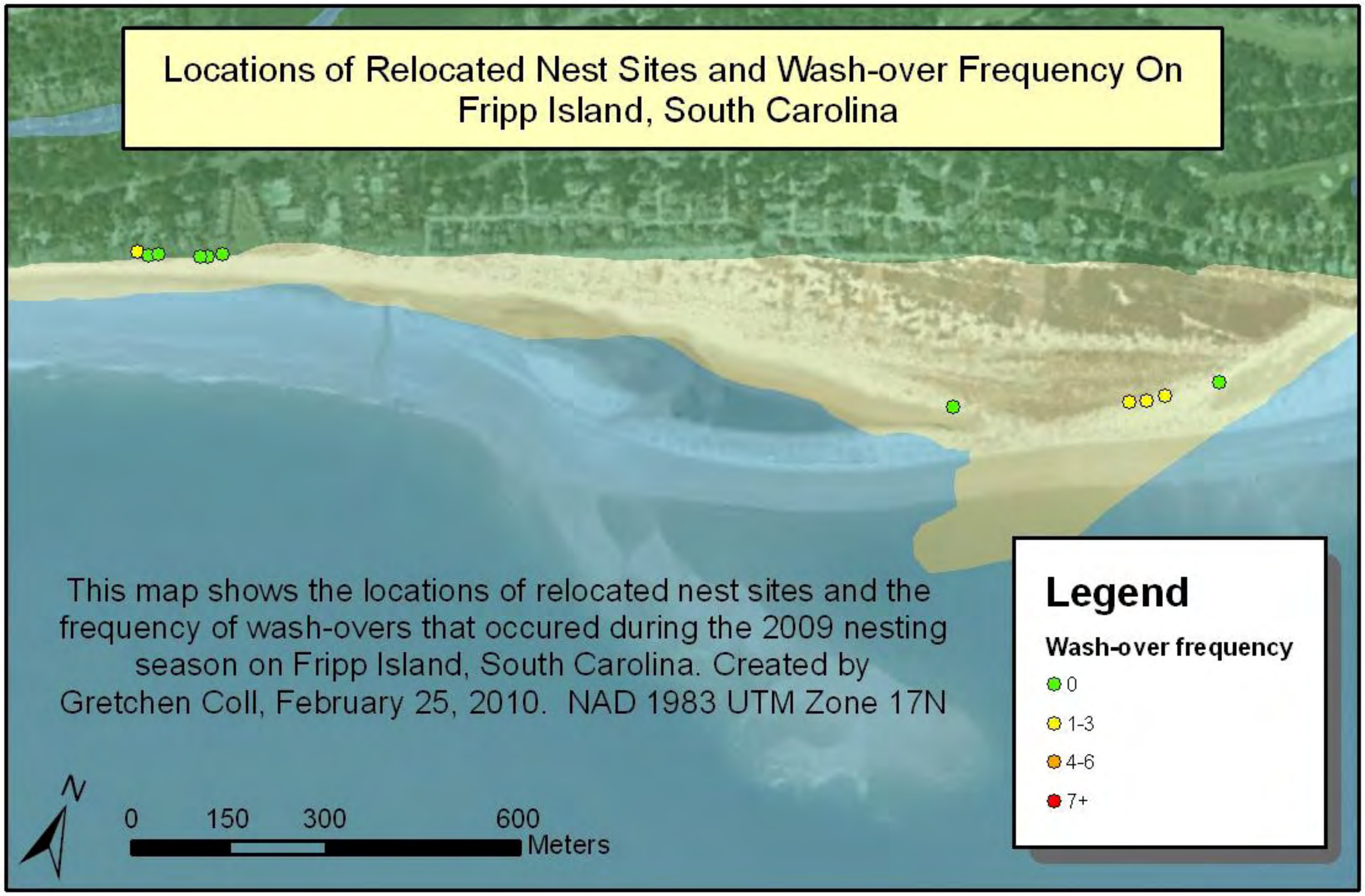

Figure 22. Locations of relocated nest sites and wash-over frequency on Fripp Island, South Carolina

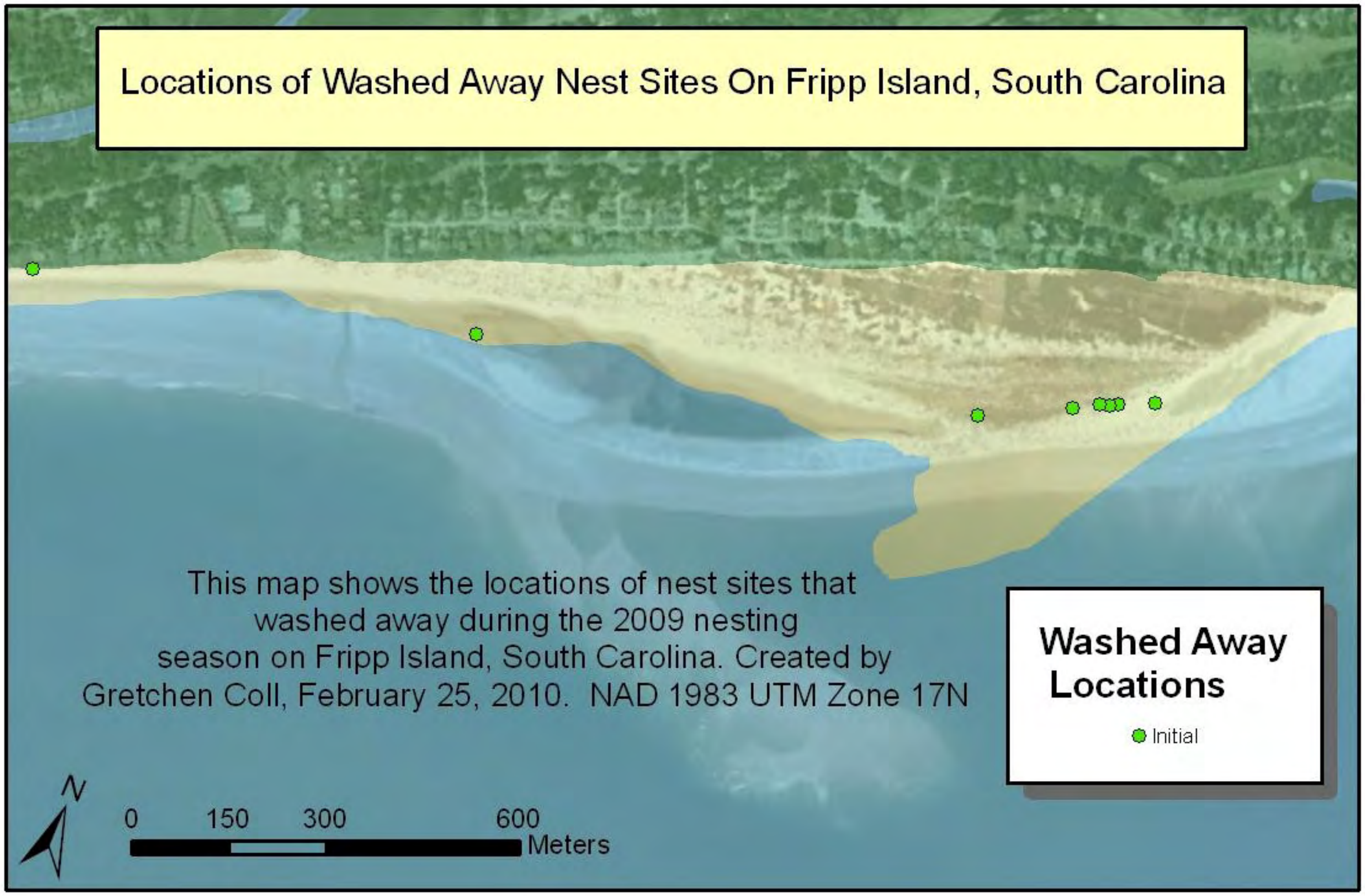

Figure 23. Locations of washed away nest sites on Fripp Island, South Carolina

Table 1. Occurrence of wash-over events and washed away events for *in situ* and relocated nests on Edisto Beach State Park, Folly Beach, and Fripp Island, South Carolina (2009).

	In Situ			Relocated		
	Edisto Beach State Park	Folly Beach	Fripp Island	Edisto Beach State Park	Folly Beach	Fripp Island
Number of nests	38	14	9	23	21	18
Number of nests washed over	5 (13.2%)	5 (35.7%)	1 (11.1%)	6 (26.1%)	8 (38.1%)	4 (22.2%)
Number of nests washed away	3 (7.9%)	1 (7.1%)	0 (0.0%)	4 (17.4%)	1 (4.8%)	0 (0.0%)

Table 2. Initial sites information, including number of initial sites, number of initial sites laid below spring high tide line, number of initial sites washed over, and number of initial sites washed away, for Edisto Beach State Park, Folly Beach, and Fripp Island, SC(2009).

	Edisto Beach State Park	Folly Beach	Fripp Island
Number of initial sites	23	18	13
Number of initial sites laid below SHTL	19 (83.3%)	7 (38.9%)	11 (84.6)
Number of initial sites washed over	20 (95.2%)	15 (83.3%)	10 (76.9%)
Number of initial sites washed away	7 (33.3%)	3 (16.6%)	9 (69.2%)

Table 3. Median hatch and emergence success of nests with wash-over events ranging from zero to four or more wash-overs in the state of South Carolina (2009).

Number of Times Washed Over	Median Hatch Success (%)	Number of Nests	p value	Median Emergence Success (%)	Number of Nests	p value
0	85.6	544		82.2	544	
1	85.7	76	0.1170	80.8	76	0.0712
2	84.1	57	0.0568	80.9	57	0.0274
3	79.5	80	0.0001	76.3	80	0.0003
4 or more times	59.7	63	0.0000	52.6	63	0.0000

Table 4. Nest management outcomes for *in situ* nests on Edisto Beach State Park, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Outcome
1	68.29	62.8	0	No	Managed Correctly
2	81.43	81.43	0	No	Managed Correctly
3	80.43	80.43	0	No	Managed Correctly
4	79.41	79.41	0	No	Managed Correctly
5	92.8	92	0	No	Managed Correctly
8	92.56	90.91	1	No	Managed Correctly
9	98.13	97.2	0	No	Managed Correctly
10	80.25	80.25	0	No	Managed Correctly
12	84.17	83.33	0	No	Managed Correctly
13	13.75	13.75	0	No	Managed Correctly
16	88.5	87.61	0	No	Managed Correctly
17	63.49	44.44	6	No	Needed further management
18	78.85	78.85	0	No	Managed Correctly
20	90.32	89.52	0	No	Managed Correctly
21	60.16	60.16	0	No	Managed Correctly
24	91.35	91.35	0	No	Managed Correctly
25	77.91	77.91	0	No	Managed Correctly
27	50	48.12	0	No	Managed Correctly
29	81.37	81.37	0	No	Managed Correctly
30	90.29	89.32	0	No	Managed Correctly
32	57.41	57.41	0	No	Managed Correctly
33	69.85	68.38	0	No	Managed Correctly
35	79.07	79.07	0	No	Managed Correctly
36	73.58	72.64	0	No	Managed Correctly
37	90.23	89.47	0	No	Managed Correctly
39	73.5	71.79	0	No	Managed Correctly
40	76.34	74.19	0	No	Managed Correctly
41	84.38	80.21	0	No	Managed Correctly
43	50	49.25	0	No	Managed Correctly
44	39.06	0	2	No	Managed Correctly
52	0	0	0	Yes	Needed further management
53	56.88	0	10	No	Needed further management
56	17.33	2.67	0	No	Managed Correctly
58	0	0	0	Yes	Needed further management
59	42.22	41.48	2	No	Managed Correctly
65	0	0	0	Yes	Needed further management
66	0	0	0	No	Managed Correctly

Table 5. Nest management outcomes for relocated nests on Edisto Beach State Park, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Number of Wash-overs at Initial Site	Washed Away Event at Initial Site	Outcome
14	81.48	71.85	0	No	7	Yes	Managed Correctly
15	100	100	0	No	11	Yes	Managed Correctly
23	95.76	94.92	0	No	0	No	Relocation not necessary
26	80.15	78.63	0	No	0	No	Relocation not necessary
28	35.11	34.35	0	No	2	No	Relocation not necessary
38	76.32	75.44	0	No	9	No	Managed Correctly
45	100	100	0	No	2	No	Relocation not necessary
46	74.22	74.22	0	No	5	No	Managed Correctly
47	0	0	0	Yes	6	Yes	Relocation site unsuccessful
48	88.24	8.4	2	No	1	Yes	Managed Correctly
49	0	0	0	Yes	2	No	Relocation not necessary
50	0	0	0	Yes	3	No	Relocation not necessary
51	21.7	21.7	2	No	5	No	Managed Correctly
54	17.46	17.46	6	No	6	No	Relocation site unsuccessful
55	16.51	14.68	2	No	3	No	Relocation not necessary
61	70.69	70.69	0	No	6	No	Managed Correctly
62	0	0	4	No	2	Yes	Relocation site unsuccessful
63	0	0	0	Yes	2	Yes	Relocation site unsuccessful

Table 6. Nest management outcomes for *in situ* nests on Folly Beach, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Outcome
1	76.09	69.57	0	No	Managed Correctly
4	84.48	81.03	0	No	Managed Correctly
5	94.12	91.91	0	No	Managed Correctly
8	73.81	62.7	0	No	Managed Correctly
11	19.77	19.77	3	No	Managed Correctly
12	88.3	87.23	3	No	Managed Correctly
16	82.83	76.77	0	No	Managed Correctly
17	76.36	73.64	0	No	Managed Correctly
22	96.84	96.84	1	No	Managed Correctly
28	84.93	84.93	2	No	Managed Correctly
31	19.53	17.97	4	No	Needed further management
32	94.02	94.02	0	No	Managed Correctly
33	0	0	0	Yes	Needed further management

Table 7. Nest management outcomes for relocated nests on Folly Beach, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Number of Wash-overs at Initial Site	Washed Away Event at Initial Site	Outcome
2	14.88	13.02	0	No	5	No	Managed Correctly
6	46.49	46.49	0	No	7	No	Managed Correctly
10	96.1	95.45	0	No	7	No	Managed Correctly
13	62.96	62.96	0	No	7	No	Managed Correctly
14	93.04	93.04	0	No	4	No	Managed Correctly
15	90.08	90.08	0	No	6	No	Managed Correctly
18	84.25	29.13	2	No	0	No	Relocation not necessary
19	84.43	81.15	0	No	6	No	Managed Correctly
20	79.28	79.28	0	No	1	No	Relocation not necessary
21	59.46	59.46	0	No	0	No	Relocation not necessary
23	60.44	56.04	2	No	5	No	Managed Correctly
24	64.35	63.48	2	No	7	No	Managed Correctly
25	75.83	75.83	2	No	8	No	Managed Correctly
26	88.24	84.56	2	No	0	No	Relocation not necessary
27	85.95	85.95	0	No	6	Yes	Managed Correctly
29	80.91	80.91	2	No	5	Yes	Managed Correctly
34	0	0	0	Yes	5	Yes	Relocation site unsuccessful
35	61.8	61.8	1	No	39	No	Managed Correctly

Table 8. Nest management outcomes for *in situ* nests on Fripp Island, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Outcome
2	1.75	0	0	No	Managed Correctly
3	28.1	25.49	0	No	Managed Correctly
7	80.43	50	0	No	Managed Correctly
9	64.8	60	0	No	Managed Correctly
11	97.87	97.87	0	No	Managed Correctly
20	3.67	3.67	0	No	Managed Correctly
22	89.06	83.59	0	No	Managed Correctly
25	4.51	4.51	2	No	Managed Correctly
26	75.23	70.64	0	No	Managed Correctly

Table 9. Nest management outcomes for relocated nests on Fripp Island, South Carolina (2009).

Nest Number	Hatch Success %	Emergence Success %	Number of Wash-overs	Washed Away Event	Number of Wash-overs at Initial Site	Washed Away Event at Initial Site	Outcome
4	96.52	96.52	1	No	8	Yes	Managed Correctly
5	94.29	94.29	1	No	17	No	Managed Correctly
6	62.6	58.78	1	No	2	Yes	Managed Correctly
8	95.1	89.22	0	No	0	No	Relocation not necessary
10	93.04	88.7	0	No	0	No	Relocation not necessary
12	88.73	30.99	0	No	1	Yes	Managed Correctly
13	86.52	83.69	0	No	0	No	Relocation not necessary
15	80.72	75.9	0	No	6	Yes	Managed Correctly
16	58.59	53.91	0	No	2	Yes	Managed Correctly
19	78.45	37.93	0	No	7	Yes	Managed Correctly
21	92.54	92.54	0	No	5	Yes	Managed Correctly
23	92.04	92.04	0	No	1	Yes	Managed Correctly
27	96.81	96.81	0	No	1	Yes	Managed Correctly