# AN EVALUATION OF NEST RELOCATION AS A LOGGERHEAD SEA TURTLE (*Caretta caretta)* MANAGEMENT TECHNIQUE IN NORTH CAROLINA

**by**
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# Abstract

A network of volunteers, under the guidance of the North Carolina Sea Turtle Protection Program, monitors and protects loggerhead nests laid on state beaches. Although volunteers are encouraged to allow nest incubation to proceed naturally and with minimal intervention, some volunteers will relocate freshly laid nests that are threatened by possible inundation by high tides, heavy beach traffic, or under a sloughing escarpment.

Nest relocation may have negative effects: it may reduce hatching success, alter incubation duration, and reduce hatchling fitness. Thus an evaluation of hatching success and incubation duration at nesting areas under the protection of the NC Sea Turtle Protection Program is warranted.

My objective for the evaluation was to use loggerhead sea turtle (*Caretta caretta*) nest activity data from four high-density North Carolina nesting areas – Bald Head Island, Cape Lookout National Seashore, Cape Hatteras National Seashore, and Topsail Island – to assess statistically the management technique of nest relocation in North Carolina. Using 1997 to 2001 data, provided by the North Carolina Sea Turtle Protection Program, I evaluated hatching success and incubation duration among in-situ nests, relocated nests, and in-situ nests affected by tidal inundation.

During each of the five years, 1997 to 2001, the average number of nests moved on the study's four North Carolina nesting areas approached 40 to 60 percent. The evaluation of hatching success showed a tendency of more loggerhead hatchlings hatching in in-situ nests than in relocated nests. Also, the evaluation indicated a tendency of in-situ nests having longer incubation durations than relocated nests.

The evaluation showed relocated nests might have shorter incubation periods, and thus present nest relocation techniques in North Carolina might be skewing northern sub-population sex-ratios more in favor of female hatchling production.

I formulated a series of nest relocation recommendations with the evaluation results: use nest relocation as a last resort, only relocate nests that will be over-washed daily by high tides, do not base nest relocation measures on previous summer storms, and do not relocate nests in heavy foot traffic areas.

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# 1.0 Introduction

## 1.1 Species Background: *Life Stages of the Northwestern Atlantic Loggerhead Sea Turtle*

Loggerhead sea turtles (*Caretta caretta*) are not sexually mature until about age thirty (Snover, 2002). Adult courtship has been documented in coastal waters of Georgia and Florida as early as mid-March (Frick et al, 1999) (Figure 1.1).

During the initial courtship stage, a male locates female. Within a meter of the female, the male begins circling her for two to three minutes. Throughout the act of circling, the female constantly adjusts her orientation towards the male, so that her head faces the male at all times. Circling ceases when the male dives underneath the female to begin nuzzling, an olfactory process loggerheads use to distinguish between sexes (Frick et al, 1999). A male begins biting the female's hind flippers for one to five minutes once he has realized that it is indeed a female. At this point the male tries mounting her. If he fails, courtship behavior proceeds, and the male moves face to face with the female and strokes her head and neck with the upper surfaces of his front flipper. After three to five minutes of stroking the male stops and attempts to mount again. Sometimes the second mounting fails and the female chases the male away (Frick et al, 1999).

The northwestern Atlantic loggerhead-nesting season begins in late spring and continues through late summer (Caldwell et al, 1959). After an incubation period ranging between 48 days and 86 days (Mrosovsky, 1988), hatchlings begin to pip (cut through the eggshell); about 4 days later they emerge from the nest (Godfrey and Mrosovsky, 1997). Upon emerging, the hatchlings quickly make their way down to the surf zone and into the water (Mrosovsky, 1985), beginning the "lost-year" period (Carr, 1987) (Figure 1.1).

The "lost-year" period refers to the northwestern Atlantic loggerhead's pelagic stage, which was largely unknown for many years and hypothesized to consist of trans-navigation of the North Atlantic Ocean and foraging in the Eastern North Atlantic for eight to eleven years (Carr, 1987). At the end of the pelagic stage, loggerheads enter a benthic stage, where juveniles return to shallow coastal waters in the western North Atlantic, to forage and mature into adults (Figure 1.1). The migration hypothesis has recently been supported by results from genetic work on mtDNA haplotype distributions in the North Atlantic.

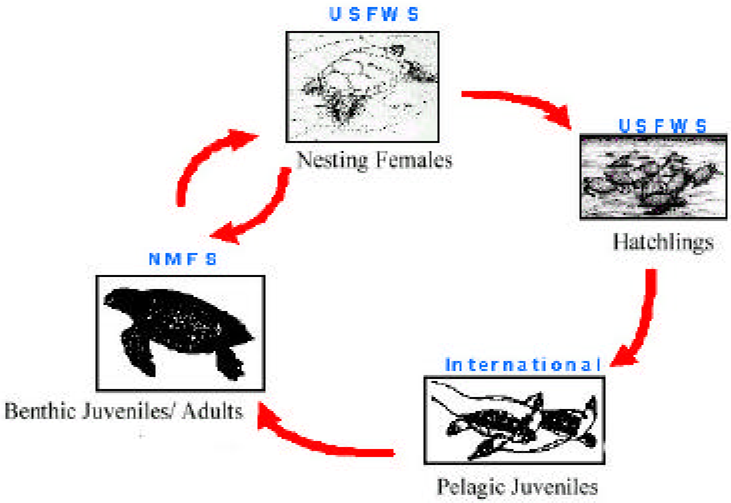


Figure 1.1: Life stages of the northwestern Atlantic loggerhead sea turtle (*Caretta caretta*). The diagram states the U.S. agency responsible for protection (Crowder, 2002).

## 1.2 Nesting Beach Threats to the Northwestern Atlantic Loggerhead Sea Turtle

Northwestern Atlantic loggerhead eggs, hatchling loggerheads, and nesting female loggerheads encounter numerous threats on the nesting beach. The threats listed in the *Recovery Plan for U.S. Population of Loggerhead Turtle* (*Caretta caretta*) include beach erosion, beach armoring, beach nourishment, artificial lighting, beach cleaning, human presence, recreational activities, vehicles, dense dune vegetation, plant roots, nest depredation, and tidal inundation (NMFS and USFWS, 1991).

Beach erosion is influenced by coastal processes, such as hurricanes and sea level rise, and may result in the loss of nesting habitat, loss of laid nests, lowered hatching success (Section 1.4.4.1) (NMFS and USFWS, 1991). Nest monitoring volunteers try to mitigate the effects of erosion on sea turtle nests by relocating them to higher sites, such as dunes (National Research Council, 1990).

Coastal landowners use beach armoring to protect against property loss via erosion. These practices include sea wall, groin, and jetty construction. Beach armoring activities may result in accelerated erosion, prevention of natural dune development, and inhibition of sea turtles from accessing nesting sites (NMFS and USFWS, 1991). The structures often cause increased wave action that may result in nest inundation during high tides or storms (NMFS and USFWS, 1991).

Beach nourishment – the practice of pumping sand onto beaches to replenish sand loss – may result in the burial of nests. Nourishment may result in the application of non-native sand sources, which may negatively affect nest site selection, nest building, incubation temperature and duration, gas exchange, the hydric environment, hatching success, and hatchling emergence (NMFS and USFWS, 1991). In a seven-year study at Jupiter Island, Florida, Steintiz et al (1988) reported that females placed fewer nests on renourished beaches than on a natural beach (not renourished).

Artificial lighting may disorient both nesting female sea turtles and emerging hatchlings. A brightly lit beach may cause a female to abort the nesting process, or result in the non-emergence of hatchlings (NMFS and USFWS, 1991). Hatchlings, using visual cues (Salmon and Wyneken, 1994), find the sea under natural conditions by crawling towards a bright, low oceanic horizon and away from darkened dunes (Lohmann, 1997). However, artificial beach lighting behind dunes sometimes causes hatchlings to crawl into dunes or a long the beach, increasing their risk of desiccation or predation.

Beach cleaning – also termed beach scraping – is the process of removing debris from a beach. The cleaning process may compact sand above nests and prevent hatchling emergence (NMFS and USFWS, 1991).

Human presence may negatively impact the nesting environment. Night-time human presence on nesting beaches may deter nesting females, and result in false crawls (female aborting the nesting process; Section 1.4.1.7:II). Human tracks, tire treads from vehicles, and recreational equipment may hinder hatchlings trying to reach the ocean. Campfires and flashlights may disorient hatchlings and frighten nesting females (NMFS and USFWS, 1991).

Vegetation may form impenetrable root mats, which inhibit female nest excavation. These root mats may also invade and desiccate eggs or trap hatchlings (NMFS and USFWS, 1991).

Nest depredation contributes heavily to both egg and hatchling loss in the southeastern United States (Ratnaswamy and Warren, 1998). Major predators include raccoons, foxes, and ghost crabs, all of which prey on incubating eggs and emerging sea turtles (Nongame and Endangered Wildlife Program, 1998, NMFS and USFWS, 1991).

Nest loss, lowered hatching success, and lowered emergence success (Section 1.4.4.2) may all result from tidal inundation and accretion of sand above nests. Inundation of nests by high tides and accretion of sand on nests, as a result of a summer storm (e.g. tropical storm), may result in high nest loss, lowered hatching success, and lowered emergence success (NMFS and USFWS, 1991).

## 1.3 U.S. Endangered Species Act: *A Federal Policy Paving the Way for Federal and State Conservation, Management, and Protection of Loggerheads*

### 1.3.1 *U.S*. Endangered Species Act: Federal Protection of the Loggerhead

The U.S. Endangered Species Act of 1973 (16 U.S.C. 1531 *et seq*.) lists all loggerhead sea turtle populations occurring in U.S. waters as threatened. Loggerheads received federal protection on July 28, 1978, because anthropogenic activities were contributing to serious declines in population sizes (National Research Council, 1990, U.S. Fish and Wildlife Service, 2003).

The U.S. Congress passed the Endangered Species Act (ESA) as an effort to provide a program for the conservation of threatened and endangered plants and animals and their habitats (National Research Council, 1990, EPA, 2003). Under the ESA, an "endangered species" is defined as "any species which is in danger of extinction throughout all or a significant portion of its range," while a "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (U.S. Fish and Wildlife Service, 2003)". The U.S. Fish and Wildlife Service (FWS) maintains a list of endangered and threatened species (EPA, 2003) and prohibits any action that would result in the taking of a listed species, or adversely affect its habitat or behavior.

At the federal level, the U.S. departments of Commerce and the Interior share federal jurisdiction over loggerheads. Section 4(f) of the ESA requires the establishment and implementation of a recovery plan for each listed species, unless the overseeing secretary of the U.S. department that has jurisdiction over that species finds that such a plan will not aid in its recovery (National Research Council, 1990, U.S. Fish and Wildlife Service, 2003). FWS (Figure 1.1) in the Department of the Interior has the responsibility for nesting beaches, and the National Marine Fisheries Service (NMFS) (Figure 1.1) in the Department of Commerce maintains jurisdiction of juveniles and adults in the Exclusive Economic Zone (EEZ), the marine area ranging 0 to 200 miles off the U.S. coast (U.S. Fish and Wildlife Service, 2003).

In 1984 NMFS approved the first sea turtle recovery plan, prepared by the Marine Turtle Recovery Team, for the six species of sea turtles living in U.S waters (National Research Council, 1990, U.S. Fish and Wildlife Service, 2003). NMFS and FWS approved a recovery plan, prepared by the Atlantic Loggerhead Sea Turtle Recovery Team, for the U.S. population of North Atlantic loggerhead sea turtles in 1991. In 2001 FWS and NMFS designated a new recovery team to revise the 1991 loggerhead recovery plan and address current threats and conservation accomplishments.

### 1.3.2 North Carolina State Protection

Section 6 of the ESA requires the Secretary of the Interior to form a cooperative agreement with any State that establishes and maintains a successful endangered or threatened species conservation program (USGS, 2003). With permission from the FWS, the NC Wildlife Resources Commission (NCWRC) created the North Carolina Sea Turtle Protection Program in accordance with Section 6 (Outer Banks Task Force, 1998). The Faunal Diversity Program – a section of the NC Wildlife Resources Commission (NCWRC) – directs the North Carolina Sea Turtle Protection Program (Nongame and Endangered Wildlife Program, 2003, Outer Banks Task Force, 1998).

Working under strict compliance with the ESA, as well as in conjunction with FWS and NMFS, the North Carolina Sea Turtle Program monitors, manages, and protects sea turtle nests. The protection program maintains an extensive statewide loggerhead-nesting database and collects sea turtle mortality data. The program relies on federal, state, and local agencies as well as an extensive volunteer network to manage nesting habitats, collect data on nesting activity in North Carolina, and deal with the numerous threats that sea turtles face in North Carolina.

## 1.4 A Scientific Foundation for Conservation, Management, and Protection Measures:

### *Nesting Ecology of the Northwestern Atlantic Loggerhead Sea Turtle*

A firm understanding of the nesting ecology is important to the conservation, management and protection of loggerhead sea turtle populations (Richardson, 1999). The following will describe northwestern Atlantic loggerhead nesting, which includes the biological processes of nesting, embryonic development, and hatching.

### 1.4.1 Nesting Biology

#### 1.4.1.1 Nesting Season

The northwestern Atlantic loggerhead nesting season roughly begins in late spring. (Caldwell et al, 1959) The season usually begins when water temperatures reach about 23°C to 24°C. Nesting rates increase with an increase in water temperature and photoperiod (Nelson, 1988). The nesting season in the northwestern Atlantic occurs between May and August. Due to its close location to the tropics, Florida’s nesting season may extend into September. At the northern extent of the southeastern US nesting range, the majority of loggerhead nests are laid by the end of July (Dodd, 1988), although some nests are laid in August and September.

During a nesting season, a loggerhead will lay about three and half clutches on average (Miller, 1997). Successive internesting intervals are spaced about twelve to fourteen days, with a range of eleven to twenty days. An internesting interval is the amount time between a sea turtle returning to the water after having laid a clutch of eggs and emerging with the intention of laying another clutch of eggs during a reproductive year (Alvarado and Murphy, 1999, Miller, 1997). Intraseasonal nesting intervals increase with a decrease in ambient water temperature, and can even extend beyond 20 days when the ocean temperatures are cold (Sato et al, 1998). Usually loggerheads will remain close to the nesting beach during the internesting period (Dodd, 1988).

#### 1.4.1.2 Periodicity

Due to multiple factors, including energy requirements, loggerheads do not lay nests every year. Scientists estimate a loggerhead's remigration interval to be 2.59 years (Miller, 1997), which equals the amount of time between successive reproduction seasons for an individual female (Alvarado and Murphy, 1999). The range is one to six years. Some loggerheads switch from two-year nesting cycles to longer or shorter cycles (Dodd, 1988). It is likely that loggerhead-renesting cycles are influenced by environmental cycles, but to a lesser extent than other species of marine turtles (Broderick et al, 2001).

#### 1.4.1.3 Nesting Beaches

Female loggerheads normally nest on continental beaches, although one of the largest nesting colonies occurs on Masirah Island, in Oman (Dodd, 1988). The southeastern United States is one of the world's major continental nesting locations. Others include Australia, Brazil, and South Africa. Island nesting takes place in the Great Barrier Reef (Australia), Japan, the Mediterranean, and the Caribbean, amongst others (Dodd, 1988).

The northwestern Atlantic loggerhead population lays nests on U.S. South Atlantic and Gulf state beaches ranging from North Carolina to Texas. Nesting effort is not evenly disturbed among the beaches, and nests are not laid contiguously along the coasts. From mtDNA analysis, there is evidence that loggerhead-nesting populations in the northwestern Atlantic are genetically structured as five subpopulations (Figure 1.2). The five subpopulations include the northern sub-population, which ranges from North Carolina to northeast Florida, South Florida, Florida Panhandle, Dry Tortugas, and Yucatan Peninsula (Bowen and Karl, 1997). In particular, the beaches of the northern sub-population host about 10 % of the nesting effort (National Research Council, 1990). nDNA analysis suggests male-mediated genes flow among the nesting subpopulations (Bowen and Karl, 1997).

Figure 1

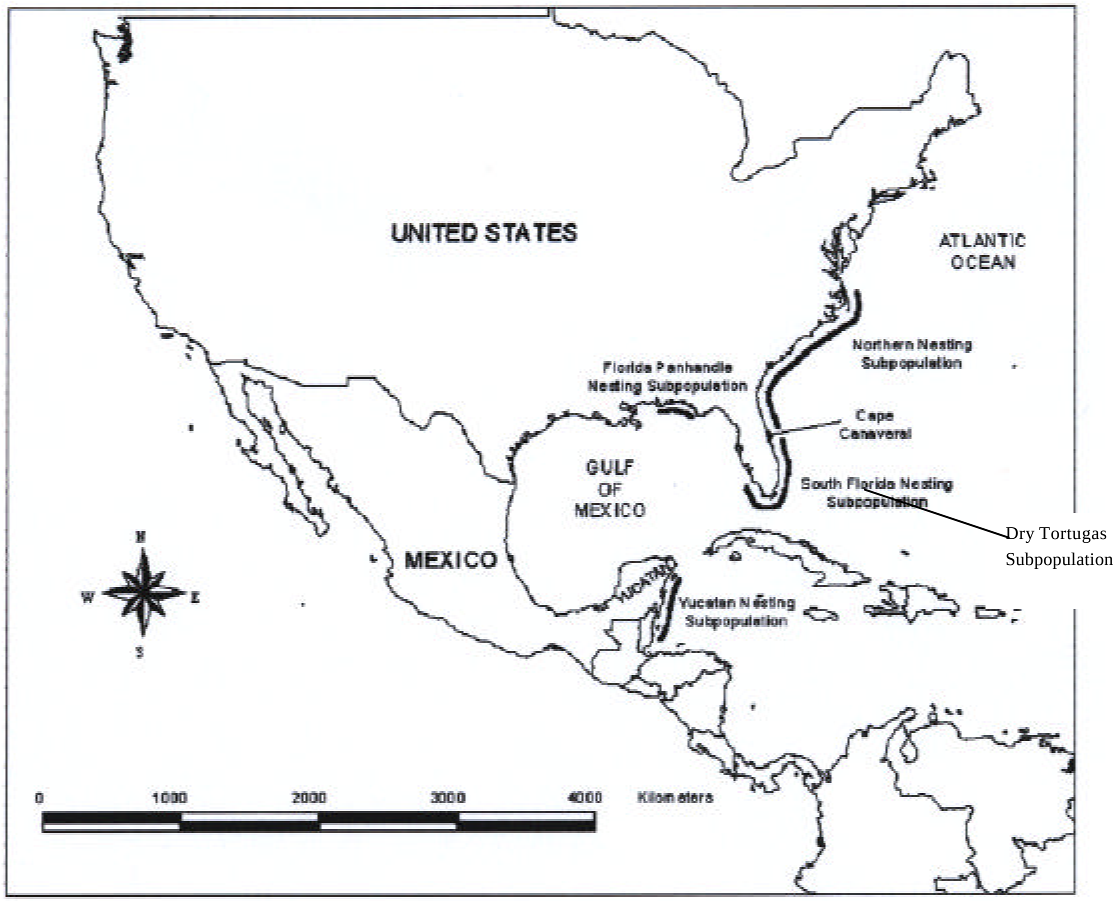


Figure 1.2: The map shows the five northwestern Atlantic loggerhead subpopulations in North and Central America. The five subpopulations include the northern subpopulation, which ranges from North Carolina to northeast Florida, South Florida, Florida Panhandle, Dry Tortugas, and Yucatan Peninsula (Bowen et al, 1997, Crowder, 2002)

### 1.4.1.4 Qualities Influencing Nest Site Selection

Loggerheads choose nesting beaches that are accessible from the sea (Mortimer, 1995, Miller, 1997). Loggerheads apparently prefer beaches close to reefs, which can be used for resting and feeding between intraseasonal nesting attempts (Nelson, 1988), although not all nesting sites have nearby reefs.

Loggerheads tend to nest well above the high tide line, in order to prevent nest inundation by tides or an underlying water table (Caldwell, 1959, Miller, 1997). The process by which a female loggerhead selects the exact location to lay her nest is not known (Miller et al. in press), although specific studies have provided possible cues. For instance, Stoneburner and Richardson (1981) and Wood and Bjorndal (2000) suggested that thermal gradients in surface sand temperature were important in nest site selection. Others have suggested that the distribution of loggerhead nests in terms of distance from the ocean was not different from a bounded random distribution (Hays et al, 1995), while others have suggested that loggerhead nests are laid in nonrandom patterns (e.g. Hays et al, 1993). Some authors have reported that sand moisture is significantly related to loggerhead nest placement (Cardinal, 1998), while others found no such relationship (Garmestani, 2000).

Northwestern Atlantic loggerheads often try to nest on wide sloping beaches with dunes (Caldwell, 1959). A desirable nesting site is within patches of vegetation (Mortimer, 1995) or sand dunes (Caldwell, 1959). High dunes and vegetation present a dark broken horizon, which aids a turtle in locating a nesting beach from the water (Caldwell, 1959).

Substrate quality is important to nest survival and construction (Mortimer, 1995, Miller, 1997). Important characteristics of a suitable substrate, such as sand, are moisture, grain size, and it will not collapse during construction of the egg chamber (Miller, 1997). Loggerheads show a tendency to nest in silica sand (Mortimer, 1995), which is the dominant substrate on southeastern US beaches.

A female may abort the nesting process during the beach ascent. The tracks from the process are termed “false crawls.” During a false crawl, a turtle had the intent of laying a nest, but aborted the process for an unknown reason.

### 1.4.1.5 Philopatry

Tagging studies show that sea turtles generally exhibit a high degree of philopatry (Miller, 1995). Philopatry refers to sea turtles showing regional discrimination when leaving the foraging area and returning to the nesting region during each remigration interval (Miller, 1997). In one study, a majority of the female loggerheads tagged on Melbourne Beach, Florida, showed strict philopatry, and returned to the same beach on consecutive remigration intervals (Bjorndal, 1983). Some individuals will switch between nesting beaches. In one instance, a loggerhead was observed nesting on both east and west coasts of Florida (LeBuff, 1990).

### 1.4.1.6 Nest Site Fidelity

Loggerheads choose nesting sites within the region of their birth. Generally loggerheads are not very site-specific, but do orient to a short stretch of coastline, which infers that the range between intraseasonal nesting attempts is very small (Bjorndal, 1983, Dodd, 1988). Intra-seasonal shifts of nesting zones occur more frequently then during inter-nesting intervals (Bjorndal, 1983). Migrations between intraseasonal nesting attempts for the same loggerhead usually range up to about 300 km, although some loggerheads have ranged more than 700 km (Dodd, 1988). The migration behavior may facilitate the spread of reproductive effort, and reduce the impact of an unpredictable nesting environment on hatchling success (Miller, 1997). Loggerheads have a tendency to nest towards the south during the spring season and further north in the summer portion of the nesting season (Dodd, 1988).

### 1.4.1.7 Stages of the Loggerhead Nesting Process

The loggerhead nesting process can be divided into ten (Hailman, 1992) or eleven stages (Ehrhart, 1995, Miller, 1997). The entire process takes about two to three hours (Miller, 1997), with digging (the body pit and egg chamber) and oviposition taking about one hour (Nelson, 1988).

Stage I: Approach of the Beach and Emergence

Female loggerheads approach the beach by swimming towards shallow coastal waters (Dodd, 1988). A broken horizon aids in helping a female find an appropriate nesting beach. During this stage, the loggerhead is most sensitive to its environment, and if disturbed, the female may retreat from the area (Dodd, 1988).

Female loggerheads emerge from the water shortly after dark and begin conducting the nesting process. Most of the nesting activity is conducted during a four or five hour period after dusk (Caldwell et al, 1959). Loggerheads probably nest at night to avoid high temperatures (Ackerman, 1997).

Stage II: Beach Ascent

When a female emerges from the water she travels up the wet, hard slopping part of the beach. During the beach ascension the female moves her flippers in a synchronous fashion, a process termed a terrestrial gait. For example, the right front flipper moves in conjunction with the left rear flipper (Hailman, 1992). The resulting track is asymmetrical and has a gait of about 90 cm (Miller, 1997).

The female may abort the nesting process during a beach ascent. The tracks from this process are termed false crawls. During a false crawl, the turtle had the intent of laying a nest, but aborted the process for an unknown reason. If the loggerhead aborts the nesting process, she will usually attempt to nest later the same night or the following night; usually the process is attempted at the same beach. On average loggerheads return 1.08 days after aborting and 87.5 percent return to the same beach (Miller, 1997).

### Stage III: Movement on the Beach

A female may occasionally change direction on the beach once she has ascended to the boundary dividing the cool wet sloping portion of the beach from the warm dry flatter portion of the beach. The boundary layer may aid the turtle in nest site selection (Miller, 1997). In some cases females will wander over vast amounts of beach area before nesting or returning to the sea (Dodd, 1988).

### Stage IV: Preparing the Nest Site

Once a loggerhead has found a nesting site above the boundary layer she prepares the site prior to digging a body pit. She sweeps her front flippers to remove debris, such as litter or vegetation (Miller, 1997).

Nest sites are often located between the mean high tide line and the seaward base of the primary dune (Nelson, 1988), although some are laid too close to or below the mean high tide line (Dodd, 1988). These nests are usually lost to erosion or tidal inundation unless relocated to safer ground by monitoring projects.

### Stage V: Digging the Body Pit

Once the female has cleared any debris from the nesting site she begins construction of a "body pit," which is proportional to the size of the turtle and dryness of the beach sand (Miller, 1997). A female uses her front flippers to clear sand located in front of her. When she is finished she moves her body into the cleared area (the body pit) and uses her hind flippers to remove any loose substrate located behind her (Miller, 1997). Loggerheads generally dig shallow, poorly developed pits, which are usually deeper at the rear (Ehrhart, 1995, Dodd, 1988).

### Stage VI: Digging the Egg Chamber

After completing the body pit, the female uses her hind flippers to dig a flask-shaped chamber that usually has a narrow neck and wide bottom. The shape and size of the egg chamber is related to the length of the turtle's hind limb and flipper size, which is in turn related to overall body size (Tiwari and Bjorndal, 2000).

Digging of the egg chamber commences with the female using her hind flippers to scrape and flick away sand from the future location of the egg chamber. The turtle uses the moist sand removed during digging of the egg chamber to fill the egg chamber. The female ceases the digging process soon after she cannot remove any more sand from the chamber (Caldwell et al, 1959, Miller, 1997). On average the depth of an egg chamber measures 49.2 cm and has a width of 28.9 cm (Tiwari and Bjorndal, 2000).

### Stage VII: Oviposition

During oviposition the loggerhead extends her hind limbs outward onto the sand and covers the nest opening with her carapace (Miller, 1997). As eggs are released through the female's cloacal 'ovipositor' (Caldwell et al, 1959), she curls the outer edges of her flippers (Ehrhart, 1995). Eggs are released singly or in groups up to four (Miller, 1997).

On average at the end of oviposition the distance from the beach surface to the topmost egg is 29.2 cm (Tiwari and Bjorndal, 2000).

### Stage VIII: Filling the Egg Chamber

At the completion of oviposition, the female fills the egg chamber with the sand that she removed during excavation of the egg chamber (Miller, 1997).

Stage IX:  Filling the Body Pit

The female fills the body pit once she has completed filling the egg chamber.  Facing the water, she uses her front flippers to throw sand backwards over her shell onto the nest site.  The sand thrown on top of the nest provides insulation for the eggs.  During the process the female moves forwards, and continues to throw sand.  The process creates a body pit a few meters from the egg chamber and restores the beach environment around the nest (Miller, 1997).

Stage X:  Walk Back Towards the Water

Upon returning to the ocean the female selects a path for return and crawls down the sloping beach (Ehrhart, 1995).  While returning, the loggerhead often stops and rests for short periods due exhaustion.  Caldwell (1959) observed an undisturbed loggerhead crawl 180 feet to the ocean in 25 minutes and a second loggerhead crawl 50 feet to the ocean in 3 minutes.

Stage XI:  Reenter the Ocean

The female reenters the ocean at the surf zone (Ehrhart, 1995).

#### 1.4.1.8 Reproductive Potential

During a nesting season loggerheads lay multiple large clutches of small eggs to increase fecundity.  On average a loggerhead will lay three and half clutches or 350 to 400 eggs, although this varies in different nesting populations (Tiwari and Bjorndal, 2000).  The maximum number of clutches laid in a nesting season is dependent upon the duration of the nesting season and a two-week preparation interval where the female prepares to lay her next clutch of eggs (Dodd, 1988).  The average clutch size for all populations of loggerheads is 112.4 eggs (Miller, 1997). A clutch is the number of yolked eggs laid into a nest (Miller, 1999).

Van Buskirk and Crowder (1994) examined the means, as reported in the literature, for several loggerhead life history traits, including body size and reproductive output.  They reported that body size was positively correlated to clutch size. Tiwari and Bjorndal (2000) found that straight carapace length and straight carapace width explained the greatest amount of variation in clutch size. The results from Tiwari and Bjorndal (2000) show that larger loggerhead females invest more energy into reproductive output. Clutch size does not differ greatly over a season, but does decrease later in the season (Frazer and Richardson, 1985, Caldwell, 1959).

### 1.4.2 Biology of Embryonic Development

#### 1.4.2.1 Characteristics of the Egg

Loggerhead eggs are white and spherical with soft calcareous shells when laid (Miller, 1997). They are coated with a mucous secretion that dries in a few hours and gives the shell a pore-free, parchment-like texture (Dodd, 1988). Eggs do not contain an air space (Nelson, 1988).

Loggerheads produce small yoked eggs relative to body size (Van Buskirk and Crowder, 1994). Eggs that are laid last are smaller than the first eggs laid at the bottom of the egg chamber (Caldwell, 1959). On average an egg weighs about 39.4 grams and has a diameter of 42.9 mm (Tiwari and Bjorndal, 2000).

#### 1.4.2.2 Overview of Embryonic Development

Embryonic Development can be divided into 6 pre-oviposition activities and 25 post-oviposition actives (Dodd, 1988). Embryonic development begins prior to oviposition (Miller, 1997).

The pre-oviposition stage of embryonic development occurs internally and takes seven days to complete. Development begins when a follicle exits the ovary and passes into the magnum – the location of sperm fertilization (Miller, 1997).

An individual female may mate with several males; genetic studies have found that as many as three different fathers have fertilized the eggs of a single clutch (Miller, 1997). Females can store sperm for up to several months between remigration intervals.

The fertilized follicle becomes the yolk of an egg. The yolk is coated with albumen in the anterior gradular region of the oviduct. The inner shell membrane forms in the shell-forming portion of the oviduct after the albumen coat has been secreted onto the egg. After the inner shell has formed, aragonite crystals coat and form the outer shell membrane. Internal development does not proceed beyond middle gastrulation – a period when the primary germ layers and basic body plan are established. Gastrulation recommences four to eight hours after oviposition (Miller, 1997). Excessive rotation of a loggerhead egg, four or more hours after being laid, may disrupt the membranes that attach to the inside of the egg, and result in the death of the embryo (Limpus et al, 1979).

Post-oviposition development commences when gastrulation recommences. The apperance of a white spot on the upper most portion of the egg signals the recommencement of gastrulation. The white spot will increase in size, and eventually cover the entire outer shell membrane. The white spot signifies the development of multiple membranes, including the vitelline, amnion, allantois, and chorion membranes (Miller, 1997). Prior to pipping, the loggerhead embryo will have grown and developed between 5 and 11 times the volume of the egg yolk (Dodd, 1988).

The energy and chemical requirements for the embryo come from the food that the mother foraged for in the coastal zone prior to laying the clutch (Miller, 1997).

### 1.4.2.3 Temperature and Its Affect on Sex

Sexual differentiation in loggerheads is dependent upon the incubation temperature, also termed the clutch temperature. The incubation temperature is influenced by both beach temperature and exchange of metabolic heat between the clutch and beach. Southeastern U.S. beach temperatures normally range from $26^{o}$C to $35^{o}$C (Ackerman, 1997). Beach temperature can be measured from the exchange of thermal energy at the beach surface with the atmosphere and the transmission of heat within the beach substrate (Ackerman, 1997).

The direction of sexual differentiation in sea turtles is determined by incubation temperature, with warmer temperatures producing more females and cooler temperatures producing more males (Mrosovsky, 1994). The pivotal temperature is defined as the constant incubation temperature that produces equal numbers of both sexes (Mrosovsky and Pieau, 1991). The pivotal temperature for loggerheads along the southeastern U.S. coastline is about $29.0^{o}$C (Mrosovsky, 1988). North Carolina beaches have lower average sand temperatures than more southerly states, and produce a higher percentage of males (Mrosovsky, 1988).

The critical period for sex determination occurs during the middle third to middle half of the incubation period (Mrosovsky and Pieau, 1991). During this period, embryonic sex is irreversibly influenced by temperature (Georges et al, 1994).

### 1.4.2.4 Incubation Period

The incubation period begins when a female lays eggs in a nest and concludes with the commencement of piping. The average incubation period for loggerhead eggs laid in the southeastern U.S. is 60 days, with a range of 46 to 65 days (Nelson, 1988). Incubation duration is approximately 10 days longer in North Carolina than in Florida (Mrosovsky, 1988).

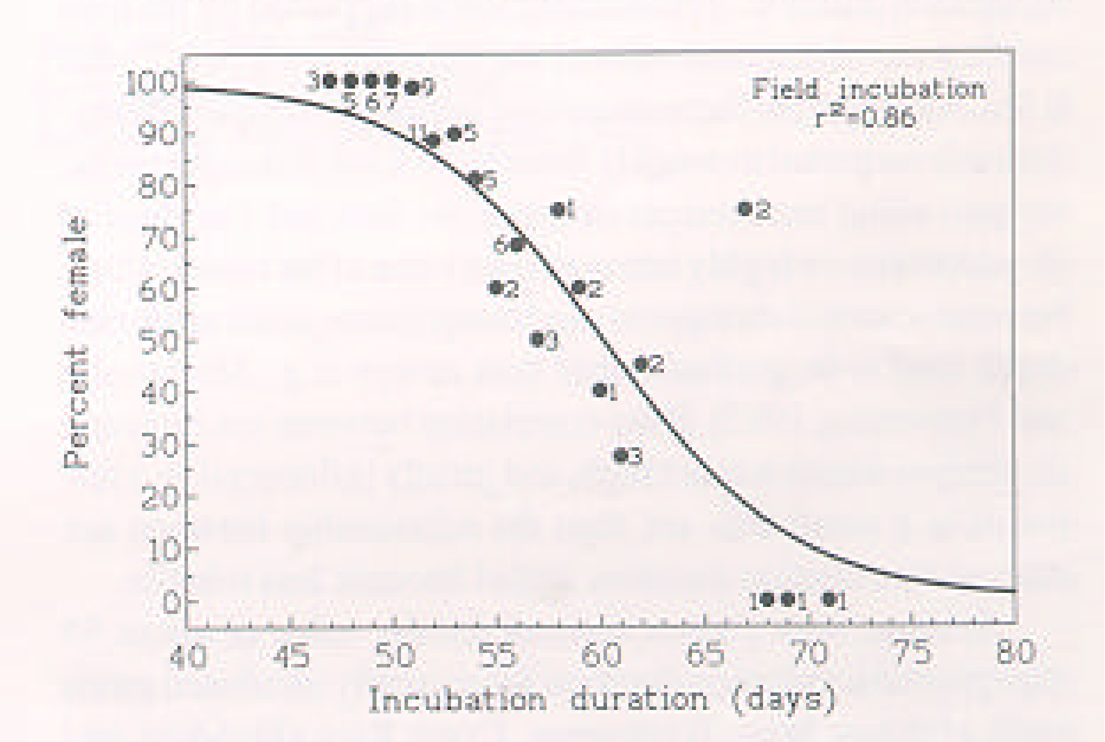


Figure 1.3: Godfrey and Mrosovsky (1997) found that natural loggerhead sex ratios corresponded to incubation duration. A sigmoidal curve was fit to data from natural loggerhead nests laid on United States beaches (Godfrey and Mrosovsky, 1997). Godfrey and Mrosovsky (1997) identified the pivotal incubation duration (50% females) as about 60 days. Figure copied from Godfrey and Mrosovsky (1997).

Incubation period is related to ambient sand temperature. There is an inverse relationship between incubation temperature and incubation duration of loggerhead eggs (Godfrey and Mrosovsky, 1997). Higher daily temperatures correlate to shorter incubation lengths, while lower temperatures correlate to longer incubation lengths. Studies show that incubation period length can be used to estimate sex ratios of hatchlings (Mrosovsky, 1988). Using natural United States field nests, Godfrey and Mrosovsky (1997) found the pivotal incubation duration (50% females) to be 60 days (Figure 1.3). Incubation durations below 60 days favor females, and incubation durations over 60 days favor male production (Godfrey and Mrosovsky, 1997; Figure 1.3).

Additionally, inhibited gas exchange (e.g. $O_2$) and increased $CO_2$ levels may prolong incubation durations (Dodd, 1988).

### 1.4.2.5 Factors Influencing Embryonic Development

I. Incubation Temperature

Loggerhead embroyonic development is correlated to incubation temperature – the temperature at which eggs develop. Loggerhead hatching success is maximized at incubation temperatures ranging from 25$^{o}$C to 32$^{o}$C (Nelson, 1988). North Carolina incubation temperatures range from about 28$^{o}$C to 32$^{o}$C (Nelson, 1988). Incubation temperatures less than 24$^{o}$C or greater than 34$^{o}$C are lethal to loggerhead eggs (Nelson, 1988).

II. Metabolic Heat

The amount of metabolic heat produced by metabolic processes associated with egg incubation gradually increases during the first five weeks and sharply increases during the following five to eight weeks (Maloney et al, 1990). At pipping (the process of a hatchling cutting through its egg shell), the metabolic heat sharply declines (Moran et al, 1999).

III. Water

Loggerhead eggs contain water at the time of oviposition; water is stored in the albumen. A sea turtle egg will exchange water with the external environment (Ackerman, 1984). The optimal nest environment is humid (Ackerman, 1997).

IV. Gas Exchange

A female loggerhead constructs the egg chamber to equalize the exchange of gas (carbon dioxide and oxygen) between all the eggs in clutch and the surrounding sand (Dodd, 1988). Gas exchange is influenced by egg mass and by incubation time (Ackerman, 1981).

Oxygen consumption occurs through the entire incubation period (Ackerman, 1981) and increases sigmoidally during incubation (Dodd, 1988). Oxygen uptake is influenced greatly by egg mass and inversely by incubation time (Ackerman, 1981). Oxygen consumption increases rapidly during the second half of the incubation period and slows prior to pipping (Dodd, 1988). However, the maximum oxygen uptake per day occurs prior to hatching (Ackerman, 1981).

### 1.4.3 Hatching Biology

#### 1.4.3.1 Hatching Process

The hatching process begins at the end of the incubation period when a hatchling begins pipping with its caruncle (egg tooth). The caruncle is an extension of the upper jaw that falls off soon after hatching (Miller, 1997, Dodd 1988). Once the baby ruptures the eggshell, it begins to tear the shell so that the allantoic, albumen and amnionic fluids can spill out and drain away. Air fills the space formally consumed by the fluids (Miller, 1997). Upon exiting the egg, a hatchling’s carapace is curled, but begins to flatten; the flattening process internalizes the remaining yolk sac and takes about 26.6 hours to complete (Miller, 1997 and Dodd, 1988).

Once the carapace has flattened, the hatchling begins to dig towards the beach surface. Hatchlings work together to reach the surface. A large volume is created when a clutch hatches that allows the hatchlings to crawl past one another. Hatchlings work together to move the nest chamber upward through periodic outbursts of scrapping sand from the edges of the nest (Miller, 1997, Dodd 1988). The depth of the egg chamber floor decreases as sand falls between the digging hatchlings to the egg chamber bottom (Miller, 1997).

The upward digging process is a negative geo-taxis (Dodd, 1988) and is usually stimulated by the hatchling activity in the bottom of the chamber. The stimulation has been termed social facilitation (Miller, 1997). The hatchlings perform anaerobic metabolism during the emergence process (Dodd, 1988). At regular intervals during the digging up time, hatchlings switch from periods of activity to bouts of rest, largely in response to the increase in lactate levels in the blood (Kraemer and Bennett, 1981).

#### 1.4.3.2 Hatchling Emergence

The loggerhead hatching process precedes emergence by an average of 4 days (Godfrey and Mrosovsky, 1997). As hatchlings reach the surface of the sand they encounter greater variation in surface ambient temperature. Hatching activity decreases with an increase in sand temperature (Dodd, 1988); warm sand temperatures inhibit the digging process (Moran et al, 1999). Sea turtle biologists think the timing of emergence is cued by changes in ambient sand temperature, but the exact process by which this occurs is not fully understood (Gyuris, 1993, Moran et al, 1999).

Loggerhead hatchling emergence usually occurs between the hours of 9 PM and 2 AM, when sand temperatures and the land-based predation risk are at the lowest. Some hatching may occur during the early morning or late afternoon, usually associated with cool, cloudy and/or rainy days (Miller, 1997). Usually emergence involves hatchlings simultaneously exiting from the nest, although there are exceptions to this (Houghton and Hays, 2001). Emergence occurs when hatchlings at the top of the nest are pushed above the surface by hatchlings underneath (Dodd, 1988).

In some instances individuals will emerge prior to the main clutch emerging or stragglers will emerge from a nest well after the main clutch has emerged. Sometimes stragglers will not emerge for a couple of nights (Dodd, 1988).

At the time of emergence, hatchlings weigh about 20 grams (Miller, 1997) and have a carapace length of about 4.5 cm (Nelson, 1988).

After emerging hatchlings usually crawl rapidly down the beach towards the water (Dodd, 1988). On occasion, hatchlings become disoriented by artificial nighttime lighting, and wander into sand dunes where they are more likely to desiccate or be preyed upon (Witherington and Bjorndal, 1991). Once in the water, hatchlings begin a swimming frenzy phase, a period of high activity that involves hatchlings swimming offshore (Wyneken and Salmon, 1992).

### 1.4.4 Measuring Reproductive Success

Reproductive success can be determined by calculating emergence success and hatching success. Hatching success is often 1% or greater than emergence success (Miller, 1999).

#### 1.4.4.1 Hatching Success

Hatching success, which is the proportion of hatchlings that hatch from their egg shells, is calculated as the following:

$$(ES)/(ES+UH+PE)$$

where ES is the number of empty shells (comprised of an egg > 50%), UH is the number of unhatched eggs remaining in the nest, and PE is the number of pipped eggs with dead hatchlings (Miller, 1999).

Sand particle size can play a major role in hatching success. Sand that is too fine or too coarse will cause a decline in hatching success (Mortimer, 1982). Hatching success is maximized in sand with particles measuring 0.25 mm to 0.125 mm (Dodd, 1988). Hatching success decreases when gas exchange is inhibited by sand particles measuring outside this range (Nelson, 1988).

Hatching success is minimized by other abiotic factors, such as erosion, tidal inundation, nest flooding, heavy rains, thermal stress, and nest density (National Research Council, 1990).

Many biotic factors lower hatching success; these factors include predation of eggs, parasites and diseases, and egg loss via root invasion of the nest (National Research Council, 1990).

#### 1.4.4.2 Emergence Success

Emergence success, which is the number hatchlings that reach the beach surface, is calculated as the following:

$$(ES-LH-DH)/(ES+UE+DE)$$

where ES is the number of empty shells, LH is the number of live hatchlings, DH is the number of dead hatchlings remaining in the nest chamber, UE is the number of unhatched eggs remaining in the nest, and DE is the number of depredated eggs (nearly complete shells containing egg residue) (Miller, 1999).

Emergence success is relatively high (greater than 80%) unless biotic factors, such as predation, or abiotic factors intervene (Miller, 1995).

## 1.5 A Conservation and Management Option Used in North Carolina: *Nest Relocation*

### 1.5.1 Introduction to Nest Relocation in North Carolina

Presently, a network of volunteers monitors and protects loggerhead nests laid on North Carolina beaches. Although volunteers are encouraged to allow nest incubation to proceed naturally and with minimal intervention, some volunteers will relocate freshly laid nests that are threatened by possible inundation by high tides, heavy beach traffic, or under a sloughing escarpment. The average number of nests moved on North Carolina beaches each year approaches 40-60 percent, which suggests that the volunteers are overestimating the potential threat (Godfrey, 2002).

### 1.5.2 Description of the Nest Relocation Procedure Used in North Carolina

#### 1.5.2.1 When to Move a Nest

The *Handbook for Sea Turtle Volunteers in North Carolina* (NEWP, 1997) states that nests should be moved only when one of the following situations is present:

(1) "The nest is laid in an area subject to heavy beach traffic, either foot or vehicular traffic (NEWP, 1997)."

(2) "The nest is below the average high tide line where regular inundation will result in embryonic mortality (NEWP, 1997)."

(3) "The nest is laid under a sloughing escarpment and is subject to being buried too deeply (NEWP, 1997)."

#### 1.5.2.2 How to Relocate a Nest

Appendix E contains the NC Sea Turtle Protection Program nest relocation protocol found in the *Handbook for Sea Turtle Volunteers in North Carolina* (NEWP, 1997).

## 1.6 Evaluating Nest Relocation as a Management Technique Used in North Carolina

### 1.6.1 Background: *Assessments of Nest Relocation*

Nest relocation can have negative effects even if the sea turtle protection program volunteers carefully excavate the nests, move the eggs, and rebury the eggs (Witherington, 1999). Nest relocation may reduce hatching success, alter incubation duration (so altering sex ratios) (see Section 1.4.2.4), and reduce hatchling fitness (Witherington, 1999). Thus an evaluation of hatching success and incubation duration at North Carolina nesting areas under the protection of the North Carolina Sea Turtle Protection Program is warranted.

Assessments of positive and negative impacts of nest relocation traditionally are superficial. Normally, comparisons of hatching success are made between relocated nests and *in-situ* nests (nests left in place). The comparison is not fair, since ideally the control group should include nests, which normally would be relocated, but actually remained in place. Also, most analyses look at hatching success over an entire season, and do not attempt to look at seasonal changes in hatching success, which may bias an overall comparison between management techniques. Finally, few analyses use other variables such as incubation duration (a sex-ratio indicator) in comparing the impacts of nest relocation (Godfrey, 2002).

### 1.6.2 Objective: *Evaluate the Management Technique of Loggerhead Sea Turtle Nest Relocation in North Carolina*

My objective for the evaluation was to assess statistically the management technique of loggerhead sea turtle nest relocation in North Carolina between 1997 and 2001. To make a fair assessment and examine the impacts of nest relocation, I looked for differences in hatching success and incubation duration among *in-situ* nests, relocated nests, and a control group (*in-situ* nests affected by inundation by high tides).

I compared hatching success and incubation duration among the three nest categories over the entire nesting season, and investigated for significant seasonal changes. Also, I investigated nest relocation rates, and looked for significant seasonal changes in relocation rates.

My last goal was to formulate a series of nest relocation recommendations.

## 2.0 Methods

### 2.1 Data Source

The North Carolina Sea Turtle Protection Program (see Section 1.3.2) supplied the data for the evaluation. The source of data was North Carolina annual nesting reports from 1997 to 2001 (Section 2.2 and 2.4).

### 2.2 Data Description

The data for the evaluation included northwestern Atlantic loggerhead sea turtle nesting activity data for the years 1997 to 2001. The nesting data were collected by North Carolina Sea Turtle Protection Program monitoring employees and volunteers at Bald Head Island, Cape Hatteras National Seashore, Cape Lookout National Seashore, and Topsail Island (Section 2.3). I used these four high density North Carolina nesting areas in the analysis to ensure large sample sizes.

The evaluation assessed hatching success, incubation duration, and relocation rates, with the following variables from the nesting activity data: sea turtle species type; nest number; nesting area; nesting date; date of first hatchling emergence; nest treatment; reason for nest relocation; number of washout days (the number of days a nest was inundated by a tide (2000 and 2001 only)); reason(s) for egg loss (if any); and reason(s) for nest loss (if any). Tidal inundation is a possible reason for egg and nest loss. The data set also included nest inventory data. The inventory data included the following: ES, which is the total number of whole eggshells (> 50%); UH, which is the number of unhatched eggs (unhatched eggs plus pipped eggs with dead hatchlings); DH, which is the number of dead hatchlings in the nest cavity that emerged from eggs (2000 and 2001 only); and LH, which is the number of live hatchlings that emerged from eggs, but did not leave the nest (2000 and 2001 only) (Nongame and Endangered Wildlife Program, 1998).

### 2.3 Description of the Nesting Areas Used in the Analysis

The four nesting areas used in the evaluation are located in North Carolina (Figure 2.1).

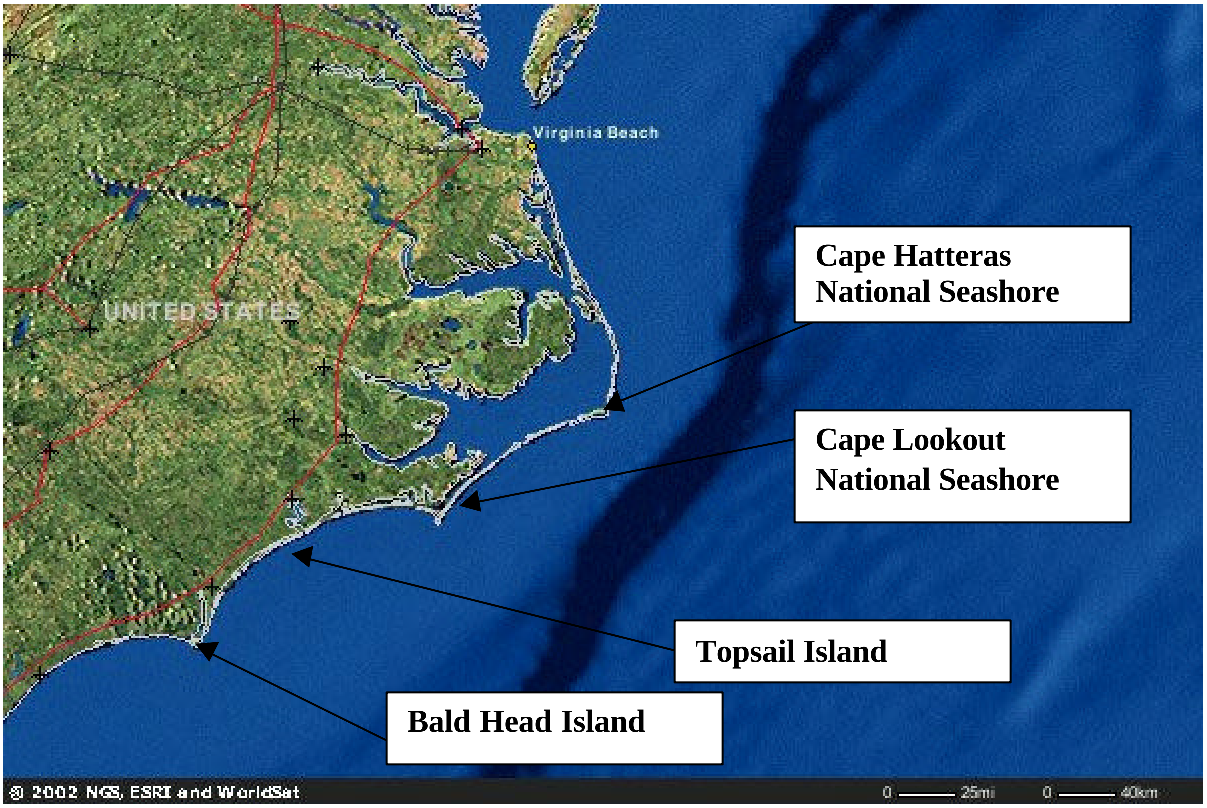


Figure 2.1: Coastal North Carolina – Cape Hatteras National Seashore, NC to Bald Head Island, NC (National Geographic, 2003). Appendix A contains site maps with a detailed picture of nesting beaches and zones.

The Bald Head Island loggerhead nesting area consists of ten miles of beaches (Appendix A, Figure A.2) (Bald Head Island Conservancy, 2003). Bald Head Island, the northern most subtropical island on the Atlantic Coast, is located two nautical miles off the coat of North Carolina at the mouth of the Cape Fear River (Bald Head Island Conservancy, 2003). The northern range of the nesting area is New Inlet and the southern range is the Cape Fear River (NEWP, 1997).

The Cape Hatteras National Seashore nesting area consists of 55 miles of beaches stretching across Hatteras Island and Ocracoke Island (Appendix A, Figure A.1) (NPS, 1999). The nesting area extends from Hatteras Inlet in the north to Ocracoke Inlet in the south (NEWP, 1997). The nesting area does not include Pea Island National Wildlife Refuge (NPS, 1999).

The Cape Lookout National Seashore nesting area consists of beaches ranging across North Core Banks, South Core Banks, and Shackleford Banks (Appendix A, Figure A.3). The northernmost island, North Core Banks is about 19 miles long, and extends from Ocracoke Inlet to New Drum Inlet (NEWP, 1997, NPS 2001). South Core Banks extends southward from New Drum Inlet to the Cape Barden Inlet (NEWP, 1997). Shackleford Banks is 9 miles long, and also part of the national park (NPS, 2001).

The Topsail Island nesting area consists of a 25-mile stretch of beaches along the barrier island (Appendix A, Figure A.2). The northern range of the nesting area is New River Inlet and the southern range is New Topsail Inlet (NEWP, 1997).

### 2.4 Data Collection Method

Appendix B contains a copy of the instructions that nest monitoring employees and volunteers use for completing North Carolina’s annual nesting activity report. The instructions are copied from the NC Volunteer Sea Turtle Handbook (NEWP, 1997, NEWP, 1998).

### 2.5 Data Analysis

For each year (1997 to 2001), I evaluated the impacts of nest relocation on each nesting area (Bald Head Island, Cape Hatteras National Seashore, Cape Lookout National Seashore, and Topsail Island) with the procedures detailed in Section 2.5.1 to 2.5.7.

### 2.5.1 Nest Categories

I assigned each nest into one of three nest categories – I, R, or C. Category I nests were *in-situ* (not relocated) and not affected by tidal inundation. Nests in category R were relocated (or moved to another area on the beach). And, category C nests were *in-situ*, and affected by at least one day of inundation (over-wash) by high tides. In other words, Category C nests, the control group, were nests that should have been relocated under the current nest relocation protocol because they were affected by inundation by high tides.

If a nest had an unknown relocation status or unknown hatching success (relocation status or hatching success not identified by data; Section 2.1), I eliminated it from the analysis.

### 2.5.2 Calculating Hatching Success

Hatching Success, which is the proportion of hatchlings that hatch from their egg shells, was calculated using the equation from Section 1.4.4.1:

$$(ES)/(ES+UH+PE)$$

where ES is the number of empty egg shells (comprised of an egg > 50%) and UH is the number of unhatched eggs remaining in the nest, and PE is the number of pipped eggs with dead hatchlings (Miller, 1999).

Hatching success was calculated for both successful and unsuccessful nests. Nest that were completely destroyed during the nesting season before any hatchling emergence commenced were assigned a hatching success of zero (0% hatching success).

### 2.5.3 Comparing Hatching Success among each Nest Category

I compared hatching success portions among each nest category – I, R, and C – for the entire nesting season. I also portioned the nesting season into three separate parts, and compared hatching success among each nest category to account for significant seasonal changes. Part one of the nesting season consisted of the nests laid on May 1 to June 21 (Early Season), part two consisted of the nests laid on June 22 to July 21 (Middle Season), and part three consisted of the nests laid on July 22 to September 30 (Late Season).

I used a Kolmogorov-Smirnov test to examine normality of hatching success portions. Nonparametric tests, Kruskal Wallis one-way analysis of variance (ANOVA) and Mann-Whitney rank sum test, were used to analyze hatching success proportions among nest categories. Kruskal Wallis ANOVAs were used when three nest categories, each containing five or more nests with few ties, were available for analysis. Where statistical differences were found, post hoc analysis using Dunn's test was performed to identify the nest categories involved. Mann Whitney rank sum tests were used to look for significant differences when only two nest categories, each containing five or more nests with few ties in hatching success, were available for analysis. The rejection level for the null hypothesis in all statistical tests was a = 0.05.

### 2.5.4 Estimating Incubation Duration

I used methods similar to those used in Godfrey and Mrosovsky (1997) to estimate incubation duration (Section 1.4.2.4). I defined incubation duration in nests as the number of days between the date laid (day 0) and the date of first emergence – the date when the first hatchling emerged from the nest (Godfrey and Mrosovsky, 1997). Therefore, I estimated incubation duration for each nest using the equation:

$$\text{Nest Laying Date} - \text{First Emergence Date}$$

where nest laying date is the date on which the nest was laid by a female and first emergence date is the date on which the first hatchling emerged from the nest.

Incubation length could only be calculated for successful nests with both a recorded nest laying date and first emergence date. Unsuccessful nests were not included in the analysis because no hatchling emergence occurred.

### 2.5.5 Comparing Estimated Incubation Lengths among each Nest Category

I compared incubation duration among each nest category – I, R, and C – for the entire nesting season. I also portioned the nesting season into three separate parts, and compared incubation duration among each nest category to account for significant seasonal changes. Part one of the nesting season consisted of the nests laid on May 1 to June 21 (Early Season), part two consisted of the nests laid on June 22 to July 21 (Middle Season), and part three consisted of the nests laid on July 22 to September 30 (Late Season).

I used a Kolmogorov-Smirnov test to examine normality of incubation duration. Nonparametric tests, Kruskal Wallis ANOVA and Mann-Whitney rank sum test, were used to analyze incubation duration among nest categories. Kruskal Wallis ANOVAs were used when three nest categories, each containing five or more nests with few ties, were available for analysis. Where statistical differences were found, post hoc analysis with Dunn's test was performed to identify the nest categories involved. Mann Whitney rank sum tests were used to look for significant differences when only two nest categories, each containing five or more nests with few ties in incubation duration, were available for analysis. The rejection level for the null hypothesis in all statistical tests was $a = 0.05$.

### 2.5.6 Examining Rates of Nest Relocation across a Season

I examined seasonal changes in relocation rates. To do this, I divided the nesting season into three separate parts to account for significant seasonal changes. Part one of the nesting season consisted of the nests laid on May 1 to June 21 (Early Season), part two consisted of the nests laid on June 22 to July 21 (Middle Season), and part three consisted of the nests laid on July 22 to September 30 (Late Season).

Next I calculated the relocation rate, or proportion of nests relocated, for the portioned nesting season using the equation:

Number of Nests Relocated / Total Number of Nests

where number of nests relocated was the number nests relocated during the period and total number of nests was the number of nests laid during the portion of the nesting season.

To investigate for significant seasonal changes in relocation rates, I performed chi-square analysis, and compared the observed number of relocated nests to the expected number of relocated nests.  The rejection level for the null hypothesis in all statistical tests was a = 0.05.

### 2.5.7 Statistical Packages

I used Microsoft Excel 2000, Analyze-it, and Sigma Stat to perform the data analysis.

## 3.0 Results

*Table 3.1: Percentage of all loggerhead (Caretta caretta) nests affected by at least one high tide event. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.*

| **Beach** | **Year** | **Nest Type** | **Number of Nests** | **Percentage of All Nests Affected by High Tides (%)** | **Percentage of Nests Affected by High Tides with No Hatching Success (%)** |
|---|---|---|---|---|---|
| BHIC | 1997 | *In-situ* | 21 | 0 | 0 |
| | | Relocated | 52 | 1.9 | 0 |
| CHNS | 1997 | *In-situ* | 6 | 16.7 | 100 |
| | | Relocated | 31 | 3.2 | 100 |
| CLNS | 1997 | *In-situ* | 23 | 13.0 | 100 |
| | | Relocated | 92 | 4.3 | 0 |
| TBVO | 1997 | *In-situ* | 53 | 1.9 | 100 |
| | | Relocated | 11 | 0 | 0 |
| BHIC | 1998 | *In-situ* | 45 | 64.4 | 96.6 |
| | | Relocated | 41 | 78.0 | 78.2 |
| CHNS | 1998 | *In-situ* | 23 | 22.7 | 76.7 |
| | | Relocated | 66 | 7.6 | 59.2 |
| CLNS | 1998 | *In-situ* | 74 | 60.8 | 64.5 |
| | | Relocated | 114 | 36.0 | 16.9 |
| TBVO | 1998 | *In-situ* | 55 | 65.5 | 97.1 |
| | | Relocated | 44 | 70.5 | 80.6 |
| BHIC | 1999 | *In-situ* | 42 | 54.8 | 100 |
| | | Relocated | 64 | 39.1 | 95.9 |
| CHNS | 1999 | *In-situ* | 32 | 53.1 | 94.2 |
| | | Relocated | 54 | 55.6 | 59.9 |
| CLNS | 1999 | *In-situ* | 113 | 48.7 | 79.9 |
| | | Relocated | 124 | 41.9 | 88.5 |
| TBVO | 1999 | *In-situ* | 86 | 46.5 | 90.1 |
| | | Relocated | 86 | 52.3 | 73.4 |
| BHIC | 2000 | *In-situ* | 22 | 26.1 | 33.3 |
| | | Relocated | 19 | 31.6 | 83.2 |
| CHNS | 2000 | *In-situ* | 50 | 54.0 | 70.4 |
| | | Relocated | 25 | 24.0 | 66.7 |
| CLNS | 2000 | *In-situ* | 68 | 32.4 | 9.0 |
| | | Relocated | 119 | 15.1 | 22.5 |
| TBVO | 2000 | *In-situ* | 67 | 3.0 | 0 |
| | | Relocated | 33 | 6.1 | 49.2 |
| BHIC | 2001 | *In-situ* | 45 | 53.3 | 41.7 |
| | | Relocated | 30 | 30.0 | 11.0 |
| CHNS | 2001 | *In-situ* | 39 | 89.7 | 54.3 |
| | | Relocated | 28 | 64.3 | 33.3 |
| CLNS | 2001 | *In-situ* | 57 | 22.8 | 38.6 |
| | | Relocated | 58 | 13.8 | 24.6 |
| TBVO | 2001 | *In-situ* | 32 | 0 | 0 |
| | | Relocated | 46 | 0 | 0 |

## 3.1 Evaluation of Hatching Success

*Table 3.2: Entire season and seasonal comparisons of median hatching success among loggerhead (Caretta caretta) nests (in-situ (I), relocated (R), and in-situ – affected by tidal inundation (C)). BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.* (*****) *= Significant difference between testable nest categories (two-sided $p<0.05$) (See Appendix C for p-values). Not enough nests for evaluation, TMT = Too many ties)*

| Beach | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|
| | | | **Entire Season** | | |
| BHIC | I>R | I>R* | I>R* | I>R*, R<C, I>C | I>R, R>C*, I>C* |
| CHNS | I<R | I>R | I>R* | I>R, R>C*, I>C* | R>C* |
| CLNS | I>R | I<R | I>R* | I<R, R<C, I<C | I>R, R>C*, I>C* |
| TBVO | I<R | I>R* | I>R* | I>R* | I>R |
| | | | **Early Season** | | |
| BHIC | I<R | I>C | I<R | I>R* | I>R |
| CHNS | NEN | I>R | I<R | I<R | R>C |
| CLNS | NEN | I<R | I>R | I<R, R>C, I<C | I<R |
| TBVO | NEN | I>R | I>R | I>R | I>R |
| | | | **Middle Season** | | |
| BHIC | I>R | TMT | I>R* | I>R | I>R*, R>C, I>C* |
| CHNS | NEN | I>R | I>R* | I>R, R>C*, I>C* | R>C* |
| CLNS | I>R | I<R | I>R | I>R, R<C, I<C | I<R |
| TBVO | I<R | TMT | I>R | I>R | I>R |
| | | | **Late Season** | | |
| BHIC | I<R | TMT | TMT | NEN | R>C |
| CHNS | NEN | NEN | TMT | I>C | NEN |
| CLNS | I>R | TMT | TMT | I<R, R>C, I>C | I>R, R>C, I>C* |
| TBVO | NEN | TMT | TMT | I<R | I>R |

### 3.1.1 Hatching Success: 1997

#### 3.1.1.1 Bald Head Island (1997)

High tides inundated none of Bald Head Island's *in-situ* nests, but inundated 1.9% of the island's relocated nests (Table 3.1).

Entire season median hatching success (median proportion of successfully hatched eggs) was greater in *in-situ* nests than in relocated nests (Figure 3.1; Table 3.2; Table D.1). A Mann-Whitney rank sum test showed no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.1; Rank sum test statistic = 731.50 and two-sided p = 0.583).

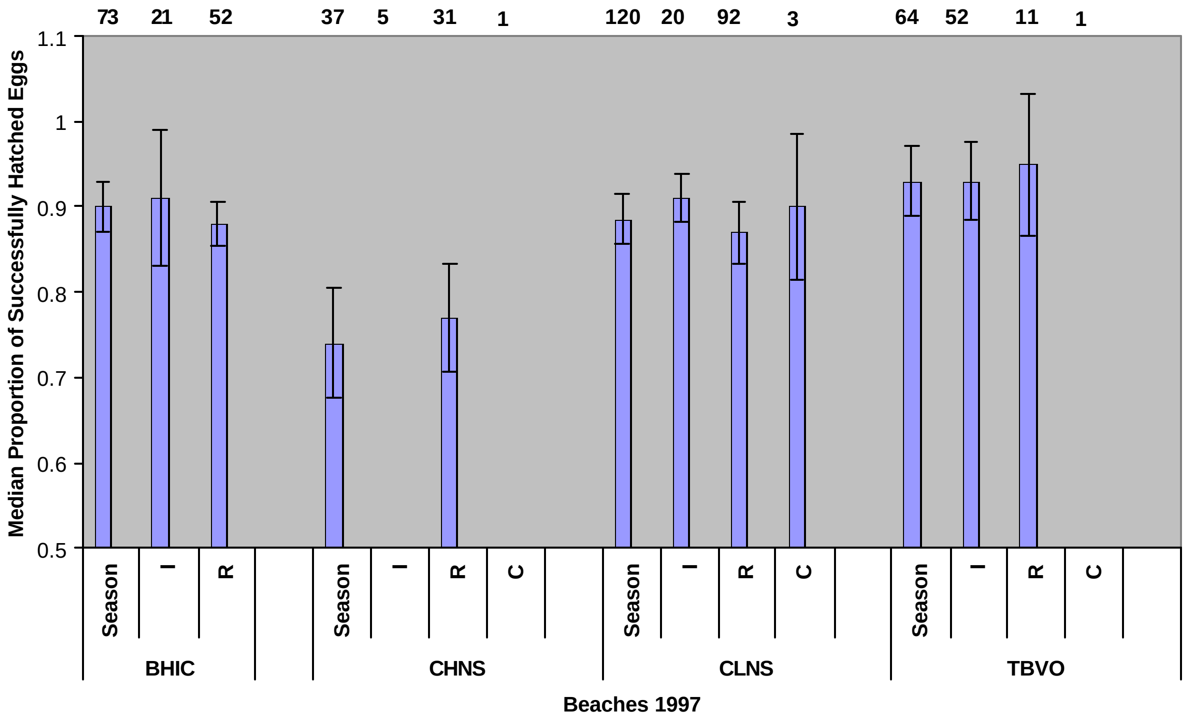


Figure 3.1: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of the median proportion of successfully hatched eggs in 1997. Error bars indicate standard error. The numbers on the top axis indicate the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.1.1.2 Cape Hatteras National Seashore (1997)

High tides inundated 16.7% of Cape Hatteras National Seashore's *in-situ* nests and 3.2% of nesting area's relocated nests (Table 3.1). No hatching success resulted in all of the *in-situ* nests and in all of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in relocated nests than in *in-situ* nests (Figure 3.1; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.1; Rank sum test statistic = 68.50 and two-sided p = 0.282). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.1; Table 3.1; Table D.1).

#### 3.1.1.3 Cape Lookout National Seashore (1997)

High tides inundated 13% of Cape Lookout National Seashore's *in-situ* nests and 4.3% of the national seashore's relocated nests (Table 3.1). No hatching success resulted in all of the *in-situ* nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.1; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.1; Rank sum test statistic = 1750.50 and two-sided p = 0.067). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.1; Table 3.1; Table D.1).

#### 3.1.1.4 Topsail Island (1997)

High tides inundated 1.9% of Topsail Island's *in-situ* nests and none of the nesting area's relocated nests (Table 3.1). No hatching success resulted in all of the *in-situ* nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in relocated nests than in *in-situ* nests (Figure 3.1; Table 3.2; Table D.1). A Mann-Whitney rank sum test indicated no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.1; Rank sum test statistic = 384.50 and two-sided p = 0.562). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.1; Table 3.1; Table D.1).

### 3.1.2 Hatching Success: 1998

#### 3.1.2.1 Bald Head Island (1998)

High tides inundated 64.4% of Bald Head Island's nests and 78% of the island's relocated nests (Table 3.1). No hatching success resulted in 96.6% of the *in-situ* nests and 78.2% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.2; Table 3.2; Table D.1). A Mann-Whitney rank sum test showed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.2; Rank sum test statistic = 1750.50 and two-sided p <0.001). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.2; Table D.1).

#### 3.1.2.2 Cape Hatteras National Seashore (1998)

High tides inundated 22.7% of Cape Hatteras' *in-situ* nests and 7.6% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 76.6% of the *in-situ* nests and 59.2% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.2; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.2; Rank sum test statistic = 802.00 and two-sided p = 0.323). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.2; Table D.1).

#### 3.1.2.3 Cape Lookout National Seashore (1998)

High tides inundated 60.8% of Cape Lookout's *in-situ* nests and 36% of the national seashore's relocated nests (Table 3.1). No hatching success resulted in 64.5% of the *in-situ* nests and 16.9% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in relocated nests than in *in-situ* nests (Figure 3.2; Table 3.2; Table D.1). A Mann-Whitney rank sum test indicated no significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.2; Rank sum test statistic = 1956.00 and two-sided p = 0.509). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.2; Table D.1).

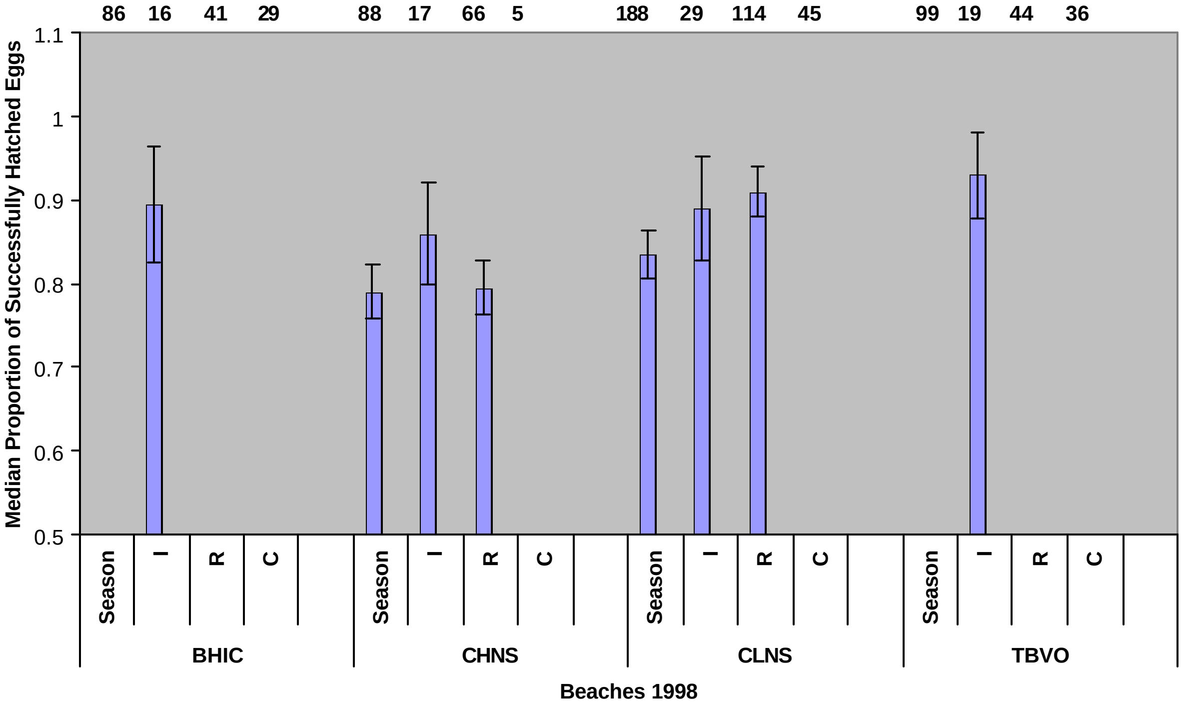


Figure 3.2: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of the median proportion of successfully hatched eggs in 1998. Error bars indicate standard error. The numbers on the top axis indicate the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.1.2.4 Topsail Island (1998)

High tides inundated 65.5% of Topsail's *in-situ* nests and 70.5% of the island's relocated nests (Table 3.1). No hatching success resulted in 97.1% of the *in-situ* nests and 80.6% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.2; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.2; Rank sum test statistic = 905.50 and two-sided p <0.001). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.2; Table D.1).

### 3.1.3 Hatching Success: 1999

#### 3.1.3.1 Bald Head Island (1999)

High tides inundated 54.8% of Bald Head Island's *in-situ* nests and 39.1% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in all of the *in-situ* nests and 95.5% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.3; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.3; Rank sum test statistic = 1028.00 and two-sided p = 0.013). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.3; Table D.1).

#### 3.1.3.1 Cape Hatteras National Seashore (1999)

High tides inundated 53.1% of Cape Hatteras' *in-situ* nests and 55.6% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 94.2% of the *in-situ* nests and 59.9% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.3; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.3; Rank sum test statistic = 759.00 and two-sided $p < 0.001$). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.3; Table D.1).

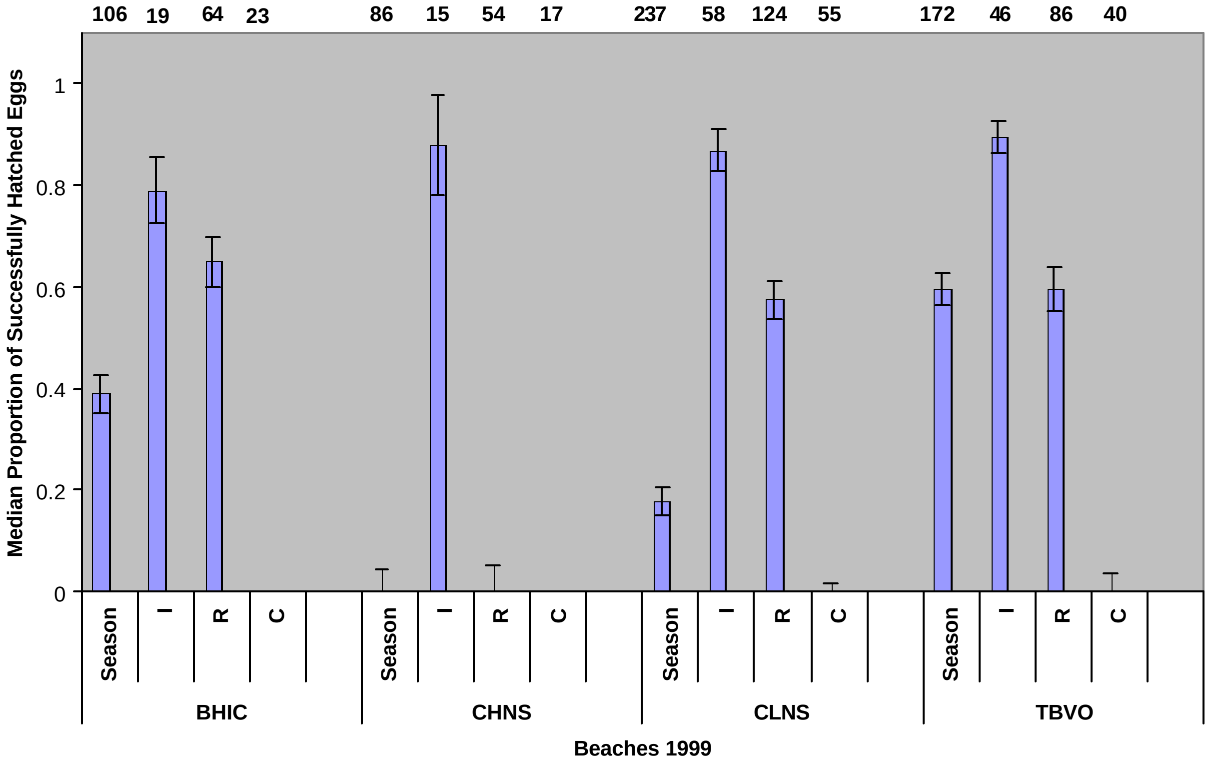


Figure 3.3: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of the median proportion of successfully hatched eggs in 1999. Error bars indicate standard error. The numbers on the top axis indicate the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.1.3.3 Cape Lookout National Seashore (1999)

High tides inundated 48.7% of the national seashore's *in-situ* nests and 41.9% of the area's relocated nests (Table 3.1). No hatching success resulted in 79.9% of the *in-situ* nests and 88.5% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.3; Table 3.2; Table D.1). A Mann-Whitney rank sum test revealed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.3; Rank sum test statistic = 6679.50 and two-sided p <0.001). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.3; Table D.1).

#### 3.1.3.4 Topsail Island (1999)

High tides inundated 46.5% of Topsail's *in-situ* nests and 52.3% of the island's relocated nests (Table 3.1). No hatching success resulted in 90.1% of the *in-situ* nests and 73.4% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.3; Table 3.2; Table D.1). A Mann-Whitney rank sum test showed a significant difference between hatching success in *in-situ* nests and relocated nests (Table 3.2; Table C.3; Rank sum test statistic = 4035.50 and two-sided p <0.001). Control nests were excluded from the analysis because the nest category contained too many ties of no hatching success (Figure 3.3; Table D.1).

### 3.1.4 Hatching Success: 2000

#### 3.1.4.1 Bald Head Island (2000)

High tides inundated 26.1% of Bald Head Island's *in-situ* nests and 31.6% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 33.3% of the *in-situ* nests and 83.2% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in both relocated nests and control nests (Figure 3.4; Table 3.2; Table D.1). Control nests had greater median hatching success than relocated nests (Figure 3.4; Table D.1). A Kruskal-Wallis one-way analysis of variance (ANOVA) revealed a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.4; Kruskal-Wallis test statistic = 8.111, d.f. = 2, and two-sided p = 0.017). Dunn's test only identified a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests (Table 3.2; Table C.4).

Early season median hatching success was greater in *in-situ* nests than in early season relocated nests (Figure 3.4; Table 3.2; Table D.2). A Mann-Whitney rank sum test revealed a significant difference between early season hatching success in *in-situ* nests and early season hatching success in relocated nests (Table 3.2; Table C.4; Rank sum test statistic = 74.00 and two-sided p = 0.004). Control nests were excluded from the analysis because the nesting area had less than five nests during the early season that fit the control nest criteria (Figure 3.4; Table D.2).

#### 3.1.4.2 Cape Hatteras National Seashore (2000)

High tides inundated 54% of the national seashore's *in-situ* nests and 24% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 70.4% of the *in-situ* nests and 66.7% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* than in both relocated and control nests (Figure 3.4; Table 3.2; Table D.1). Reloacted nests had greater median hatching success than control nests (Figure 3.4; Table 3.2; Table D.1). A Kruskal-Wallis ANOVA revealed a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.4; Kruskal-Wallis test statistic = 20.343, d.f. = 2, and two-sided p <0.001). Dunn's test identified a significant difference between hatching success in *in-situ* nests and hatching success in control nests, as well as, between hatching success in relocated nests and hatching success in control nests (Table 3.2; Table C.4).

Middle season median hatching success was greater in *in-situ* nests than in middle season relocated nests and middle season control nests (Figure 3.4; Table 3.2; Table D.2). Relocated nests had greater median hatching success than control nests (Figure 3.4; Table 3.2; Table D.2). A Kruskal-Wallis ANOVA revealed a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.4; Kruskal-Wallis test statistic = 18.751, d.f. = 2, and two-sided p <0.001). Dunn's test identifed a significant difference between hatching success in *in-situ* nests and hatching success in control nests, as well as, between hatching success in relocated nests and hatching success in control nests (Table 3.2; Table C.4).

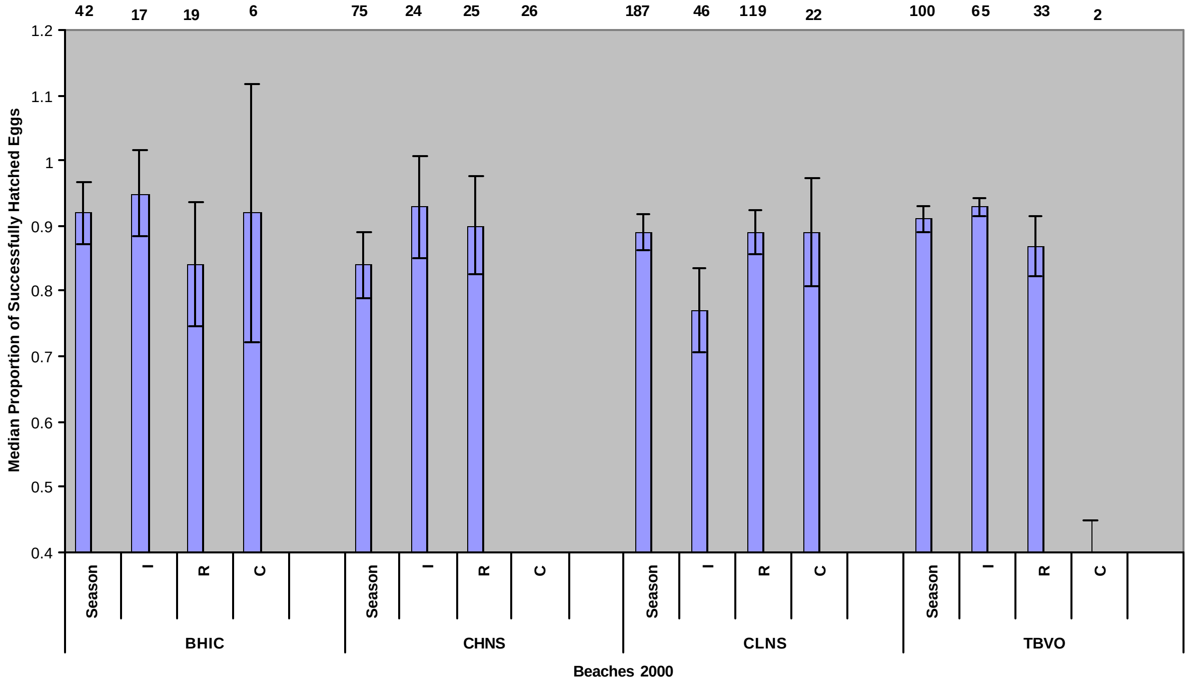


Figure 3.4: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), control (C)) of the median proportion of successfully hatched eggs in 2000. Error bars indicate standard error. The numbers on the top axis indicate the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

#### 3.1.4.3 Cape Lookout National Seashore (2000)

High tides inundated 32.4% of the Cape Lookout's *in-situ* nests and 15.1% of the national seashore's relocated nests (Table 3.1). No hatching success resulted in 9% of the *in-situ* nests and 22.5% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in control nests than in both *in-situ* nests and relocated nests (Figure 3.4; Table 3.2; Table D.1). Relocated nests had greater median hatching success than *in-situ* nests (Figure 3.4; Table 3.2; Table D.1). A Kruskal-Wallis ANOVA showed no significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.4; Kruskal-Wallis test statistic = 1.985, d.f. = 2, and two-sided p = 0.371).

#### 3.1.4.4 Topsail Island (2000)

High tides inundated 3% of Topsail Island's *in-situ* nests and 6.1% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 49.2% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.4; Table 3.2; Table D.1). A Mann-Whitney rank sum test indicated a significant difference between *in-situ* nests and relocated nests (Table 3.2; Table C.4; Rank sum test statistic = 1320.00 and two-sided p = 0.019). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.4; Table D.2).

### 3.1.5 Hatching Success: 2001

#### 3.1.5.1 Bald Head Island (2001)

High tides inundated 53.3% of Bald Head Island's *in-situ* nests and 30% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 41.7% of the *in-situ* nests and 11% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in both relocated nests and control nests (Figure 3.5; Table 3.2; Table D.1). Relocated nests had greater median hatching success than control nests (Figure 3.5; Table 3.2; Table D.1). A Kruskal-Wallis ANOVA showed a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.5; Kruskal-Wallis test statistic = 15.253, d.f. = 2, and two-sided p <0.001). Dunn's test identified a significant difference between hatching success in *in-situ* nests and hatching success in control nests, as well as, between hatching success in relocated nests and hatching success in control nests (Table 3.2; Table C.5).

Middle season median hatching success was greater in *in-situ* nests than in both middle season relocated nests and control nests (Figure 3.5; Table 3.2; Table D.2). Relocated nests had greater median hatching success than control nests (Figure 3.5; Table 3.2; Table D.2). A Kruskal-Wallis ANOVA revealed a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.5; Kruskal-Wallis test statistic = 10.646, d.f. = 2, and two-sided p = 0.005). Dunn's test identifed a significant difference between hatching success in *in-situ* nests and hatching success in relocated nests, as well as, between hatching success in *in-situ* nests and hatching success in control nests (Table 3.2; Table C.5).

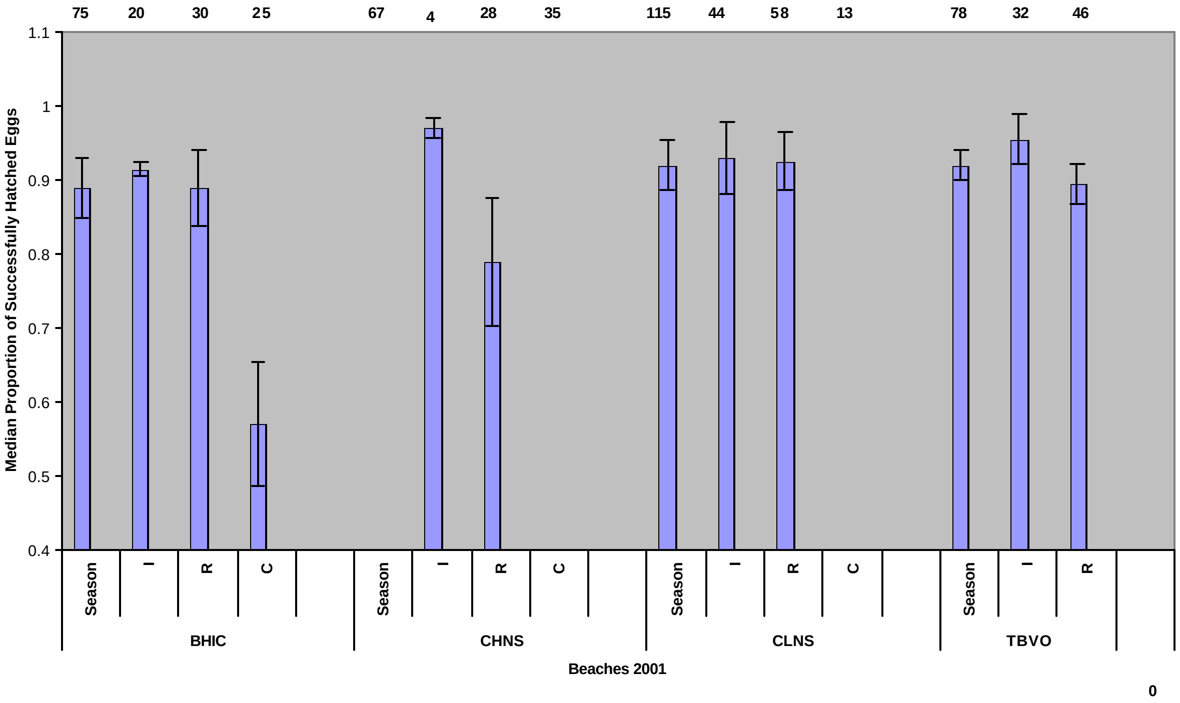


Figure 3.5: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of the median proportion of successfully hatched eggs in 2000. Error bars indicate standard error. The numbers on the top axis indicate the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.1.5.2 Cape Hatteras National Seashore (2001)

High tides inundated 89.7% of the national seashore's *in-situ* nests and 64.3% of the nesting area's relocated nests (Table 3.1). No hatching success resulted in 54.3% of the *in-situ* nests and 33.3% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in relocated nests than in control nests (Figure 3.5; Table 3.2; Table D.1). A Mann-Whitney rank sum test showed a significant difference between hatching success in relocated and hatching success in control nests (Table 3.2; Table C.5; Rank sum test statistic = 1048.50 and two-sided p = 0.035). *In-situ* nests were excluded from the analysis because the nesting area had less than five nests that fit the *in-situ* nest criteria (Figure 3.5; Table D.1).

Middle season median hatching success was greater in relocated nests than in middle season control nests (Figure 3.5; Table D.2). A Mann-Whitney rank sum test revealed a significant difference between hatching success in middle season relocated nests and middle season hatching success in control nests (Table 3.5; Table C.5; Rank sum test statistic = 349.00 and two-sided p = 0.009). *In-situ* nests were excluded from the analysis because the nesting area during middle season had less than five nests that fit the *in-situ* nest criteria (Figure 3.5; Table D.2).

### 3.1.5.3 Cape Lookout National Seashore (2001)

High tides inundated 22.8% of the Cape Lookout's *in-situ* nests and 13.8% of the national seashore's relocated nests (Table 3.1). No hatching success resulted in 38.6% of the *in-situ* nests and 24.6% of the relocated nests affected by inundation (Table 3.1).

Entire season median hatching success was greater in *in-situ* nests than in both relocated nests and control nests (Figure 3.5; Table 3.2; Table D.1). Relocated nests had greater median hatching success than control nests (Figure 3.5; Table 3.2; Table D.1). A Kruskal-Wallis ANOVA indicated a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.5; Kruskal-Wallis test statistic = 9.674, d.f. = 2, and two-sided p = 0.008). Dunn's test identified a significant difference between hatching success in *in-situ* nests and hatching success in control nests, as well as, between hatching success in relocated nests and hatching success in control nests (Table 3.2; Table C.5).

Late season median hatching success was greater in *in-situ* nests than in both late season relocated nests and control nests (Figure 3.5; Table 3.2; Table D.2). Relocated nests had greater median hatching success than control nests (Figure 3.5; Table 3.2; Table D.2). A Kruskal-Wallis ANOVA indicated a significant difference among hatching success in *in-situ* nests, relocated nests, and control nests (Table 3.2; Table C.5; Kruskal-Wallis test statistic = 6.606, d.f. = 2, and two-sided p = 0.037). Dunn’s test revealed a significant difference between hatching success in *in-situ* nests and relocated nests, as well as, between hatching success in *in-situ* nests and hatching success in control nests (Table 3.2; Table C.5).

### 3.1.5.4 Topsail Island (2001)

Entire nesting season median hatching success was greater in *in-situ* nests than in relocated nests (Figure 3.5; Table 3.2; Table D.1). A Mann-Whitney rank sum test showed no significant difference between hatching success in *in-situ* and hatching success in relocated nests (Table 3.5; Table 3.2; Table C.5; Rank sum test statistic = 1435.50 and two-sided p = 0.082).

## 3.2 Evaluation of Incubation Duration

*Table 3.3: Entire season and seasonal comparisons of median incubation duration among loggerhead (Caretta caretta) nests (in-situ (I), relocated (R), and in-situ – affected by tidal inundation (C)). BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach. (*) = Significant difference between testable nest categories (two-sided p<0.05) (See Appendix C for p-values). (NEN = Not enough nests for evaluation)*

| Beach | 1997 | 1998 | 1999 | 2000 | 2001 |
|---|---|---|---|---|---|
| **Entire Season** | | | | | |
| BHIC | I>R* | I>R* | I>R | I<R, R<C, I<C | I>R*, R<C*, I=C |
| CHNS | NA | I<R | I>R | I>R, R<C, I<C | R<C |
| CLNS | I>R* | I<R, R<C, I<C | I>R, R<C, I<C | I<R.R<C, I<C | I<R |
| TBVO | I>R | I>R | I>R | I>R | I>R* |
| **Early Season** | | | | | |
| BHIC | I>R | I>R* | I=R | I<R | I>R |
| CHNS | NA | I<R | I>R | I>R | R<C |
| CLNS | I>R | I<R | I<R | I<R | I<R |
| TBVO | NEN | I>R | I<R | I>R | I>R* |
| **Middle Season** | | | | | |
| BHIC | I>R | NEN | I>R | I>R | I>R*, R<C*, I<C* |
| CHNS | NA | I<R | I>R | I>R | R>C |
| CLNS | I>R | R=C | I<R | I<R, R>C, I<C | I<R |
| TBVO | I>R* | NEN | I>R | I=R | I>R* |
| **Late Season** | | | | | |
| BHIC | NEN | NEN | NEN | NEN | NEN |
| CHNS | NA | NEN | NEN | NEN | NEN |
| CLNS | I>R* | NEN | NEN | I>R | NEN |
| TBVO | NEN | NEN | NEN | I>R | I=R |

### 3.2.1 Incubation Duration: 1997

#### 3.2.1.1 Bald Head Island (1997)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.6; Table 3.3; Table D.3). A Mann-Whitney rank sum test showed a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.6; Rank sum test statistic = 735.50 and two-sided p = 0.015).

#### 3.2.1.2 Cape Hatteras National Seashore (1997)

Cape Hatteras National Seashore (1997) was excluded from the analysis because the data did not contain hatchling emergence dates.

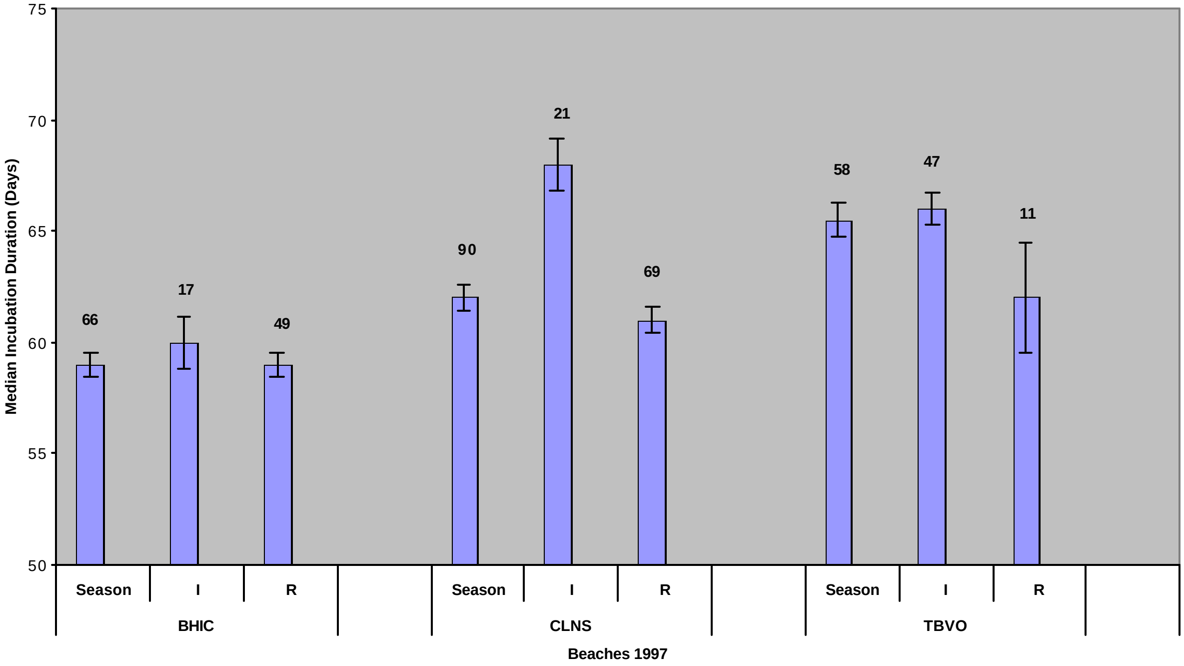


Figure 3.6: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of median incubation duration (days) in 1997. Error bars indicate standard error. The number above each bar indicates the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.2.1.3 Cape Lookout National Seashore (1997)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.6; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.6; Rank sum test statistic = 1367.50 and two-sided p <0.001).

### 3.2.1.4 Topsail Island (1997)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.6; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.6; Rank sum test statistic = 273.50 and two-sided p = 0.316).

## 3.2.2 Incubation Duration: 1998

### 3.2.2.1 Bald Head Island (1998)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.7; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3 Table C.7; Rank sum test statistic = 215.50 and two-sided p = 0.043). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.7; Table D.3).

Early season median incubation durations were longer in *in-situ* nests than in early season relocated nests (Figure 3.7; Table 3.3; Table D.4). A Mann-Whitney rank sum test showed a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.7; Rank sum test statistic = 22.00 and two-sided p = 0.023).

Control nests were excluded from the analysis because the nesting area had less than five nests during the early season that fit the control nest criteria (Figure 3.7; Table D.4).

### 3.2.2.2 Cape Hatteras National Seashore (1998)

Entire season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.7; Table 3.3; Table D.1). A Mann-Whitney rank sum test showed no significant difference between incubation durations in relocated nests and incubation durations in *in-situ* nests (Table 3.3; Table C.7; Rank sum test statistic = 302.50 and two-sided p = 0.283).

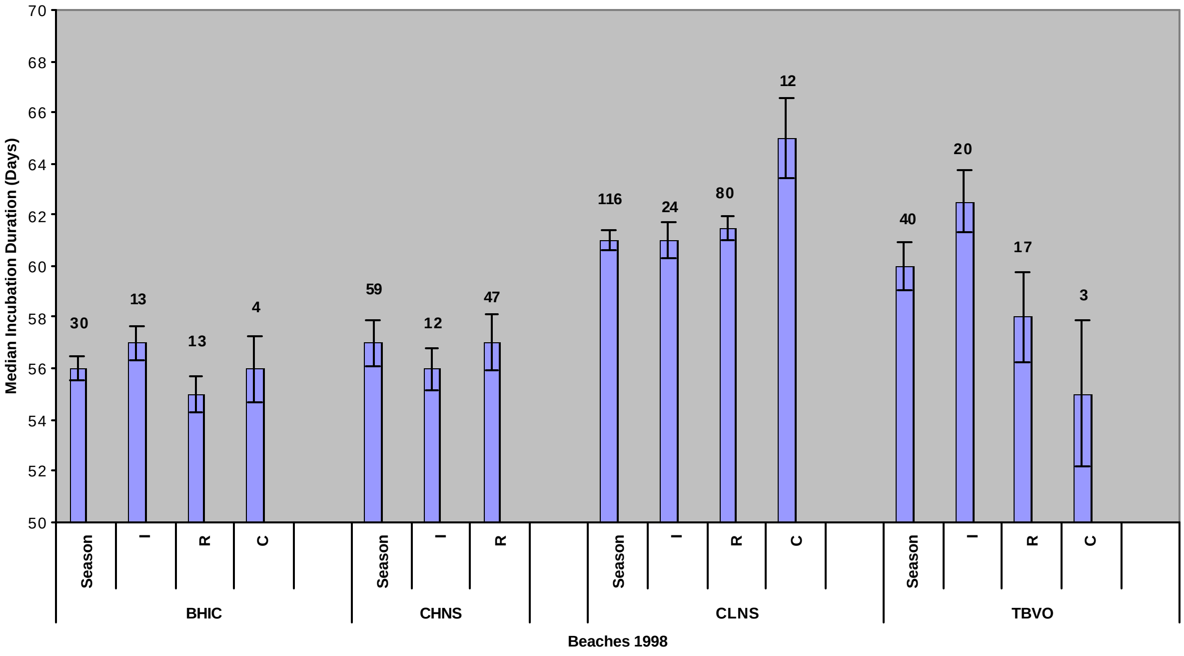


Figure 3.7: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of median incubation duration (days) in 1998. Error bars indicate standard error. The number above each bar indicates the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.2.2.3 Cape Lookout National Seashore (1998)

Entire nesting season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.7; Table 3.3; Table D.1). Control nests had longer median incubation durations than both relocated nests and *in-situ* nests (Figure 3.7; Table 3.3; Table D.1). A Kruskal-Wallis ANOVA indicated no significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.7; Kruskal-Wallis test statistic = 5.764, d.f. = 2, and two-sided p = 0.056).

#### 3.2.2.4 Topsail Island (1998)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.7; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.7; Rank sum test statistic = 298.00 and two-sided p = 0.455). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.7; Table D.3).

### 3.2.3 Incubation Duration: 1999

#### 3.2.3.1 Bald Head Island (1999)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.8; Table 3.3; Table D.3). A Mann-Whitney rank sum test showed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.8; Rank sum test statistic = 603.00 and two-sided p = 0.598).

#### 3.2.3.2 Cape Hatteras National Seashore (1999)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.8; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed no significant difference between incubation durations in *in-situ* and incubation durations in relocated nests (Table 3.3; Table C.8; Rank sum test statistic = 285.00 and two-sided p = 0.274).

### 3.2.3.3 Cape Lookout National Seashore (1999)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.8; Table 3.3; Table D.3). Control nests had longer median incubation durations than both relocated nests and *in-situ* nests (Figure 3.8; Table 3.3; Table D.3). A Kruskal-Wallis ANOVA indicated no significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.8; Kruskal-Wallis test statistic = 5.493, d.f. = 2, and two-sided p = 0.064).

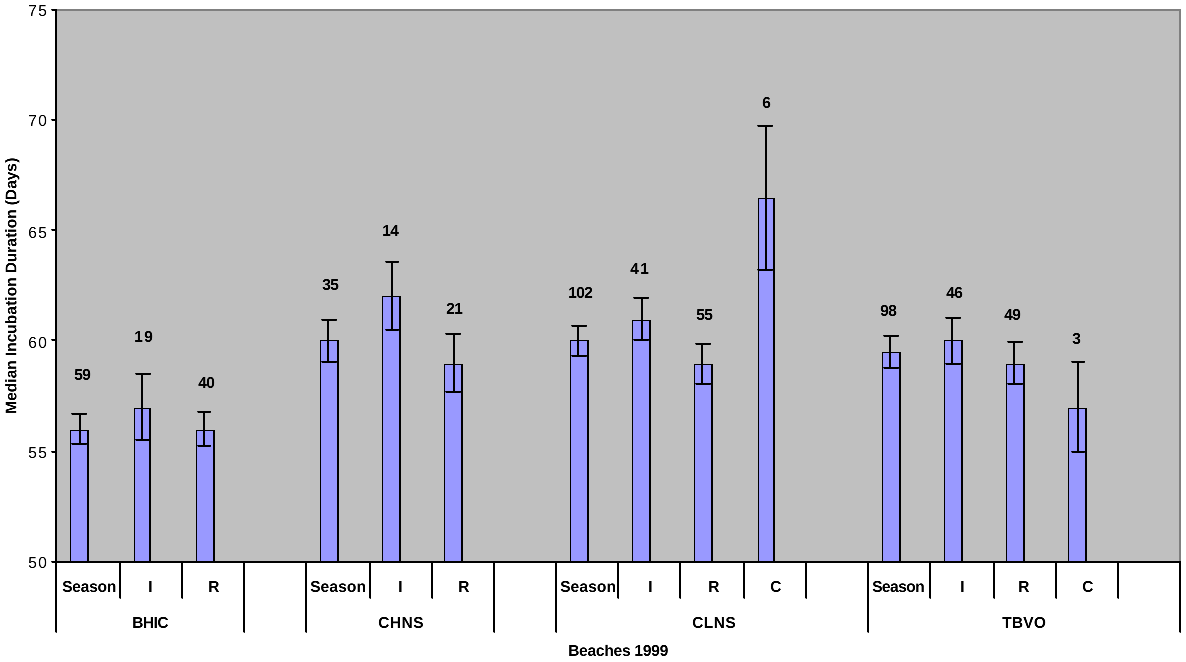


Figure 3.8: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of median incubation duration (days) in 1999. Error bars indicate standard error. The number above each bar indicates the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.2.3.4 Topsail Island (1999)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.8; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.8; Rank Sum Statistic = 2363.00 and two-sided p = 0.250). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.8; Table D.3).

### 3.2.4 Incubation Duration: 2000

#### 3.2.4.1 Bald Head Island (2000)

Entire season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.9; Table 3.3; Table D.3). Control nests had longer median incubation durations than both relocated nests and *in-situ* nests (Figure 3.9; Table 3.3; Table D.3). A Kruskal-Wallis ANOVA indicated no significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.9; Kruskal-Wallis test statistic = 0.557, d.f. = 2, and two-sided p = 0.757).

#### 3.2.4.1 Cape Hatteras National Seashore (2000)

Entire season median incubation durations were longer in *in-situ* nests than in both relocated nests and control nests (Figure 3.9; Table 3.3; Table D.3). Control nests had longer median incubation durations than relocated nests. A Kruskal-Wallis ANOVA indicated no significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.9; Kruskal-Wallis test statistic = 1.912, two-sided p = 0.384).

#### 3.2.4.3 Cape Lookout National Seashore (2000)

Entire season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.9; Table 3.3; Table D.3). Control nests had longer median incubation durations than both relocated nests and *in-situ* nests (Figure 3.9; Table 3.3; Table D.3). A Kruskal-Wallis ANOVA indicated no significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.9; Kruskal-Wallis test statistic = 1.332, d.f. = 2, and two-sided p = 0.514).

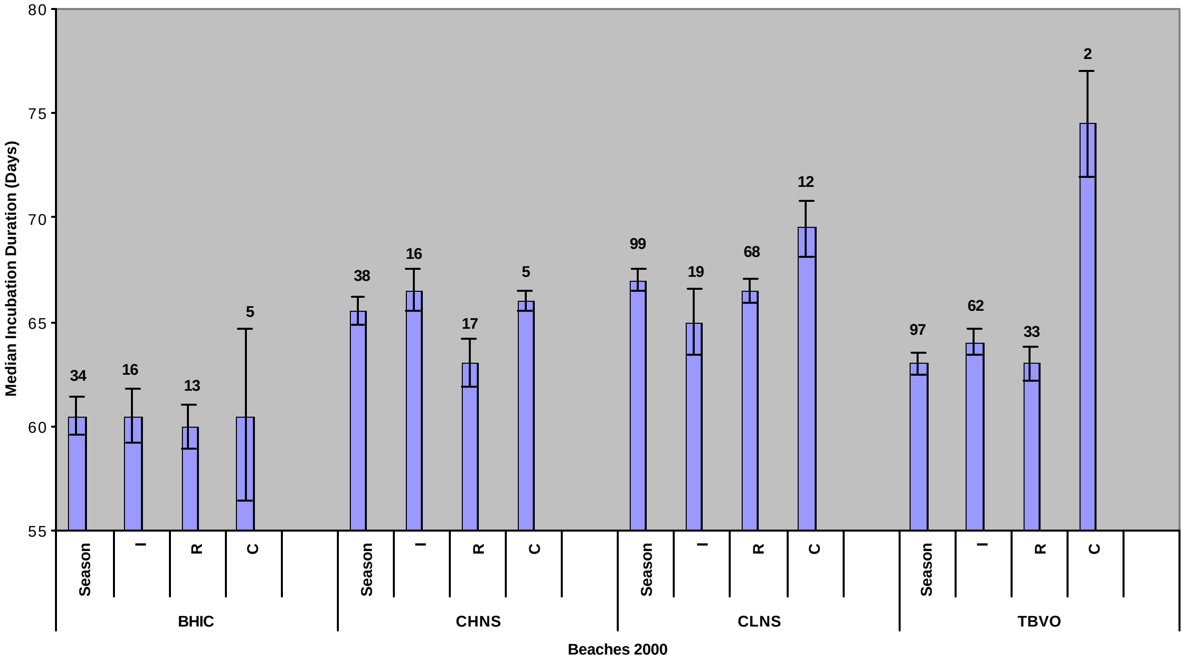


Figure 3.9: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), control (C)) of median incubation duration (days) in 2000. Error bars indicate standard error. The number above each bar indicates the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.2.4.4 Topsail Island (2000)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.9; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.9; Rank sum test statistic = 1339.50 and two-sided p = 0.056). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.9; Table D.3).

### 3.2.5 Incubation Duration: 2001

#### 3.2.5.1 Bald Head Island (2001)

Entire season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.10; Table 3.3; Table D.3). Control nests had longer median incubation durations than relocated nests and the same as *in-situ* nests (Figure 3.10; Table 3.3; Table D.3). A Kruskal-Wallis ANOVA indicated a significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.10; Kruskal-Wallis test statistic = 12.187, d.f. = 2, and two-sided p = 0.002). Dunn's test identified a significant difference between incubation durations in *in-situ* and incubation durations in relocated nests, as well as, b between incubation durations in relocated nests and incubation durations in control nests (Table 3.3; Table C.10).

Middle season median incubation durations were longer in *in-situ* nests than in middle season relocated nests (Figure 3.10; Table 3.3; Table D.4). Control nests had longer median incubation durations than both relocated nests and *in-situ* nests (Figure 3.10; Table 3.3; Table D.4). A Kruskal-Wallis ANOVA showed a significant difference among incubation durations in *in-situ* nests, relocated nests, and control nests (Table 3.3; Table C.10; Kruskal-Wallis test statistic = 13.758, d.f. = 2, and two-sided p = 0.001). Dunn's test identified a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests, as well as, between incubation durations in relocated nests and incubation durations in control nests (Table 3.3; Table C.10).

#### 3.2.5.2 Cape Hatteras National Seashore (2001)

Entire season median incubation durations were longer in relocated nests than in control nests (Figure 3.10; Table 3.3; Table D.3). A Mann-Whitney rank sum test showed no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.10; Rank sum test statistic = 175.00 and two-sided p = 0.312). *In-situ* nests were excluded from the analysis because the nesting area had less than five nests that fit the *in-situ* nest criteria (Figure 3.10; Table D.3).

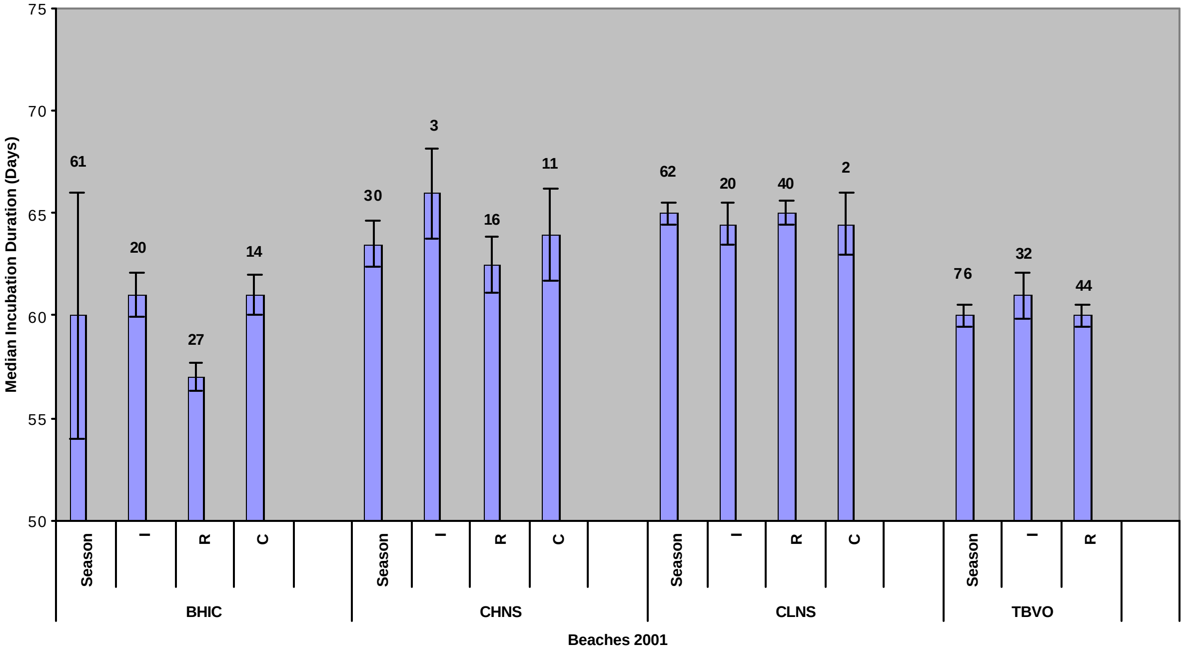


Figure 3.10: Graphical comparisons among nest categories (*in-situ* (I), relocated (R), and control (C)) of median incubation duration (days) in 2001. Error bars indicate standard error. The number above each bar indicates the number of nests in each nest category. BHIC = Bald Head Island, CLNS = Cape Lookout National Seashore, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Beach.

### 3.2.5.3 Cape Lookout National Seashore (2001)

Entire season median incubation durations were longer in relocated nests than in *in-situ* nests (Figure 3.10; Table 3.3; Table D.3). A Mann-Whitney rank sum test indicated no significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.10; Rank sum test statistic = 663.500 and two-sided p = 0.855). Control nests were excluded from the analysis because the nesting area had less than five nests that fit the control nest criteria (Figure 3.10; Table D.3).

#### 3.2.5.4 Topsail Island (2001)

Entire season median incubation durations were longer in *in-situ* nests than in relocated nests (Figure 3.10; Table 3.3; Table D.3). A Mann-Whitney rank sum test revealed a significant difference between incubation durations in *in-situ* nests and incubation durations in relocated nests (Table 3.3; Table C.10; Rank sum test statistic = 1443.00 and two-sided p = 0.027).

Both early season and middle season median incubation durations were longer in *in-situ* nests than in early season and middle season relocated nests, respectively (Figure 3.10; Table 3.3; Table D.4). A Mann-Whitney rank sum test showed a significant difference between early season incubation durations in *in-situ* nests and early season incubation durations in relocated nests (Table 3.3; Table C.10; Rank sum test statistic = 100.50 and two-sided p = 0.022). A Mann-Whitney rank sum test revealed a significant difference between middle season incubation durations in *in-situ* nests and middle season incubation durations in relocated nests (Table 3.3; Table C.10; Rank sum test statistic = 372.00 and two-sided p = 0.018).

## 3.3 Evaluation of Rate of Nest Relocation

*Table 3.4: Nest relocation rates (proportion of nests relocated) subdivided by beach, year, entire nesting season, and nesting season part (early season, middle season, and late season). Average rates of relocation are shown. BHIC = Bald Head Island, CHNS = Cape Hatteras National Seashore, and TBVO = Topsail Island.*

| Beach | Year | Entire Season | Early Season | Middle Season | Late Season |
|---|---|---|---|---|---|
| BHIC | 1997 | 0.71 | 0.50 | 0.78 | 0.72 |
| CHNS | 1997 | 0.84 | 0.50 | 0.88 | 0.78 |
| CLNS | 1997 | 0.74 | 0.73 | 0.79 | 0.65 |
| TBVO | 1997 | 0.17 | 0.08 | 0.26 | 0.11 |
| **Average** | **1997** | **0.62** | **0.45** | **0.68** | **0.57** |
| BHIC | 1998 | 0.48 | 0.29 | 0.57 | 0.39 |
| CHNS | 1998 | 0.74 | 0.56 | 0.73 | 0.87 |
| CLNS | 1998 | 0.61 | 0.50 | 0.66 | 0.63 |
| TBVO | 1998 | 0.44 | 0.32 | 0.35 | 0.72 |
| **Average** | **1998** | **0.57** | **0.42** | **0.58** | **0.65** |
| BHIC | 1999 | 0.60 | 0.58 | 0.61 | 0.64 |
| CHNS | 1999 | 0.60 | 0.50 | 0.64 | 0.63 |
| CLNS | 1999 | 0.51 | 0.29 | 0.58 | 0.60 |
| TBVO | 1999 | 0.49 | 0.29 | 0.49 | 0.61 |
| **Average** | **1999** | **0.55** | **0.42** | **0.58** | **0.62** |
| BHIC | 2000 | 0.43 | 0.41 | 0.45 | 0.40 |
| CHNS | 2000 | 0.29 | 0.35 | 0.27 | 0.25 |
| CLNS | 2000 | 0.65 | 0.65 | 0.69 | 0.51 |
| TBVO | 2000 | 0.32 | 0.42 | 0.26 | 0.30 |
| **Average** | **2000** | **0.42** | **0.46** | **0.42** | **0.37** |
| BHIC | 2001 | 0.40 | 0.56 | 0.38 | 0.29 |
| CHNS | 2001 | 0.46 | 0.48 | 0.47 | 0.38 |
| CLNS | 2001 | 0.50 | 0.46 | 0.57 | 0.45 |
| TBVO | 2001 | 0.61 | 0.73 | 0.64 | 0.38 |
| **Average** | **2001** | **0.49** | **0.56** | **0.52** | **0.38** |

### 3.3.1 Nest Relocation Rate: 1997

In 1997, the proportion of nests relocated ranged from 0.84 (or 84% of the nests were relocated) at Cape Hatteras National Seashore to 0.17 (or 17% of the nests were relocated) at Topsail Island (Table 3.4). The average rate of nest relocation for the entire nesting was 0.62 (62%) (Table 3.4).

### 3.3.2 Nest Relocation Rate: 1998

In 1998, the proportion of nests relocated ranged from 0.74 (74%) at Cape Hatteras National Seashore to 0.44 (44%) at Topsail Island (Table 3.4). Cape Lookout National Seashore ($X^2 = 64.46$, d.f. = 2, and p = <0.0001) and Topsail Island ($X^2 = 9.76$, d.f. = 2, p = 0.0076) were both found to have a significant change in the number of nests relocated during the nesting season (Table C.11). The average rate of nest relocation for the entire nesting was 0.57 (57%) (Table 3.4).

### 3.3.3 Nest Relocation Rate: 1999

In 1999, the proportion of nests relocated ranged from 0.60 (60%) at Bald Head Island and Cape Hatteras National Seashore to 0.49 (49%) at Topsail Island (Table 3.4). The average rate of nest relocation for the entire nesting was 0.55 (55%) (Table 3.4).

### 3.3.4 Nest Relocation Rate: 2000

In 2000, the proportion of nests relocated ranged from 0.65 (65%) at Cape Lookout National Seashore National Seashore to 0.29 (29%) at Cape Hatteras National Seashore (Table 3.4). The average rate of nest relocation for the entire nesting was 0.42 (42%) (Table 3.4).

### 3.3.5 Nest Relocation Rate: 2001

In 2001, the proportion of nests relocated ranged from 0.61 (61%) at Topsail Island to 0.40 (40%) at Bald Head Island (Table 3.4). The average rate of nest relocation for the entire nesting was 0.49 (49%) (Table 3.4).

## 4.0 Discussion

## 4.1 Nest Relocation in North Carolina

Until recently, relocation of sea turtle nests threatened by tidal inundation, heavy beach traffic, and sloughing escarpments to *safer* locations has been common practice in North Carolina. North Carolina sea turtle managers used relocation as a management strategy, with the goal of producing as many hatchlings as possible. The *Recovery Plan for U.S. Population of Loggerhead Turtle* (*Caretta caretta*) suggested avoiding nest relocation and using less manipulative loggerhead nest and loggerhead hatchling management techniques to increase the proportion of successfully hatched loggerheads eggs (hatching success) (National Marine Fisheries Service and U.S. Fish and Wildlife Service, 1991).

During each of the five nesting seasons (1997 to 2001), the average number of nests moved on Bald Head Island, Cape Hatteras National Seashore, Cape Lookout National Seashore, and Topsail Island approached 40 to 60 percent (Table 3.4). The percentage held true throughout the nesting season (Table 3.4).

According to Godfrey (2002), high rates of nest relocation showed that North Carolina volunteers were over estimating the potential threats of tidal inundation, beach traffic, and sloughing escarpments to sea turtle nests. Such high rates of human intervention in North Carolina might be reducing loggerhead hatching success, decreasing average loggerhead nest incubation durations, and reducing loggerhead hatchling fitness.

## 4.2 Impacts of Nest Relocation and Tidal Inundation on Hatching Success

Witherington (1999) suggested that nest relocation might result in reduced hatching success. My evaluation showed an overall tendency of more hatchling loggerheads hatching in *in-situ* nests than in relocated nests and in *in-situ* nests affected by tidal inundation by high tides (control nests) (Table 3.2). Except for 1997, the nesting seasons showed a tendency of hatching success being favored in *in-situ* nests rather than in relocated nests and in control nests (when applicable) (Table 3.2).

In 1997, *in-situ* nests at Bald Head Island and Cape Lookout National Seashore had greater hatching success than relocated nests. In 1998, *in-situ* nests at Bald Head Island and Topsail Island had significantly greater hatching success than relocated nests, while *in-situ nests* at Cape Hatteras National Seashore had greater hatching success than relocated nests. In 1999, *in-situ* nests at each of the four beaches had significantly greater hatching success than relocated nests. In 2000, *in-situ* nests at Bald Head Island and Topsail Island had significantly higher hatching success than relocated nests, while *in-situ* nests at Cape Hatteras National Seashore had greater hatching success than relocated nests. Also, *in-situ* nests at Cape Hatteras had significantly higher hatching success than control nests, while *in-situ* nests at Bald Head Island had greater hatching success than control nests. And in 2001, *in-situ* nests at Bald Head Island, Cape Lookout National Seashore, and Topsail Island had greater hatching success than relocated nests. Additionally, *in-situ* nests at Bald Head Island and Cape Lookout National Seashore had significantly higher hatching success than control nests.

Egg movement that occurs during relocation (Witherington, 1999) could kill developing embryos, and therefore, reduce hatching success (Limpus et al, 1979; Section 1.4.2.2). Relocating a nest in oxygen (Ackerman, 1981) or moisture deficient sand (McGehee, 1990) might decrease hatching success (Faunal Diversity Program, 2003; Section 1.4.2.5). Ackerman (1980) found that sea turtle embryonic growth rates were related to respiratory gas exchange, and that impaired gas exchange could result in embryonic death. Thus, relocating a nest to a beach area with gas exchange rates below natural levels could lower hatching success (Faunal Diversity Program, 2003). Temperatures greater than 34°C are lethal to loggerhead eggs (Nelson, 1988;

Section 1.4.2.5). Therefore, relocating a nest to an area with an average temperature greater than 34°C might result in lowered hatching success or no hatching success (Faunal Diversity Program, 2003).

I did not see any significant seasonal changes in hatching success, but uncovered a lot of seasonal variability in hatching success among the three nest categories, the portioned nesting season (early season, middle season, and late season), each nesting season, and the four nesting areas (Table 3.2). The greater median hatching success switched among different nest categories across the season (Table 3.2). The variation has lots of sources: nest relocation, nest depredation, storms (e.g. tropical storms), beach erosion and accretion, beach width, and tidal inundation by high tides (Faunal Diversity Program, 2003).

During each of the five nesting seasons, both *in-situ* nests and relocated nests (nests possibly moved to avoid inundation) were impacted by high tides (Table 3.1). The number of control nests and relocated nests (affected by inundation by high tides) varied among beaches and nesting seasons (Table 3.1).

A large percentage of the *in-situ* nests (affected by tidal inundation by high tides) and relocated nests (affected by tidal inundation by high tides) had no hatching success (0% hatching success) (Table 3.1). Except for 2000, more control nests had no hatching success than the relocated nests over-washed by high tides (Table 3.1). The high percentage of control nests with no hatching success might indicate that high tides frequently over-washed control nests. The high percentage of control nests (inundated *in-situ* nests) supported the technique of making comparisons among three nest categories (in-situ nests, relocated nests, and control nests), and not only between *in-situ* and relocated nests. Although the nest activity data did not allow for such an analysis, it would be interesting to look for a relationship between the number of nest over-wash days and hatching success among each nest category (*in-situ* nests, relocated nests, and control nests) (Section 4.5).

As well as explaining variation in hatching success, unpredictable inundation of nests by high tides might explain lowered hatching success in relocated nests (affected by inundation by high tides) and control nests. The nest activity data does not indicate the reason for the tidal inundation. However, since loggerheads tend to nest above the high tide line (Caldwell, 1959, Miller, 1997; Section 1.4.4.1) and tidal inundation affected a large number of nests (including relocated) (Table 3.1) during each of the five years, I hypothesize that unpredictable summer storm events that resulted in large storm surges (e.g. tropical storms), resulted in reduced hatching success. The Florida Fish and Wildlife Conservation Commission stated that unpredicted storm events, such as tropical storms, that accelerate beach erosion and accretion could reduce hatching success (Faunal Diversity Program, 2003). North Carolina has a history of being hit by powerful tropical storms (Pilkey et al, 1998). In August of 1998, Hurricane Bonnie made landfall at Bald Head Island as a category three hurricane (Saffir-Simpson scale) (State Climate Office of North Carolina, 2003). In September 1999, Tropical Storm Dennis made land fall at Cape Lookout National Seashore and Hurricane Floyd made landfall in North Carolina as a category two hurricane (Saffir-Simpson scale) (State Climate Office of North Carolina, 2003).

Since summer storms are unpredictable and nest relocation has many negative impacts, nest relocation would not be beneficial (Section 5.1).

### 4.3 Impact of Nest Relocation on Incubation Duration and Its Population Implications

Witherington (1999) suggested that nest relocation might result in reduced sea turtle nest incubation durations. My evaluation showed an overall tendency of *in-situ* nests having longer incubation durations than relocated nests, but shorter incubation durations than control nests.

In 1997, *in-situ* nests at Bald Head Island and Cape Lookout National Seashore had significantly longer incubation durations than relocated nests, while *in-situ* nests at Topsail Island had longer incubation durations than relocated nests. In 1998, *in-situ* nests at Bald Head Island had significantly longer incubation durations than relocated nests, while *in-situ* nests at Topsail Island had longer incubation durations than relocated nests. During 1998, control nests at Cape Lookout National Seashore had longer incubation durations than both *in-situ* nests and relocated nests. In 1999, *in-situ* nests at all the nesting areas had longer incubation durations than relocated nests. However, control nests at Cape Lookout National Seashore had longer incubation durations than both *in-situ* nests and relocated nests. In 2000, *in-situ* nests at Cape Hatteras National Seashore and Topsail Island had longer incubation durations than relocated nests. While, control nests at Bald Head Island, Cape Hatteras National Seashore, and Cape Lookout National Seashore had longer incubation durations than the two other nest categories. And in 2001, in-situ nests at Bald Head Island and Topsail Island had significantly longer incubation durations than relocated nests. Control nests at Cape Hatteras National Seashore had longer incubation durations than relocated nests.

Mean ambient sand temperature is inversely related to the incubation duration of loggerhead eggs (Godfrey and Mrosovsky, 1997; Section 1.4.2.4). For example, lower average sand temperatures result in longer incubation durations. The average ambient sand temperature of control nests might have been lowered by cool ocean over-wash, and might explain why control nests had longer incubation durations than the two other nest categories. It also might suggest why relocated nests (nests moved to warmer and less frequently inundated areas) had shorter incubation durations than *in-situ* nests and control nests.

Mrosovsky (1988) suggested a relationship between sex-ratios and incubation duration. Godfrey and Mrosovsky (1997) found a pivotal incubation duration of 60 days. A pivotal incubation duration of 60 days might suggest that relocated nests, with a 4 to 5 day decrease in incubation duration due to nest relocation, might be producing a higher percentage of females than under normal conditions (field validation is necessary) (Figure 1.3; Section 1.4.2.4). Mrosovsky et al (1984) found that *in-situ* northern sub-population loggerhead nests (which includes North Carolina; Figure 1.2; Section 1.4.1.3) produced about 56% females, while Murphy and Hopkins (1984) found that southern sub-population loggerhead nests (Figure 1.2; Section 1.4.1.3) produced about 90% females. Therefore, high rates of nest relocation in North Carolina could be skewing northern sub-population sex-ratios further in favor of female hatchlings.

The north sub-population, which has experienced a decline in the number of nests laid each year, hosts about 10% of the population's nesting effort (National Research Council, 1990). Therefore, reduced nesting effort, low nesting effort, and reduced inundation periods (from high rates of nest relocation in North Carolina) might be contributing to reduced numbers of males and, more importantly, reduced genetic variability in the entire northwestern Atlantic loggerhead population.

### 4.4 Impact of Nest Relocation on Loggerhead Hatchling Fitness

Nest relocation may adversely impact loggerhead hatchling fitness (Witherington, 1999). A hatchling's hatchling fitness can be reduced by relocating a nest in oxygen (Ackerman, 1981) or moisture deficient sand (McGehee, 1990, Faunal Diversity Program, 2003; Section 1.4.2.5).

One type of reduced hatchling fitness is less available yolk (Kraemer and Bennet, 1981) necessary to power hatchlings during their post emergence frenzy to the Gulf Stream (Section 1.4.3.2).

### 4.5 Recommendations for Future Evaluations

I.) Measure the Relationship between Inundation and Hatching Success

The nest activity data did not allow for such an analysis, but I would recommend investigating for a relationship between the number of nest over-wash days and hatching success. I would look for a relationship among each nest category (*in-situ* nests, relocated nests, and control nests). The evaluation could facilitate management decisions about when to relocate a nest.

II.) Evaluate the impact of nest screening on loggerhead nests

North Carolina uses the management technique of sea turtle nest screening to reduce the threat of nest depredation. I recommend performing a similar evaluation on the impact of nest screening in North Carolina. I would statistically compare hatching success between screened and non-screened nests.

## 5.0 Conclusions

## 5.1 Recommendations for North Carolina’s Sea Turtle Nest Relocation Protocol

I.) Relocate as a last resort

Volunteers should only relocate nests as a last resort. My evaluation showed a tendency of in-situ nests having higher high higher hatching success and longer incubation durations than relocated nests. Relocating sea turtle eggs may result in many adverse impacts: reduced hatching success, skewed sex-ratios, death of the embryo, and reduced hatchling fitness.

II.) Only relocate nests that will be over-washed daily by high tides

Nests should only be relocated if they are low enough on the beach to be over-washed by high tides on a regular basis, or are situated in known high risk areas. The Florida Fish and Wildlife Conservation Commission recommended relocating only the nests that are affected by high tides on a daily basis, or the nests that are in areas that experience severe erosion or egg loss (Faunal Diversity Program, 2003).

III.) Do not base nest relocation measures on previous summer storms

Summer storms, such as tropical storms, are unpredictable. Do not relocate a nest just because the nesting habitat area was hit by a large storm the previous year. The negative effects of relocation are too great.

IV.) Do not relocate nests in heavy foot traffic areas

Nests in heavy foot traffic areas should not be relocated. These nests should be fenced off and marked, so that pedestrians will avoid them.

## Appendix A Sea Turtle Management Zones

## From the *Handbook for Sea Turtle Volunteers in North Carolina* (NEWP, 1997)

## Sea Turtle Nesting Zone Designations

North Carolina Wildlife Resources Commission
Faunal Diversity Program

“Zones for reporting sea turtle nests have been established throughout the coast of North Carolina. Zones are one-mile segments of beach numbered sequentially from North to South and/or East to West. These zones should be used in reporting all sea turtle nests in North Carolina. Following are zone designations according to beach divisions (barrier islands) (NEWP, 1997).”

| Beach Division | N or E Limit | S or W Limit | Zone Beginning | Zone End |
|---|---|---|---|---|
| Hatteras Island | Oregon Inlet | Hatteras Inlet | 58 | 108 |
| Ocracoke Island | Hatteras Inlet | Ocracoke Inlet | 109 | 124 |
| Core Banks North | Ocracoke Inlet | New Drum Inlet | 125 | 146 |
| Core Banks South | New Drum Inlet | Barden Inlet | 147 | 171 |
| Shackleford Banks | Barden Inlet | Beaufort Inlet | 172 | 180 |
| Topsail Island | New River Inlet | New Topsail Inlet | 219 | 240 |
| Bald Head Island | New Inlet | Cape Fear River | 275 | 284 |

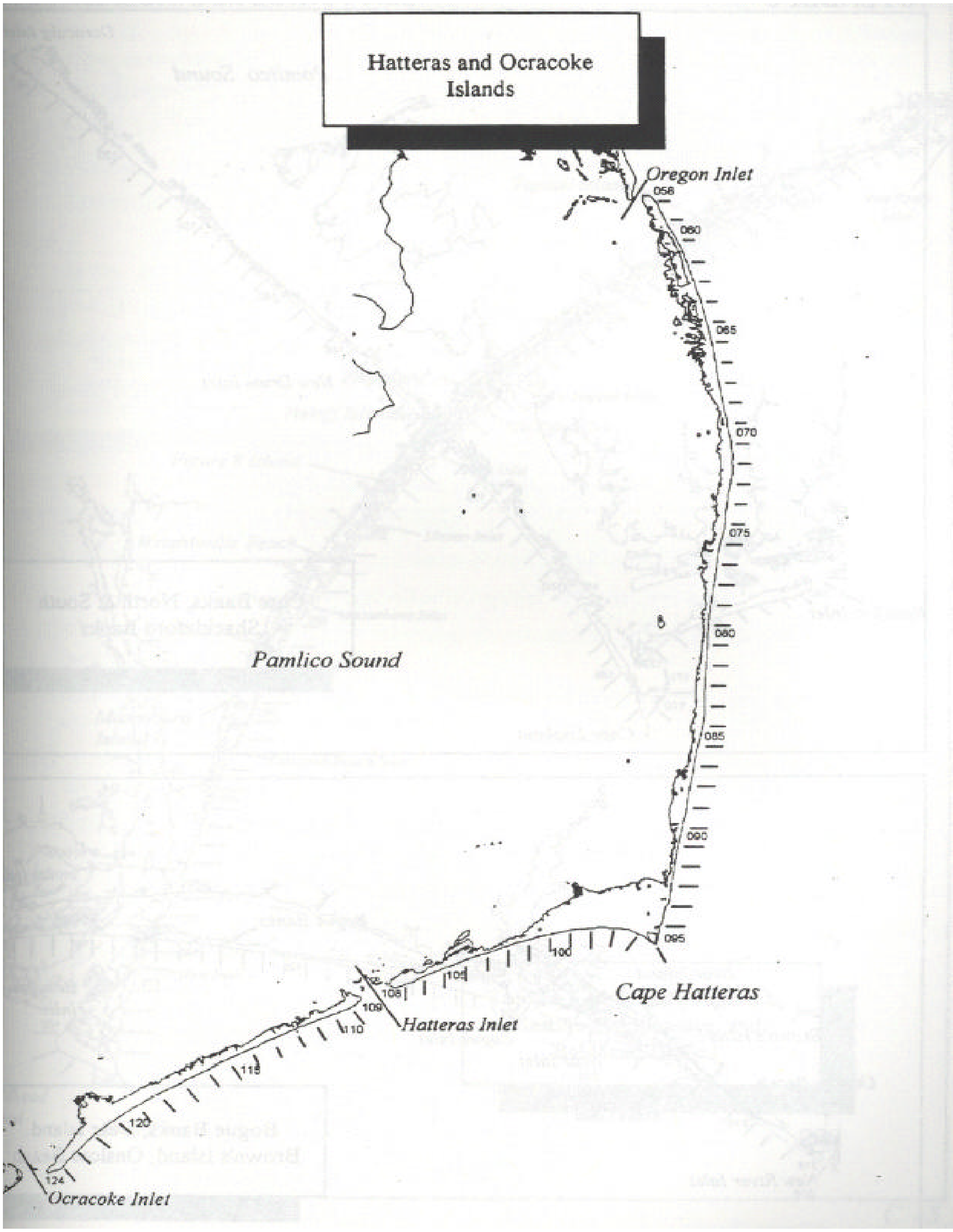


Figure A.1: Hatteras and Ocracoke Islands (NEWP, 1997).

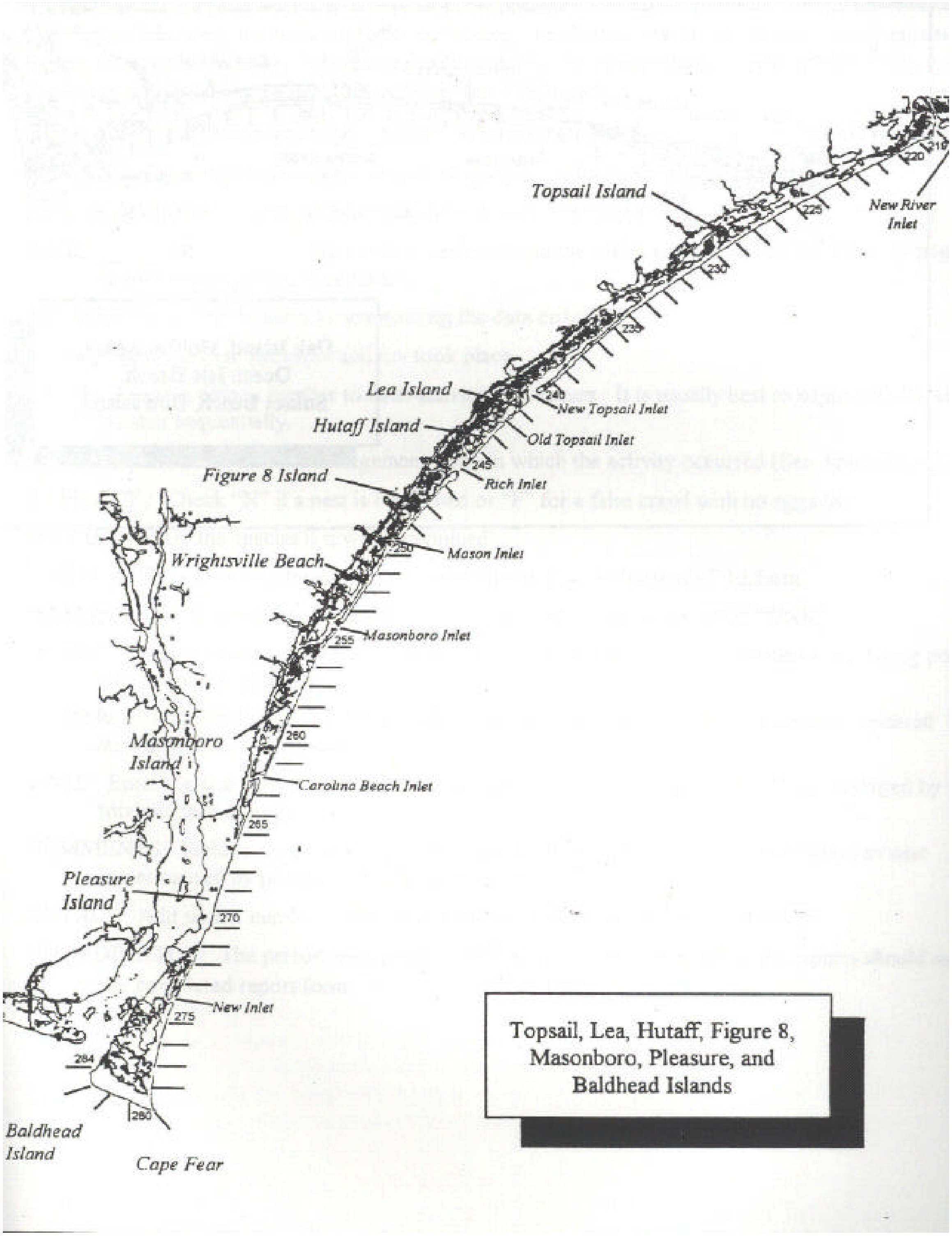


Figure A.2: Topsail and Baldhead Islands (NEWP, 1997).

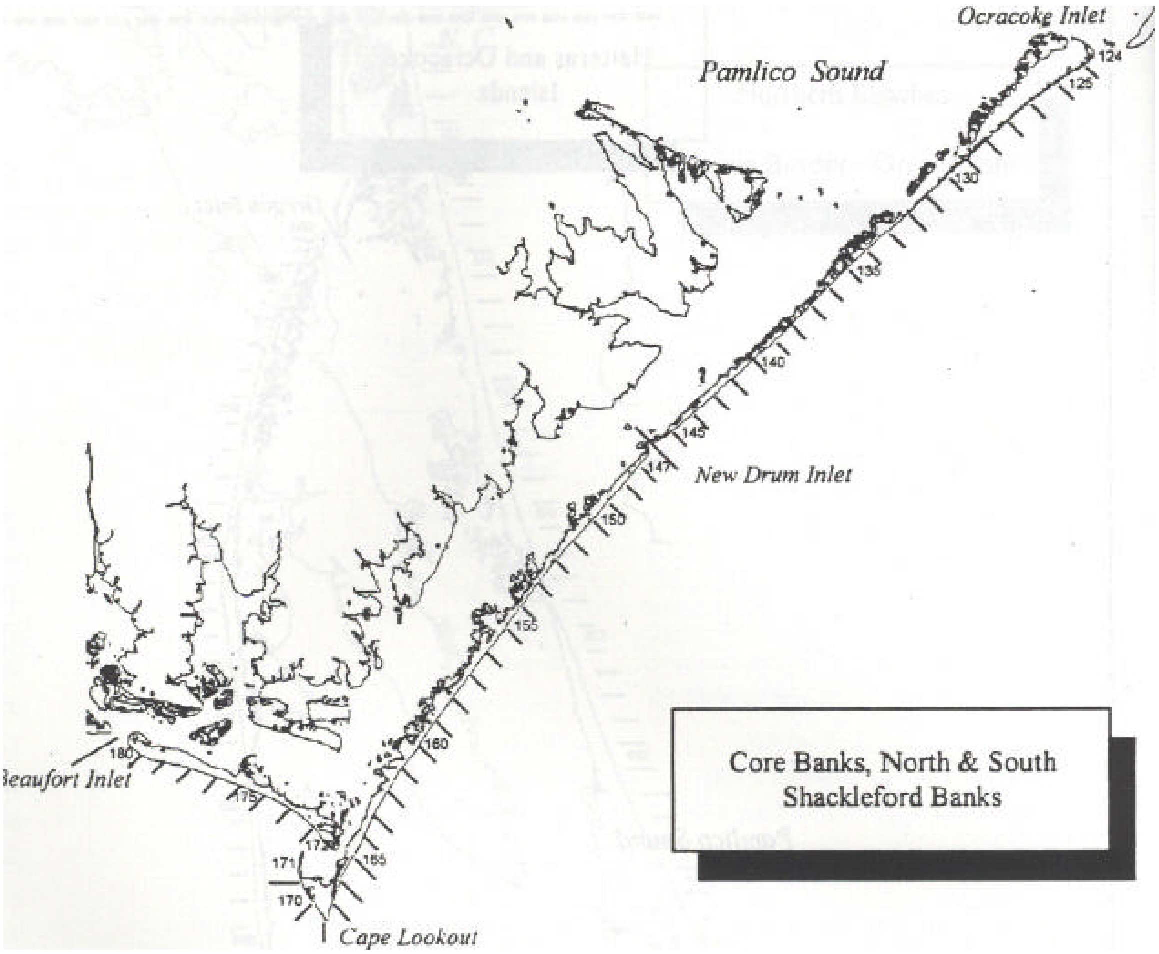


Figure A.3: Core Banks, North & South, and Shackleford Banks (NEWP, 1997).

The annual nesting report contains a beach's nesting activity data for a specified year.

## Instructions for 1997, 1998, and 1999: From the *Handbook for Sea Turtle Volunteers in North Carolina* (NEWP, 1997)

The following are instructions for completing the Annual Sea Turtle Nest Beach Management Report (next page) form which follows. Submitting this form fulfills the requirements in your permit for an Annual report if it meets the deadline of December 1 as stated.

YEAR: Enter the year in which the project was conducted.

PROJECT: Enter the name of your project or geographic location of your project.

BEACH DIVISION: Enter the Beach Division as listed on page C - 6.

PAGE ____OF ____: Enter the page number in the first blank and the total number of pages in your report in the second blank.

The following are instructions for completing the data columns.

DATE: Enter the date the turtle activity took place.

ACT.#: Assign a unique number to each activity as it occurs. It is usually best to begin with 01 and number sequentially.

ZONE: Enter the Sea Turtle Management Zone in which the activity occurred (See Appendix C).

*TYPE* ACT.: Check *<ON'* if a nest is confirmed or "F' for a false crawl with no eggs laid.

SPECIES: Enter the species if it was determined.

TREAT.CODE: Enter codes as indicated under Note 2 at the bottom of the form.

HATCHDATE: Enter the date the nest actually hatched. If unknown, enter "UNK".

# EGGS: Enter the number of eggs in the nest as determined either during relocation or during post-hatching excavation.

#EMERGED: Enter the number of hatchlings that emerged from the nest. Include any released during post-hatching excavation.

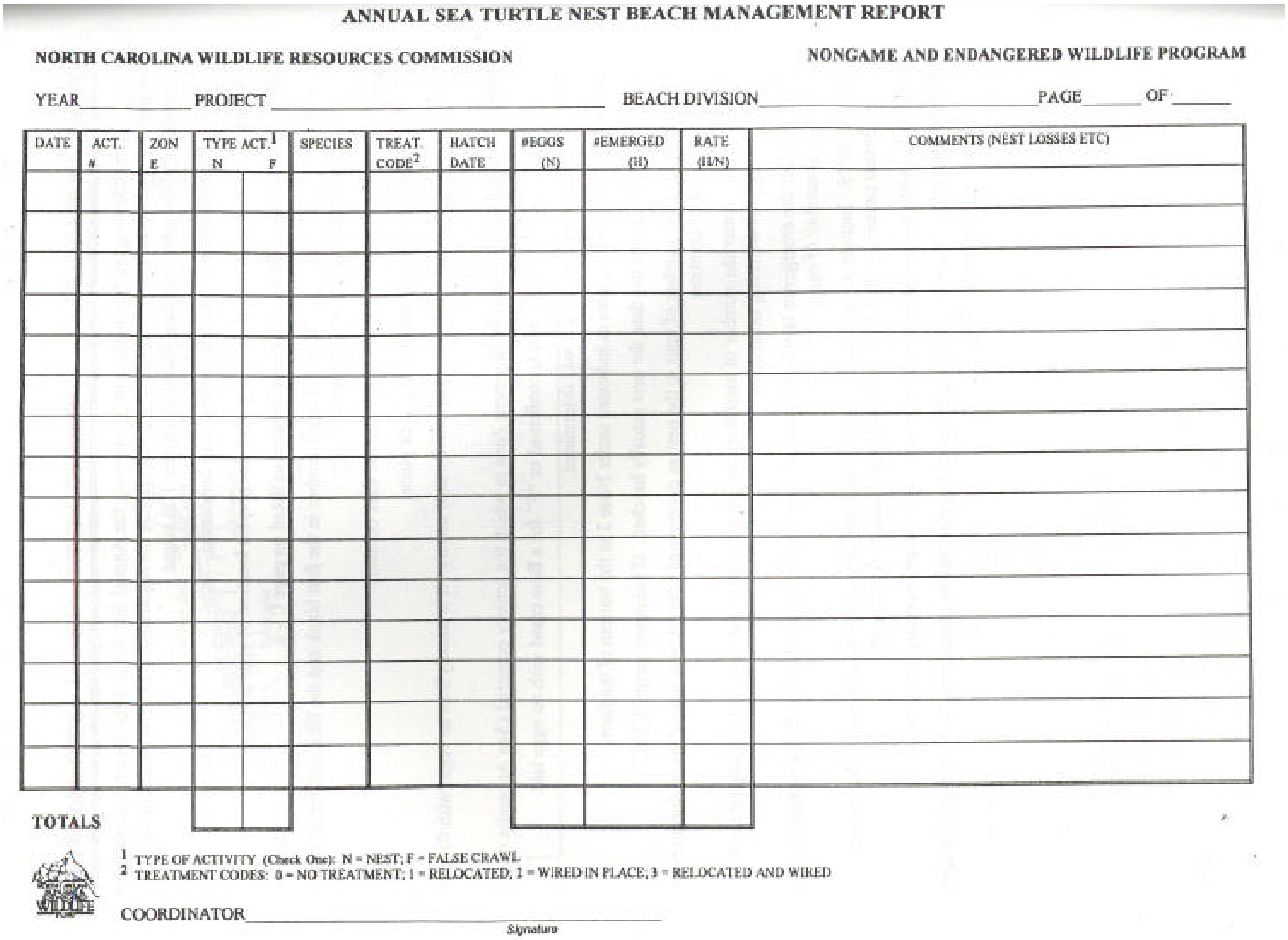
RATE: Enter the emergence rate as determined by dividing the number of hatchlings emerged by the total number of eggs.

COMMENTS: Include any information which you deem important. Include such things as nest losses caused by predation, human activity, erosion, flooding etc.

TOTALS: Add up the numbers in the column or perform the necessary calculations.

COORDINATOR: The person responsible for the project and/or completing the reports should sign the completed report form.

### *Annual Sea Turtle Nest Beach Management Report*



ANNUAL SEA TURTLE NEST BEACH MANAGEMENT REPORT

**NORTH CAROLINA WILDLIFE RESOURCES COMMISSION** **NONGAME AND ENDANGERED WILDLIFE PROGRAM**

YEAR__________ PROJECT ____________________________ BEACH DIVISION_________________________ PAGE_____ OF_____

| DATE | ACT. # | ZONE | TYPE ACT.[1] |  | SPECIES | TREAT. CODE[2] | HATCH DATE | #EGGS (N) | #EMERGED (H) | RATE (H/N) | COMMENTS (NEST LOSSES ETC) |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | N | F |  |  |  |  |  |  |  |
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| **TOTALS** |  |  |  |  |  |  |  |  |  |  |  |

[1] TYPE OF ACTIVITY (Check One): N = NEST; F = FALSE CRAWL

[2] TREATMENT CODES: 0 = NO TREATMENT; 1 = RELOCATED; 2 = WIRED IN PLACE; 3 = RELOCATED AND WIRED

COORDINATOR____________________________________
Signature

## Instructions for 2000 and 2001: From the Handbook for Sea Turtle Volunteers in North Carolina (NCWRC, 1998)

### INDIVIDUAL CRAWL RECORD

CRAWL DATE:__________________________(for all crawls discovered *after* midnight, enter the date the crawl was found. For all crawls found/reported *before* midnight, enter the next day's date.

CRAWL TYPE (check one): ☐=FALSE CRAWLor ☐=NEST

SPECIES (check one): ☐Loggerhead ☐Green turtle ☐ Leatherback ☐ Kemp's ridley

CRAWL NUMBER:_____________

TREATMENT (check one) ☐=0-No treatment
☐=1-Relocated
☐=2-wired in place
☐=3-Relocated and wired

CRAWL LOCATION:________________________________________________________________________________________

CRAWL WAS FOUND IN SEA TURTLE NEST MANAGEMENT ZONE_________________

CRAWL LATITUDE_________________________LONGITUDE___________________________WAYPOINT #________________

RELOCATED NEST LOCATION:_____________________________________________________________________________

REL. SITE LATITUDE________________________LONGITUDE_________________________WAYPOINT #_______________

REASON FOR MOVING NEST____________________________________________________________________________________

NUMBER OF EGGS RELOCATED:________________ NEST DEPTH__________________in./cm.

TRANSPONDER BALL BURIED WITH NEST? Y / N TIME NEST WAS MOVED_________________________

## NEST DISTURBANCES

**Enter "Y" if nest was washed by the tide, enter "N" if nest was not washed by the tide for each day of the incubation period.**

Day 1________
Day 2________
Day 3________
Day 4________
Day 5________
Day 6________
Day 7________
Day 8________
Day 9________
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Day 86________
Day 87________
Day 88________
Day 89________
Day 90________

TOTAL NUMBER OF DAYS NEST WAS WASHED OVER___________________________

**Record of nest disturbances that resulted in partial or total loss of eggs or hatchlings, including loss of nest markers, during the incubation period.**

| Date | Type of disturbance | Comments (include estimated # of lost eggs/hatchlings) |
|---|---|---|
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## Appendix B Instructions for Completing the Annual Nesting Report

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**HATCHING/NEST INVENTORY DATA** *SEE VOLUNTEER HANDBOOK FOR MORE DETAILED INSTRUCTIONS ON PERFORMING NEST EXCAVATIONS.*

Date of first hatchling emergence (if first emergence was seen *after* midnight, record that day's date; if first emergence was seen *before* midnight, record the next day's date)_____________________________

Date of last hatchling emergence (if last emergence was seen *after* midnight, record that day's date; if last emergence was seen *before* midnight, record the next day's date)_____________________________.

Nest inventory date:______________________________ Excavated by:_____________________________________________________

Perform the following steps to assist with the determination of the nest's hatch success rate.

1. Separate whole eggshells (>50%) from pieces (<50%);
only count whole eggshells (each whole eggshell represents one hatched egg): **ES** = _______________

2. Count the number of whole unhatched eggs: **UH** = _______________

3. Count the # of pipped eggs with live or dead hatchlings: **PE** = _______________

4. Count the # of dead hatchlings that emerged from eggs but did not leave the nest: **DH** = _______________

5. Count the # of live hatchlings free of eggshells but remaining in the nest, irrespective of their condition. **LH** = _______________

**If the nest contains live hatchlings that emerged from the egg shell, but did not leave the nest cavity or pipped eggs with live hatchlings, see the volunteer handbook for further instructions.*

PLEASE VERIFY SPECIES, BASED ON HATCHLINGS: ☐ Loggerhead ☐ Green turtle ☐ Leatherback ☐ Kemp's ridley

RECORD ANY NEST DISTURBANCES SEEN WHILE PERFORMING THE NEST INVENTORY (e.g., root invasion, fire ant invasion, dead hatchlings that appeared to be trapped by compacted sand, etc.) IN THE NEST DISTURBANCE TABLE ABOVE.

Additional comments (e.g., status of embryos among unhatched eggs, etc.):

_______________________________________________________________________________________________

Table C.1: Results from 1997 statistical comparison of hatching success among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/ Number of Nest /Medians** | **Test Statistic** | **P-Value** |
|---|---|---|---|---|---|---|
| BHIC | 1997 | Season | MW | I (21) (0.91)<br>R (52) (0.88) | T = 731.500 | P = 0.583 |
| | 1997 | ES | MW | I (7) (0.76)<br>R (7) (0.82) | T = 42.000 | P = 0.209 |
| | 1997 | MS | MW | I (9) (0.93)<br>R (32) (0.855) | T = 227.500 | P = 0.231 |
| | 1997 | LS | MW | I (5) (0.92)<br>R (13) (0.95) | T = 39.500 | P = 0.460 |
| CHNS | 1997 | Season | MW | I (5) (0.01000)<br>R (31) (0.77) | T = 68.500 | P = 0.282 |
| | 1997 | ES | | NEN | | |
| | 1997 | MS | | NEN | | |
| | 1997 | LS | | NEN | | |
| CLNS | 1997 | Season | MW | I (25) (0.91)<br>R (92) (0.87) | T = 1750.50 | P = 0.067 |
| | 1997 | ES | | NEN | | |
| | 1997 | MS | MW | I (9) (0.90)<br>R (46) (0.89) | T = 271.000 | P = 0.674 |
| | 1997 | LS | MW | I (12) (0.92)<br>R (27) (0.89) | T = 295.00 | P = 0.097 |
| TBVO | 1997 | Season | MW | I (52) (0.93)<br>R (11) (0.95) | T = 384.50 | P = 0.562 |
| | 1997 | ES | MW | NEN | | |
| | 1997 | MS | MW | I (20) (0.945)<br>R (7) (0.96) | T = 99.50 | P = 0.956 |
| | 1997 | LS | | NEN | | |

Table C.2: Results from 1998 statistical comparison of hatching success among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| Beach | Year | Time Period | Test (MW/KW) | Nest Categories/ Number of Nest /Medians | Test Statistic | P-Value |
|---|---|---|---|---|---|---|
| | | | | | | |
| BHIC | 1998 | Season | MW | I (16) (0.895)<br>R (41) (0.00) | T =342.000 | P <0.001 |
| | 1998 | ES | MW | I (12) (0.84)<br>C (5) (0.82) | T = 39.500 | P = 0.598 |
| | 1998 | MS | | TMT | | |
| | 1998 | LS | | TMT | | |
| | | | | | | |
| CHNS | 1998 | Season | MW | I (17) (0.86)<br>R (66) (0.795) | T = 802.000 | P = 0.323 |
| | 1998 | ES | MW | I (7) (0.90)<br>R (9) (0.81) | T = 67.500 | P = 0.427 |
| | 1998 | MS | MW | I (9) (0.86)<br>R (36) (0.815) | T = 228.50 | P = 0.551 |
| | 1998 | LS | | NEN | | |
| | | | | | | |
| CLNS | 1998 | Season | MW | I (29) (0.89)<br>R (114) (0.91) | T = 1956.00 | P = 0.509 |
| | 1998 | ES | MW | I (18) (0.87)<br>R (25) (0.88) | T = 384.500 | P = 0.787 |
| | 1998 | MS | MW | I (7) (0.65)<br>R (59) (0.91) | T = 161.500 | P = 0.131 |
| | 1998 | LS | MW | NEN | T = 230.500 | P <0.001 |
| | | | | | | |
| TBVO | 1998 | Season | MW | I (19) (0.93)<br>R (44) (0.00) | T = 905.500 | P <0.001 |
| | 1998 | ES | MW | I (16) (0.95)<br>R (9) (0.92) | T = 104.00 | P = 0.479 |
| | 1998 | MS | | TMT | | |
| | 1998 | LS | | TMT | | |

Table C.3: Results from 1999 statistical comparison of hatching success among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| Beach | Year | Time Period | Test (MW/KW) | Nest Categories/ Number of Nest /Medians | Test Statistic | P-Value |
|---|---|---|---|---|---|---|
| | | | | | | |
| BHIC | 1999 | Season | MW | I (19) (0.79)<br>R (64) (0.65) | T = 1028.00 | P = 0.013 |
| | 1999 | ES | MW | I (12) (0.77)<br>R (22) (0.805) | T = 197.00 | P = 0.652 |
| | 1999 | MS | MW | I (5) (0.89)<br>R (28) (0.67) | T = 141.000 | P = 0.005 |
| | 1999 | LS | | TMT | | |
| | | | | | | |
| CHNS | 1999 | Season | MW | I (15) (0.88)<br>R (54) (0.00) | T = 759.00 | P <0.001 |
| | 1999 | ES | MW | I (10) (0.79)<br>R (11) (0.81) | T = 100.000 | P = 0.503 |
| | 1999 | MS | MW | I (5) (0.94)<br>R (28) (0.00) | T = 133.500 | P = 0.016 |
| | 1999 | LS | | TMT | | |
| | | | | | | |
| CLNS | 1999 | Season | MW | I (58) (0.87)<br>R (124) (0.575) | T = 6679.50 | P <0.001 |
| | 1999 | ES | MW | I (37) (0.88)<br>R (18) (0.81) | T = 436.500 | P = 0.229 |
| | 1999 | MS | MW | I (20) (0.845)<br>R (68) (0.655) | T = 988.00 | P = 0.332 |
| | 1999 | LS | | TMT | | |
| | | | | | | |
| TBVO | 1999 | Season | MW | I (46) (0.895)<br>R (86) (0.595) | T = 4035.50 | P <0.001 |
| | 1999 | ES | MW | I (25) (0.89)<br>R (11) (0.84) | T = 187.000 | P = 0.583 |

| | | | | | |
|---|---|---|---|---|---|
| 1999 | MS | MW | I (21) (0.92)<br>R (36) (0.855) | T = 714.00 | P = 0.084 |
| 1999 | LS | | TMT | | |
| | | | | | |

Table C.4: Results from 2000 statistical comparison of hatching success among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/ Number of Nest /Medians** | **Test Statistic** | **P-Value** | **Significant Difference/ (Q-Value)** |
|---|---|---|---|---|---|---|---|
| BHIC | 2000 | Season | KW | I (17) (0.95)<br>R (19) (0.84)<br>C (6) (0.92) | H = 8.111 with 2 degrees of freedom | P = 0.017 | I v R: Yes (2.786)<br>I v C: No (1.501)<br>R v C: No (0.464) |
| | 2000 | ES | MW | I (7) (0.96)<br>R (7) (0.88) | T = 74.000 | P = 0.004 | Yes |
| | 2000 | MS | MW | I (7) (0.93)<br>R (10) (0.46) | T = 74.500 | P = 0.283 | |
| | 2000 | LS | | NEN | | | |
| CHNS | 2000 | Season | KW | I (24) (0.93)<br>R (25) (0.90)<br>C (26) (0.00) | H = 20.343 with 2 degrees of freedom | P <0.001 | I v R: No (0.522)<br>R v C: Yes (3.809)<br>I v C: Yes (4.296) |
| | 2000 | ES | MW | I (10) (0.905)<br>R (9) (0.91) | T = 92.000 | P = 0.903 | |
| | 2000 | MS | KW | I (9) (0.95)<br>R (12) (0.88)<br>C (17) (0.00) | H = 18.751 with 2 degrees of freedom | P <0.001 | Iv R: No (0.847)<br>R v C: Yes (3.170)<br>I v C: Yes (3.806) |
| | 2000 | LS | MW | I (5) (0.020)<br>C (7) (0.000) | T = 41.000 | P = 0.202 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CLNS | 2000 | Season | KW | I (46) (0.77)<br>R (119) (0.89)<br>C (22) (0.91) | H = 1.985 with 2 degrees of freedom | P = 0.371 | |
| | 2000 | ES | KW | I (11) (0.17)<br>R (33) (0.90)<br>C (8) (0.89) | H = 5.935 with 2 degrees of freedom | P = 0.051 | |
| | 2000 | MS | KW | I (22) (0.925)<br>R (68) (0.88)<br>C (9) (0.960) | H = 3.520 with 2 degrees of freedom | P = 0.172 | |
| | 2000 | LS | KW | I (13) (0.760)<br>R (18) (0.830)<br>C (5) (0.0400) | H = 3.870 with 2 degrees of freedom | P = 0.144 | |
| | | | | | | | |
| TBVO | 2000 | Season | MW | I (65) (0.93)<br>R (33) (0.87) | T = 1320.00 | P = 0.019 | Yes |
| | 2000 | ES | MW | I (18) (0.895)<br>R (14) (0.85) | T = 205.500 | P = 0.342 | |
| | 2000 | MS | MW | I (28) (0.935)<br>R (11) (0.93) | T = 171.500 | P = 0.134 | |
| | 2000 | LS | MW | I (19) (0.91)<br>R (8) (0.935) | T = 103.00 | P = 0.652 | |

Table C.5: Results from 2001 statistical comparison of hatching success among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/ Number of Nest /Medians** | **Test Statistic** | **P-Value** | **Significant Difference/ (Q-Value)** |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| BHIC | 2001 | Season | KW | I (20) (0.915)<br>R (30) (0.89)<br>C (25) (0.57) | H = 15.253 with 2 degrees of freedom | P <0.001 | I v R: No (1.335)<br>R v C: Yes (2.740)<br>I v C: Yes (3.758) |
| | 2001 | ES | MW | I (6) (0.89)<br>R (9) (0.91) | T = 43.000 | P = 0.596 | |
| | 2001 | MS | KW | I (12) (0.945)<br>R (16) (0.87)<br>C (14) (0.58) | H = 10.646 with 2 degrees of freedom | P = 0.005 | I v R: No (2.135)<br>R v C: No (1.241)<br>I v C: Yes (3.226) |
| | 2001 | LS | MW | R (5) (0.93)<br>C (10) (0.0750) | T = 51.000 | P = 0.198 | |
| | | | | | | | |
| CHNS | 2001 | Season | MW | R (28) (0.79)<br>C (35) (0.000) | T = 1048.50 | P = 0.035 | Yes |
| | 2001 | ES | MW | R (10) (0.84)<br>C (11) (0.25) | T = 116.00 | P = 0.698 | |
| | 2001 | MS | MW | R (15) (0.89)<br>C (20) (0.000) | T = 349.000 | P = 0.009 | Yes |
| | 2001 | LS | | NEN | | | |
| | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CLNS | 2001 | Season | KW | I (44) (0.93)<br>R (58) (0.925)<br>C (13) (0.110) | H = 9.674 with 2 degrees of freedom | P = 0.008 | I v R: No (0.724)<br>R v C: Yes (3.098)<br>I v C: Yes (2.553) |
| | 2001 | ES | MW | I (19) (0.85)<br>R (18) (0.935) | T = 385.50 | P = 0.191 | |
| | 2001 | MS | MW | I (16) (0.92)<br>R (27) (0.92) | T = 336.00 | P = 0.697 | |
| | 2000 | LS | KW | I (9) (0.960)<br>R (13) (0.920)<br>C (7) (0.000) | H = 6.606 with 2 degrees of freedom | P = 0.037 | I v C: Yes (2.488)<br>I v R: No (0.793)<br>C v R: No (1.941) |
| | | | | | | | |
| TBVO | 2001 | Season | MW | I (32) (0.955)<br>R (46) (0.895) | T = 1435.50 | P = 0.082 | |
| | 2001 | ES | MW | I (6) (0.935)<br>R (16) (0.90) | T = 75.500 | P = 0.658 | |
| | 2001 | MS | MW | I (15) (0.96)<br>R (24) (0.85) | T = 367.500 | P = 0.053 | |
| | 2001 | LS | MW | I (11) (0.92)<br>R (6) (0.935) | T = 57.000 | P = 0.802 | |
| | | | | | | | |

Table C.6: Results from 1997 statistical comparison of incubation duration among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/Nest Number/Median** | **Test Statistic** | **P-Value** |
|---|---|---|---|---|---|---|
| | | | | | | |
| BHIC | 1997 | Season | MW | I (17) (60)<br>R (49) (59) | T = 735.500 | P = 0.015 |
| | 1997 | ES | MW | I (5) (61)<br>R (5) (56) | T = 35.500 | P = 0.095 |
| | 1997 | MS | MW | I (8) (59)<br>R (31) (58) | T = 197.500 | P = 0.198 |
| | 1997 | LS | | NEN | | |
| | | | | | | |
| CHNS | 1997 | Season | | NA | | |
| | 1997 | ES | | NA | | |
| | 1997 | MS | | NA | | |
| | 1997 | LS | | NA | | |
| | | | | | | |
| CLNS | 1997 | Season | MW | I (21) (68)<br>R (69) (61) | T = 1367.50 | P = <0.001 |
| | 1997 | ES | MW | I (5) (72)<br>R (15) (62) | T = 71.000 | P = 0.116 |
| | 1997 | MS | MW | I (6) (63)<br>R (38) (60) | T = 190.500 | P = 0.060 |
| | 1997 | LS | MW | I (10) (69)<br>R (16) (65) | T = 186.500 | P = 0.007 |
| | | | | | | |
| TBVO | 1997 | Season | MW | I (47) (66)<br>R (11) (62) | T = 273.500 | P = 0.316 |
| | 1997 | ES | | NEN | | |
| | 1997 | MS | MW | I (20) (64)<br>R (7) (61) | T = 54.000 | P = 0.016 |
| | 1997 | LS | | NEN | | |
| | | | | | | |

Table C.7: Results from 1998 statistical comparison of incubation duration among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/Nest Number/Median** | **Test Statistic** | **P-Value** |
|---|---|---|---|---|---|---|
| BHIC | 1998 | Season | MW | I (13) (57)<br>R (13) (55) | T = 215.500 | P = 0.043 |
| | 1998 | ES | MW | I (11) (58)<br>R (5) (54) | T = 22.000 | P = 0.023 |
| | 1998 | MS | | NEN | | |
| | 1998 | LS | | NEN | | |
| CHNS | 1998 | Season | MW | I (12) (56)<br>R (47) (57) | T = 302.500 | P = 0.283 |
| | 1998 | ES | | I (5) (56)<br>R (8) (57.5) | T = 25.500 | P = 0.171 |
| | 1998 | MS | | I (12) (55)<br>R (20) (57) | T = 180.000 | P = 0.496 |
| | 1998 | LS | | NEN | | |
| CLNS | 1998 | Season | KW | I (24) (61)<br>R (80) (61.5)<br>C (12) (65) | H = 5.764 with 2 degrees of freedom | P = 0.056 |
| | 1998 | ES | MW | I (19) (61)<br>R (25) (61.5) | T = 368.000 | P = 0.425 |
| | 1998 | MS | MW | R (40) (60.5)<br>C (6) (60.5) | T = 152.000 | P = 0.732 |
| | 1998 | LS | | NEN | | |
| TBVO | 1998 | Season | MW | I (20) (62.5)<br>R (17) (58) | T = 298.000 | P = 0.455 |
| | 1998 | ES | MW | I (17) (63)<br>R (9) (59) | T = 108.500 | P = 0.500 |

| | | |
|---|---|---|
| 1998 | MS | NEN |
| 1998 | LS | NEN |
| | | |

Table C.8: Results from 1999 statistical comparison of incubation duration among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/Nest Number/Median** | **Test Statistic** | **P-Value** |
|---|---|---|---|---|---|---|
| | | | | | | |
| BHIC | 1999 | Season | MW | I (19) (57)<br>R (40) (56) | T = 603.000 | P = 0.598 |
| | 1999 | ES | MW | I (12) (59.5)<br>R (20) (59.5) | T = 203.000 | P = 0.861 |
| | 1999 | MS | MW | I (11) (56)<br>R (35) (57) | T = 58.5 | P = 0.684 |
| | 1999 | LS | | NEN | | |
| | | | | | | |
| CHNS | 1999 | Season | MW | I (14) (62)<br>R (21) (59) | T = 285.000 | P = 0.274 |
| | 1999 | ES | MW | I (9) (63)<br>R (10) (62) | T = 103.500 | P = 0.288 |
| | 1999 | MS | MW | I (5) (57)<br>R (11) (56) | T = 39.000 | P = 0.734 |
| | 1999 | LS | | NEN | | |
| | | | | | | |
| CLNS | 1999 | Season | KW | I (41) (61)<br>R (55) (59)<br>C (6) (66.5) | H = 5.493 with 2 degrees of freedom | P = 0.064 |
| | 1999 | ES | MW | I (29) (62)<br>R (15) (67) | T = 414.000 | P = 0.060 |
| | 1999 | MS | MW | I (11) (56)<br>R (35) (57) | T = 262.500 | P = 0.928 |
| | 1999 | LS | | NEN | | |
| | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| TBVO | 1999 | Season | MW | I (46) (60)<br>R (49) (59) | T = 2363.00 | P = 0.250 |
| | 1999 | ES | MW | I (25) (67)<br>R (11) (69) | T = 234.500 | P = 0.295 |
| | 1999 | MS | MW | I (21) (57)<br>R (31) (56) | T = 601.000 | P = 0.412 |
| | 1999 | LS | | NEN | | |

Table C.9: Results from 2000 statistical comparison of incubation duration among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| Beach | Year | Time Period | Test (MW/KW) | Nest Categories/Nest Number/Median | Test Statistic | P-Value |
|---|---|---|---|---|---|---|
| | | | | | | |
| BHIC | 2000 | Season | KW | I (16) (60)<br>R (13) (60.5)<br>C (5) (65) | H = 0.557 with 2 degrees of freedom | P = 0.757 |
| | 2000 | ES | MW | I (7) (58)<br>R (7) (60) | T = 50.000 | P = 0.805 |
| | 2000 | MS | MW | I (7) (61)<br>R (5) (59) | T = 24.000 | P = 0.202 |
| | 2000 | LS | | NEN | | |
| | | | | | | |
| CHNS | 2000 | Season | KW | I (16) (66.5)<br>R (17) (63)<br>C (5) (66) | H = 1.912 with 2 degrees of freedom | P = 0.384 |
| | 2000 | ES | MW | I (9) (69)<br>R (6) (62.5) | T = 33.000 | P = 0.087 |
| | 2000 | MS | MW | I (7) (66)<br>R (10) (66.5) | T = 65.500 | P = 0.845 |
| | 2000 | LS | | NEN | | |
| | | | | | | |
| CLNS | 2000 | Season | KW | I (19) (65)<br>R (68) (66.5)<br>C (12) (69.5) | H = 1.332 with 2 degrees of freedom | P = 0.514 |
| | 2000 | ES | MW | I (7) (61)<br>I (25) (65) | T = 94.000 | P = 0.338 |
| | 2000 | MS | KW | I (7) (64)<br>R (31) (66)<br>C (6) (65.5) | H = 1.594 with 2 degrees of freedom | P = 0.451 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | 2000 | LS | MW | I (5) (72)<br>R (12) (71.5) | T = 46.500 | P = 0.916 |
| | | | | | | |
| TBVO | 2000 | Season | MW | I (62) (64)<br>R (33) (63) | T = 1339.50 | P = 0.056 |
| | 2000 | ES | MW | I (16) (64)<br>R (14) (61.5) | T = 174.500 | P = 0.081 |
| | 2000 | MS | MW | I (30) (63)<br>R (11) (63) | T = 221.000 | P = 0.780 |
| | 2000 | LS | MW | I (16) (67)<br>R (8) (66) | T = 88.500 | P = 0.500 |

Table C.10: Results from 2001 statistical comparison of incubation duration among nest categories (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties. Season = Entire nesting season, ES = early season, MS = middle season, and LS = late season.

| **Beach** | **Year** | **Time Period** | **Test (MW/KW)** | **Nest Categories/Nest Number/Median** | **Test Statistic** | **P-Value** | **Significant Difference/ (Q-Value)** |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| BHIC | 2001 | Season | KW | I (20) (61)<br>R (27) (57)<br>C (14) (61) | H = 12.187 with 2 degrees of freedom | P = 0.002 | I v R: Yes (3.141)<br>I v C: No (0.224)<br>R v C: Yes (2.577) |
| | 2001 | ES | MW | I (6) (68)<br>R (9) (61) | T = 64.000 | P = 0.068 | |
| | 2001 | MS | KW | I (12) (59.5)<br>R (14) (56.5)<br>C (9) (61) | H = 13.758 with 2 degrees of freedom | P = 0.001 | I v C: No (0.981)<br>I v R: Yes (2.645)<br>R v C: Yes (3.447) |
| | 2001 | LS | | | | | |
| | | | | | | | |
| CHNS | 2001 | Season | MW | R (16) (62.5)<br>C (11) (64) | T = 175.000 | P = 0.312 | |
| | 2001 | ES | MW | R (6) (67.5)<br>C (6) (73.5) | T = 28.000 | P = 0.093 | |
| | 2001 | MS | MW | R (10) (62)<br>C (5) (61) | T = 39.500 | P = 1.000 | |
| | 2001 | LS | | NEN | | | |
| | | | | | | | |
| CLNS | 2001 | Season | MW | I (20) (64.5)<br>R (40) (65) | T = 628.500 | P = 0.778 | |
| | 2001 | ES | MW | I (9) (64)<br>R (17) (65) | T = 129.500 | P = 0.686 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2001 | MS | MW | I (5) (62.5)<br>R (18) (65) | T = 55.000 | P = 0.737 | |
| | 2000 | LS | | NEN | | | |
| TBVO | 2001 | Season | MW | I (32) (61)<br>R (44) (60) | T = 1443.00 | P = 0.027 | Yes |
| | 2001 | ES | MW | I (6) (70)<br>R (16) (61.5) | T = 100.500 | P = 0.022 | Yes |
| | 2001 | MS | MW | I (15) (61)<br>R (23) (59) | T = 372.000 | P = 0.018 | Yes |
| | 2001 | LS | MW | I (11) (60)<br>R (5) (60) | T = 39.000 | P = 0.734 | |

Table C.11: Results from statistical comparison of rate of nest relocation among seasonal divisions (early season (ES), middle season (MS), and late season (LS)). MW = Mann Whitney Test and KW = Kruskal-Wallis Test. NEN = Not enough nests and TMT = Too many ties.

| Beach | Year | Season | Nest Number | Number Relocated (Observed) | Number Relocated (Expected) | Chi-Square Test Statistic ($X^2$) | P-value |
|---|---|---|---|---|---|---|---|
| BHIC | 1997 | ES | 14 | 7 | 10 | 4.02 | n.s.(0.1341) |
| | 1997 | MS | 41 | 32 | 29.2 | | |
| | 1997 | LS | 18 | 13 | 12.8 | | |
| CHNS | 1997 | ES | 2 | 1 | 1.7 | 2.34 | n.s.(0.3107) |
| | 1997 | MS | 26 | 23 | 21.8 | | |
| | 1997 | LS | 9 | 7 | 7.5 | | |
| CLNS | 1997 | ES | 26 | 19 | 19.1 | 2.48 | n.s(0.2888) |
| | 1997 | MS | 58 | 46 | 42.6 | | |
| | 1997 | LS | 40 | 26 | 29.4 | | |
| TBVO | 1997 | ES | 26 | 2 | 4 | 3.85 | n.s.(0.1457) |
| | 1997 | MS | 27 | 7 | 4.1 | | |
| | 1997 | LS | 19 | 2 | 2.9 | | |
| BHIC | 1998 | ES | 17 | 5 | 8.1 | 4.56 | n.s.(0.1025) |
| | 1998 | MS | 51 | 29 | 24.3 | | |
| | 1998 | LS | 18 | 7 | 8.6 | | |
| CHNS | 1998 | ES | 32 | 9 | 19.3 | 23.67 | *(<0.0001) |
| | 1998 | MS | 43 | 36 | 25.9 | | |
| | 1998 | LS | 33 | 20 | 19.9 | | |
| CLNS | 1998 | ES | 50 | 25 | 30.3 | 3.35 | n.s.(0.1871) |
| | 1998 | MS | 90 | 59 | 54.6 | | |
| | 1998 | LS | 48 | 30 | 29.1 | | |
| TBVO | 1998 | ES | 28 | 9 | 12.2 | 11.00 | *(0.0041) |
| | 1998 | MS | 48 | 17 | 20.9 | | |
| | 1998 | LS | 25 | 18 | 10.9 | | |
| BHIC | 1999 | ES | 38 | 22 | 22.9 | 0.20 | n.s.(0.9047) |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1999 | MS | 46 | 28 | 27.8 | | |
| | 1999 | LS | 22 | 14 | 13.3 | | |
| CHNS | 1999 | ES | 22 | 11 | 13.2 | 1.22 | n.s.(0.5429) |
| | 1999 | MS | 44 | 28 | 26.4 | | |
| | 1999 | LS | 24 | 15 | 14.4 | | |
| CLNS | 1999 | ES | 134 | 17 | 49.6 | 64.46 | *(<0.0001) |
| | 1999 | MS | 110 | 68 | 40.8 | | |
| | 1999 | LS | 88 | 38 | 32.6 | | |
| TBVO | 1999 | ES | 38 | 11 | 18.7 | 9.76 | *(0.0076) |
| | 1999 | MS | 73 | 36 | 35.9 | | |
| | 1999 | LS | 64 | 39 | 31.5 | | |
| | | | | | | | |
| BHIC | 2000 | ES | 17 | 7 | 7.3 | 0.09 | n.s.(0.9537) |
| | 2000 | MS | 22 | 10 | 9.5 | | |
| | 2000 | LS | 5 | 2 | 2.2 | | |
| CHNS | 2000 | ES | 23 | 8 | 6.7 | 0.56 | n.s.(0.7549) |
| | 2000 | MS | 44 | 12 | 12.7 | | |
| | 2000 | LS | 16 | 4 | 4.6 | | |
| CLNS | 2000 | ES | 52 | 34 | 33.5 | 3.39 | n.s.(0.1838) |
| | 2000 | MS | 99 | 68 | 63.9 | | |
| | 2000 | LS | 35 | 18 | 22.6 | | |
| TBVO | 2000 | ES | 33 | 14 | 10.6 | 2.53 | n.s.(0.2822) |
| | 2000 | MS | 43 | 11 | 13.8 | | |
| | 2000 | LS | 27 | 8 | 8.7 | | |
| | | | | | | | |
| BHIC | 2001 | ES | 16 | 9 | 6.4 | 2.62 | n.s.(0.2701) |
| | 2001 | MS | 42 | 16 | 16.8 | | |
| | 2001 | LS | 17 | 5 | 6.8 | | |
| CHNS | 2001 | ES | 21 | 10 | 9.7 | 0.28 | n.s.(0.8688) |
| | 2001 | MS | 38 | 18 | 17.6 | | |
| | 2001 | LS | 8 | 3 | 3.7 | | |
| CLNS | 2001 | ES | 39 | 18 | 19.7 | 1.49 | n.s.(0.4739) |
| | 2001 | MS | 51 | 29 | 25.7 | | |
| | 2001 | LS | 29 | 13 | 14.6 | | |
| TBVO | 2001 | ES | 22 | 16 | 13.4 | 5.15 | n.s.(0.0763) |
| | 2001 | MS | 39 | 25 | 23.8 | | |
| | 2001 | LS | 16 | 6 | 9.8 | | |
| | | | | | | | |

Table D.1: Mean and median values of hatching success subdivided by beach, year, and nest category (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)).

| Beach | Year | Nest Category | Number of Nests | Mean | SD | SE | Median |
|---|---|---|---|---|---|---|---|
| **BHIC** | **1997** | **Season** | **73** | **0.792** | **0.251** | **0.0293** | **0.900** |
| | | I | 21 | 0.702 | 0.364 | 0.0794 | 0.910 |
| | | R | 52 | 0.828 | 0.180 | 0.0249 | 0.880 |
| | | C | 0 | -- | -- | -- | -- |
| **CHNS** | **1997** | **Season** | **37** | **0.572** | **0.388** | **0.0638** | **0.740** |
| | | I | 5 | 0.362 | 0.492 | 0.220 | 0.01000 |
| | | R | 31 | 0.625 | 0.357 | 0.0641 | 0.770 |
| | | C | 1 | 0.000 | -- | -- | 0.000 |
| **CLNS** | **1997** | **Season** | **120** | **0.727** | **0.316** | **0.0289** | **0.885** |
| | | I | 20 | 0.861 | 0.135 | 0.0271 | 0.910 |
| | | R | 92 | 0.687 | 0.344 | 0.0359 | 0.870 |
| | | C | 3 | 0.857 | 0.150 | 0.0865 | 0.900 |
| **TBVO** | **1997** | **Season** | **64** | **0.773** | **0.330** | **0.0412** | **0.930** |
| | | I | 52 | 0.777 | 0.327 | 0.0454 | 0.930 |
| | | R | 11 | 0.822 | 0.275 | 0.0828 | 0.950 |
| | | C | 1 | 0.000 | -- | -- | 0.000 |
| **BHIC** | **1998** | **Season** | **86** | **0.282** | **0.399** | **0.0430** | **0.000** |
| | | I | 16 | 0.792 | 0.274 | 0.0686 | 0.895 |
| | | R | 41 | 0.278 | 0.387 | 0.0605 | 0.000 |
| | | C | 29 | 0.00621 | 0.0334 | 0.00621 | 0.000 |
| **CHNS** | **1998** | **Season** | **88** | **0.674** | **0.303** | **0.0323** | **0.790** |
| | | I | 17 | 0.759 | 0.250 | 0.0606 | 0.860 |
| | | R | 66 | 0.701 | 0.269 | 0.0331 | 0.795 |
| | | C | 5 | 0.0260 | 0.0581 | 0.0260 | 0.000 |
| **CLNS** | **1998** | **Season** | **188** | **0.616** | **0.400** | **0.0292** | **0.835** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | 29 | 0.731 | 0.337 | 0.0625 | 0.890 |
| | | R | 114 | 0.753 | 0.313 | 0.0293 | 0.910 |
| | | C | 45 | 0.194 | 0.344 | 0.0513 | 0.000 |
| **TBVO** | **1998** | **Season** | **99** | **0.293** | **0.412** | **0.0414** | **0.000** |
| | | I | 19 | 0.847 | 0.225 | 0.0517 | 0.930 |
| | | R | 44 | 0.281 | 0.398 | 0.0600 | 0.000 |
| | | C | 36 | 0.0161 | 0.0967 | 0.0161 | 0.000 |
| **BHIC** | **1999** | **Season** | **106** | **0.401** | **0.396** | **0.0385** | **0.390** |
| | | I | 19 | 0.684 | 0.288 | 0.0660 | 0.790 |
| | | R | 64 | 0.461 | 0.389 | 0.0486 | 0.650 |
| | | C | 23 | 0.000 | 0.000 | 0.000 | 0.000 |
| **CHNS** | **1999** | **Season** | **86** | **0.312** | **0.406** | **0.0437** | **0.000** |
| | | I | 15 | 0.660 | 0.379 | 0.0977 | 0.880 |
| | | R | 54 | 0.313 | 0.401 | 0.0545 | 0.000 |
| | | C | 17 | 0.000588 | 0.00243 | 0.000588 | 0.000 |
| **CLNS** | **1999** | **Season** | **237** | **0.417** | **0.427** | **0.0278** | **0.180** |
| | | I | 58 | 0.732 | 0.324 | 0.0425 | 0.870 |
| | | R | 124 | 0.443 | 0.422 | 0.0379 | 0.575 |
| | | C | 55 | 0.0253 | 0.135 | 0.0182 | 0.000 |
| **TBVO** | **1999** | **Season** | **172** | **0.477** | **0.424** | **0.0323** | **0.595** |
| | | I | 46 | 0.820 | 0.220 | 0.0324 | 0.895 |
| | | R | 86 | 0.483 | 0.412 | 0.0445 | 0.595 |
| | | C | 40 | 0.0715 | 0.231 | 0.0366 | 0.000 |
| **BHIC** | **2000** | **Season** | **42** | **0.720** | **0.369** | **0.0569** | **0.920** |
| | | I | 17 | 0.881 | 0.193 | 0.0468 | 0.950 |
| | | R | 19 | 0.606 | 0.413 | 0.0949 | 0.840 |
| | | C | 6 | 0.622 | 0.482 | 0.197 | 0.920 |
| **CHNS** | **2000** | **Season** | **75** | **0.535** | **0.444** | **0.0512** | **0.840** |
| | | I | 24 | 0.730 | 0.382 | 0.0780 | 0.930 |
| | | R | 25 | 0.716 | 0.374 | 0.0748 | 0.900 |
| | | C | 26 | 0.182 | 0.339 | 0.0665 | 0.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CLNS** | **2000** | **Season** | **187** | **0.649** | **0.387** | **0.0283** | **0.890** |
| | | I | 46 | 0.559 | 0.436 | 0.0644 | 0.77 |
| | | R | 119 | 0.676 | 0.364 | 0.0333 | 0.89 |
| | | C | 22 | 0.692 | 0.392 | 0.0835 | 0.91 |
| | | | | | | | |
| **TBVO** | **2000** | **Season** | **100** | **0.844** | **0.205** | **0.0205** | **0.910** |
| | | I | 65 | 0.891 | 0.111 | 0.0138 | 0.930 |
| | | R | 33 | 0.788 | 0.266 | 0.0464 | 0.870 |
| | | C | 2 | 0.225 | 0.318 | 0.225 | 0.225 |
| | | | | | | | |
| **BHIC** | **2001** | **Season** | **75** | **0.712** | **0.352** | **0.0407** | **0.890** |
| | | I | 20 | 0.915 | 0.0431 | 0.00964 | 0.915 |
| | | R | 30 | 0.789 | 0.279 | 0.0510 | 0.890 |
| | | C | 25 | 0.458 | 0.422 | 0.0844 | 0.570 |
| | | | | | | | |
| **CHNS** | **2001** | **Season** | **67** | **0.428** | **0.449** | **0.0548** | **0.130** |
| | | I | 4 | 0.960 | 0.0283 | 0.0141 | 0.970 |
| | | R | 28 | 0.525 | 0.457 | 0.0863 | 0.790 |
| | | C | 35 | 0.289 | 0.405 | 0.0685 | 0.000 |
| | | | | | | | |
| **CLNS** | **2001** | **Season** | **115** | **0.744** | **0.348** | **0.0325** | **0.920** |
| | | I | 44 | 0.772 | 0.325 | 0.0489 | 0.930 |
| | | R | 58 | 0.802 | 0.301 | 0.0395 | 0.925 |
| | | C | 13 | 0.392 | 0.436 | 0.121 | 0.110 |
| | | | | | | | |
| **TBVO** | **2001** | **Season** | **78** | **0.851** | **0.186** | **0.0210** | **0.920** |
| | | I | 32 | 0.868 | 0.194 | 0.0342 | 0.955 |
| | | R | 46 | 0.839 | 0.181 | 0.0267 | 0.895 |
| | | C | 0 | -- | -- | -- | -- |

Table D.2: Mean and median values of hatching success subdivided by beach, year, portion of nesting season (early season (ES), middle season (MS), and late season (LS)), and nest category (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)).

| **Beach** | **Year** | **Season** | **Nest Category** | **Number of Nests** | **Mean** | **SD** | **SE** | **Median** |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **BHIC** | **1997** | **ES** | -- | 14 | 0.685 | 0.308 | 0.0823 | 0.785 |
| | | | I | 7 | 0.541 | 0.388 | 0.147 | 0.760 |
| | | | R | 7 | 0.829 | 0.0836 | 0.0316 | 0.820 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 41 | 0.789 | 0.232 | 0.0362 | 0.870 |
| | | | I | 9 | 0.800 | 0.311 | 0.104 | 0.930 |
| | | | R | 32 | 0.786 | 0.211 | 0.0372 | 0.855 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 18 | 0.881 | 0.223 | 0.0524 | 0.945 |
| | | | I | 5 | 0.752 | 0.415 | 0.186 | 0.920 |
| | | | R | 13 | 0.930 | 0.0554 | 0.0154 | 0.950 |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **CHNS** | **1997** | **ES** | -- | 2 | 0.200 | 0.283 | 0.200 | 0.200 |
| | | | I | 1 | 0.000 | -- | -- | 0.000 |
| | | | R | 1 | 1.000 | -- | -- | 1.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 26 | 0.584 | 0.411 | 0.0806 | 0.805 |
| | | | I | 3 | 0.287 | 0.488 | 0.282 | 0.01000 |
| | | | R | 23 | 0.623 | 0.396 | 0.0825 | 0.810 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | **--** | 9 | 0.621 | 0.320 | 0.107 | 0.680 |
| | | | I | 1 | 0.950 | -- | -- | 0.950 |
| | | | R | 7 | 0.663 | 0.228 | 0.0863 | 0.680 |
| | | | C | 1 | 0.000 | -- | -- | 0.000 |
| | | | | | | | | |
| **CLNS** | **1997** | **ES** | -- | 23 | 0.587 | 0.357 | 0.0745 | 0.720 |
| | | | I | 4 | 0.830 | 0.0796 | 0.0398 | 0.815 |
| | | | R | 19 | 0.536 | 0.373 | 0.0855 | 0.640 |
| | | | C | 0 | -- | -- | -- | -- |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **MS** | -- | 57 | 0.804 | 0.231 | 0.0305 | 0.890 |
| | | | I | 9 | 0.863 | 0.121 | 0.0404 | 0.900 |
| | | | R | 46 | 0.792 | 0.248 | 0.0366 | 0.890 |
| | | | C | 2 | 0.835 | 0.205 | 0.145 | 0.835 |
| | | **LS** | -- | 40 | 0.698 | 0.369 | 0.0583 | 0.900 |
| | | | I | 12 | 0.870 | 0.165 | 0.0476 | 0.920 |
| | | | R | 27 | 0.614 | 0.412 | 0.0793 | 0.890 |
| | | | C | 1 | 0.900 | -- | -- | 0.900 |
| **TBVO** | **1997** | **ES** | -- | 18 | 0.598 | 0.403 | 0.0949 | 0.830 |
| | | | I | 16 | 0.633 | 0.405 | 0.101 | 0.850 |
| | | | R | 2 | 0.320 | 0.339 | 0.240 | 0.320 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 27 | 0.885 | 0.190 | 0.0366 | 0.950 |
| | | | I | 20 | 0.871 | 0.218 | 0.0488 | 0.945 |
| | | | R | 7 | 0.924 | 0.0591 | 0.0223 | 0.960 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 19 | 0.779 | 0.354 | 0.0813 | 0.940 |
| | | | I | 16 | 0.804 | 0.324 | 0.0810 | 0.935 |
| | | | R | 2 | 0.965 | 0.0212 | 0.0150 | 0.965 |
| | | | C | 1 | 0.000 | -- | -- | 0.000 |
| **BHIC** | **1998** | **ES** | -- | 17 | 0.751 | 0.258 | 0.0626 | 0.820 |
| | | | I | 12 | 0.740 | 0.301 | 0.0868 | 0.840 |
| | | | R | 5 | 0.776 | 0.128 | 0.0573 | 0.820 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 51 | 0.206 | 0.371 | 0.0520 | 0.000 |
| | | | I | 4 | 0.950 | 0.0337 | 0.0168 | 0.965 |
| | | | R | 29 | 0.231 | 0.373 | 0.0692 | 0.000 |
| | | | C | 18 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | **LS** | -- | 18 | 0.0544 | 0.191 | 0.0450 | 0.000 |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 7 | 0.114 | 0.302 | 0.114 | 0.000 |
| | | | C | 11 | 0.0164 | 0.0543 | 0.0164 | 0.000 |
| **CHNS** | **1998** | **ES** | -- | 16 | 0.754 | 0.204 | 0.0509 | 0.815 |
| | | | I | 7 | 0.819 | 0.175 | 0.0662 | 0.900 |
| | | | R | 9 | 0.704 | 0.220 | 0.0732 | 0.810 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 49 | 0.652 | 0.338 | 0.0483 | 0.800 |
| | | | I | 9 | 0.737 | 0.305 | 0.102 | 0.860 |
| | | | R | 36 | 0.700 | 0.295 | 0.0492 | 0.815 |
| | | | C | 4 | 0.0325 | 0.0650 | 0.0325 | 0.000 |
| | | **LS** | -- | 23 | 0.664 | 0.283 | 0.0589 | 0.760 |
| | | | I | 1 | 0.550 | -- | -- | 0.550 |
| | | | R | 21 | 0.701 | 0.252 | 0.0551 | 0.770 |
| | | | C | 1 | 0.000 | -- | -- | 0.000 |
| **CLNS** | **1998** | **ES** | -- | 46 | 0.763 | 0.288 | 0.0425 | 0.875 |
| | | | I | 18 | 0.774 | 0.266 | 0.0627 | 0.870 |
| | | | R | 25 | 0.741 | 0.322 | 0.0644 | 0.880 |
| | | | C | 4 | 0.870 | 0.0608 | 0.0351 | 0.840 |
| | | **MS** | -- | 89 | 0.600 | 0.413 | 0.0438 | 0.830 |
| | | | I | 7 | 0.496 | 0.475 | 0.180 | 0.650 |
| | | | R | 59 | 0.765 | 0.307 | 0.0400 | 0.910 |
| | | | C | 23 | 0.208 | 0.369 | 0.0770 | 0.000 |
| | | **LS** | -- | 53 | 0.516 | 0.431 | 0.0592 | 0.650 |
| | | | I | 4 | 0.950 | 0.0497 | 0.0248 | 0.955 |
| | | | R | 30 | 0.740 | 0.327 | 0.0596 | 0.895 |
| | | | C | 19 | 0.0711 | 0.174 | 0.0399 | 0.000 |
| **TBVO** | **1998** | **ES** | -- | 26 | 0.845 | 0.253 | 0.0495 | 0.930 |
| | | | I | 16 | 0.902 | 0.0977 | 0.0244 | 0.950 |
| | | | R | 9 | 0.836 | 0.292 | 0.0975 | 0.920 |
| | | | C | 1 | 0.000 | -- | -- | 0.000 |
| | | **MS** | -- | 48 | 0.0965 | 0.253 | 0.0365 | 0.000 |
| | | | I | 3 | 0.550 | 0.478 | 0.276 | 0.780 |
| | | | R | 17 | 0.141 | 0.296 | 0.0719 | 0.000 |
| | | | C | 28 | 0.0207 | 0.110 | 0.0207 | 0.000 |
| | | **LS** | -- | 25 | 0.0980 | 0.237 | 0.0474 | 0.000 |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 18 | 0.136 | 0.272 | 0.0640 | 0.000 |
| | | | C | 7 | 0.000 | 0.000 | 0.000 | 0.000 |
| **BHIC** | **1999** | **ES** | -- | 38 | 0.591 | 0.348 | 0.0565 | 0.755 |
| | | | I | 12 | 0.652 | 0.275 | 0.0794 | 0.770 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | R | 22 | 0.666 | 0.315 | 0.0672 | 0.805 |
| | | | C | 4 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | **MS** | -- | 46 | 0.419 | 0.399 | 0.0588 | 0.620 |
| | | | I | 5 | 0.886 | 0.0832 | 0.0372 | 0.890 |
| | | | R | 28 | 0.530 | 0.355 | 0.0671 | 0.670 |
| | | | C | 13 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | **LS** | -- | 22 | 0.0336 | 0.149 | 0.0318 | 0.000 |
| | | | I | 2 | 0.370 | 0.467 | 0.330 | 0.370 |
| | | | R | 14 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | C | 6 | 0.000 | 0.000 | 0.000 | 0.000 |
| **CHNS** | **1999** | **ES** | **--** | 22 | 0.641 | 0.325 | 0.0692 | 0.800 |
| | | | I | 10 | 0.606 | 0.362 | 0.114 | 0.790 |
| | | | R | 11 | 0.731 | 0.232 | 0.0698 | 0.810 |
| | | | C | 1 | 0.01000 | -- | -- | 0.01000 |
| | | **MS** | -- | 41 | 0.300 | 0.425 | 0.0663 | 0.000 |
| | | | I | 5 | 0.768 | 0.430 | 0.192 | 0.940 |
| | | | R | 28 | 0.301 | 0.416 | 0.0785 | 0.000 |
| | | | C | 8 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | **LS** | -- | 23 | 0.0183 | 0.0876 | 0.0183 | 0.000 |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 15 | 0.0280 | 0.108 | 0.0280 | 0.000 |
| | | | C | 8 | 0.000 | 0.000 | 0.000 | 0.000 |
| **CLNS** | **1999** | **ES** | **--** | 58 | 0.723 | 0.308 | 0.0404 | 0.855 |
| | | | I | 37 | 0.792 | 0.241 | 0.0396 | 0.880 |
| | | | R | 18 | 0.703 | 0.303 | 0.0713 | 0.810 |
| | | | C | 3 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | **MS** | -- | 117 | 0.406 | 0.432 | 0.0400 | 0.000 |
| | | | I | 20 | 0.610 | 0.425 | 0.0950 | 0.845 |
| | | | R | 68 | 0.516 | 0.423 | 0.0513 | 0.655 |
| | | | C | 29 | 0.00793 | 0.0408 | 0.00758 | 0.000 |
| | | **LS** | -- | 62 | 0.151 | 0.318 | 0.0404 | 0.000 |
| | | | I | 1 | 0.940 | -- | -- | 0.940 |
| | | | R | 38 | 0.191 | 0.342 | 0.0556 | 0.000 |
| | | | C | 23 | 0.0504 | 0.204 | 0.0425 | 0.000 |
| **TBVO** | **1999** | **ES** | **--** | 37 | 0.755 | 0.257 | 0.0422 | 0.870 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | I | 25 | 0.764 | 0.271 | 0.0542 | 0.890 |
| | | | R | 11 | 0.727 | 0.243 | 0.0733 | 0.840 |
| | | | C | 1 | 0.830 | -- | -- | 0.830 |
| | | **MS** | -- | 71 | 0.677 | 0.372 | 0.0441 | 0.850 |
| | | | I | 21 | 0.886 | 0.109 | 0.0238 | 0.920 |
| | | | R | 36 | 0.762 | 0.292 | 0.0487 | 0.855 |
| | | | C | 14 | 0.145 | 0.317 | 0.0847 | 0.000 |
| | | **LS** | -- | 64 | 0.0952 | 0.240 | 0.0300 | 0.000 |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 39 | 0.156 | 0.293 | 0.0469 | 0.000 |
| | | | C | 25 | 0.000 | 0.000 | 0.000 | 0.000 |
| **BHIC** | **2000** | **ES** | -- | 17 | 0.906 | 0.0821 | 0.0199 | 0.930 |
| | | | I | 7 | 0.953 | 0.0180 | 0.00680 | 0.960 |
| | | | R | 7 | 0.847 | 0.102 | 0.0387 | 0.880 |
| | | | C | 3 | 0.933 | 0.0252 | 0.0145 | 0.930 |
| | | **MS** | -- | 20 | 0.595 | 0.453 | 0.101 | 0.915 |
| | | | I | 7 | 0.893 | 0.109 | 0.0413 | 0.930 |
| | | | R | 12 | 0.472 | 0.498 | 0.157 | 0.460 |
| | | | C | 3 | 0.310 | 0.537 | 0.310 | 0.465 |
| | | **LS** | -- | 5 | 0.584 | 0.382 | 0.171 | 0.690 |
| | | | I | 3 | 0.687 | 0.430 | 0.248 | 0.920 |
| | | | R | 2 | 0.430 | 0.368 | 0.260 | 0.430 |
| | | | C | 0 | -- | -- | -- | -- |
| **CHNS** | **2000** | **ES** | -- | 21 | 0.725 | 0.362 | 0.0789 | 0.900 |
| | | | I | 10 | 0.795 | 0.290 | 0.0917 | 0.905 |
| | | | R | 9 | 0.704 | 0.404 | 0.135 | 0.910 |
| | | | C | 2 | 0.470 | 0.608 | 0.430 | 0.470 |
| | | **MS** | -- | 38 | 0.534 | 0.444 | 0.0720 | 0.825 |
| | | | I | 9 | 0.851 | 0.309 | 0.103 | 0.95 |
| | | | R | 12 | 0.808 | 0.273 | 0.0788 | 0.880 |
| | | | C | 17 | 0.174 | 0.326 | 0.0791 | 0.000 |
| | | **LS** | -- | 16 | 0.289 | 0.441 | 0.110 | 0.000 |
| | | | I | 5 | 0.382 | 0.514 | 0.230 | 0.0200 |
| | | | R | 4 | 0.470 | 0.544 | 0.272 | 0.450 |
| | | | C | 7 | 0.120 | 0.317 | 0.120 | 0.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CLNS** | **2000** | **ES** | **--** | 52 | 0.658 | 0.369 | 0.0511 | 0.885 |
| | | | I | 11 | 0.382 | 0.439 | 0.132 | 0.170 |
| | | | R | 33 | 0.735 | 0.311 | 0.0542 | 0.900 |
| | | | C | 8 | 0.719 | 0.346 | 0.122 | 0.890 |
| | | **MS** | -- | 99 | 0.678 | 0.389 | 0.0391 | 0.910 |
| | | | I | 22 | 0.626 | 0.446 | 0.0950 | 0.925 |
| | | | R | 68 | 0.660 | 0.386 | 0.0468 | 0.880 |
| | | | C | 9 | 0.941 | 0.0280 | 0.00935 | 0.960 |
| | | **LS** | -- | 36 | 0.558 | 0.404 | 0.0674 | 0.760 |
| | | | I | 13 | 0.597 | 0.410 | 0.114 | 0.760 |
| | | | R | 18 | 0.629 | 0.372 | 0.0876 | 0.830 |
| | | | C | 5 | 0.202 | 0.391 | 0.175 | 0.0400 |
| **TBVO** | **2000** | **ES** | **--** | 32 | 0.837 | 0.135 | 0.0239 | 0.870 |
| | | | I | 18 | 0.840 | 0.151 | 0.0355 | 0.895 |
| | | | R | 14 | 0.834 | 0.117 | 0.0314 | 0.850 |
| | | | C | 0 | **--** | **--** | **--** | **--** |
| | | **MS** | -- | 41 | 0.848 | 0.223 | 0.0348 | 0.930 |
| | | | I | 28 | 0.914 | 0.1000 | 0.0189 | 0.935 |
| | | | R | 11 | 0.795 | 0.262 | 0.0790 | 0.930 |
| | | | C | 2 | 0.225 | 0.318 | 0.225 | 0.225 |
| | | **LS** | -- | 27 | 0.844 | 0.250 | 0.0481 | 0.910 |
| | | | I | 19 | 0.907 | 0.0619 | 0.0142 | 0.910 |
| | | | R | 8 | 0.696 | 0.432 | 0.153 | 0.935 |
| | | | C | 0 | **--** | **--** | **--** | **--** |
| **BHIC** | **2001** | **ES** | **--** | 16 | 0.877 | 0.0840 | 0.0210 | 0.890 |
| | | | I | 6 | 0.883 | 0.0367 | 0.0150 | 0.890 |
| | | | R | 9 | 0.896 | 0.0813 | 0.0271 | 0.910 |
| | | | C | 1 | 0.670 | -- | **--** | 0.670 |
| | | **MS** | -- | 42 | 0.736 | 0.328 | 0.0506 | 0.890 |
| | | | I | 12 | 0.931 | 0.0412 | 0.0119 | 0.945 |
| | | | R | 16 | 0.792 | 0.239 | 0.0598 | 0.870 |
| | | | C | 14 | 0.504 | 0.419 | 0.112 | 0.580 |
| | | **LS** | -- | 17 | 0.500 | 0.463 | 0.112 | 0.860 |
| | | | I | 2 | 0.910 | 0.0283 | 0.0200 | 0.910 |
| | | | R | 5 | 0.590 | 0.512 | 0.229 | 0.930 |
| | | | C | 10 | 0.373 | 0.452 | 0.143 | 0.0750 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CHNS** | **2001** | **ES** | -- | 23 | 0.535 | 0.444 | 0.0926 | 0.800 |
| | | | I | 2 | 0.970 | 0.0141 | 0.01000 | 0.970 |
| | | | R | 10 | 0.551 | 0.477 | 0.151 | 0.840 |
| | | | C | 11 | 0.442 | 0.426 | 0.128 | 0.250 |
| | | **MS** | -- | 36 | 0.426 | 0.452 | 0.0753 | 0.0700 |
| | | | I | 1 | 0.920 | -- | -- | 0.920 |
| | | | R | 15 | 0.613 | 0.434 | 0.112 | 0.890 |
| | | | C | 20 | 0.260 | 0.410 | 0.0917 | 0.000 |
| | | **LS** | -- | 8 | 0.129 | 0.344 | 0.122 | 0.000 |
| | | | I | 1 | 0.980 | -- | -- | 0.980 |
| | | | R | 3 | 0.000 | 0.000 | 0.000 | 0.000 |
| | | | C | 4 | 0.0125 | 0.0250 | 0.0125 | 0.000 |
| **CLNS** | **2001** | **ES** | -- | 39 | 0.786 | 0.297 | 0.0476 | 0.930 |
| | | | I | 19 | 0.771 | 0.293 | 0.0673 | 0.850 |
| | | | R | 18 | 0.837 | 0.257 | 0.0605 | 0.935 |
| | | | C | 2 | 0.475 | 0.672 | 0.475 | 0.475 |
| | | **MS** | -- | 47 | 0.757 | 0.342 | 0.0499 | 0.910 |
| | | | I | 16 | 0.736 | 0.375 | 0.0938 | 0.920 |
| | | | R | 27 | 0.799 | 0.313 | 0.0603 | 0.920 |
| | | | C | 4 | 0.558 | 0.405 | 0.203 | 0.630 |
| | | **LS** | -- | 29 | 0.667 | 0.416 | 0.0772 | 0.910 |
| | | | I | 9 | 0.838 | 0.318 | 0.106 | 0.960 |
| | | | R | 13 | 0.762 | 0.348 | 0.0965 | 0.920 |
| | | | C | 7 | 0.273 | 0.432 | 0.163 | 0.000 |
| **TBVO** | **2001** | **ES** | -- | 22 | 0.857 | 0.146 | 0.0311 | 0.910 |
| | | | I | 6 | 0.817 | 0.231 | 0.0945 | 0.935 |
| | | | R | 16 | 0.873 | 0.105 | 0.0263 | 0.900 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 39 | 0.833 | 0.222 | 0.0355 | 0.920 |
| | | | I | 15 | 0.864 | 0.237 | 0.0613 | 0.960 |
| | | | R | 24 | 0.813 | 0.214 | 0.0437 | 0.850 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 17 | 0.884 | 0.138 | 0.0335 | 0.920 |
| | | | I | 11 | 0.902 | 0.0885 | 0.0267 | 0.920 |
| | | | R | 6 | 0.852 | 0.209 | 0.0852 | 0.935 |
| | | | C | 0 | -- | -- | -- | -- |

Table D.3: Mean and median values of incubation duration subdivided by beach, year, and nest category (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)).

| Beach | Year | Nest Category | Number of Nests | Mean | SD | SE | Median |
|---|---|---|---|---|---|---|---|
| **BHIC** | **1997** | **Season** | **66** | **59.833** | **4.352** | **0.536** | **59.000** |
| | | I | 17 | 62.294 | 4.753 | 1.153 | 60.000 |
| | | R | 49 | 58.980 | 3.902 | 0.557 | 59.000 |
| | | C | 0 | -- | -- | -- | -- |
| **CHNS** | **1997** | **Season** | **NA** | | | | |
| | | I | NA | | | | |
| | | R | NA | | | | |
| | | C | NA | | | | |
| **CLNS** | **1997** | **Season** | **90** | **63.389** | **5.444** | **0.574** | **62.000** |
| | | I | 21 | 67.619 | 5.482 | 1.196 | 68.000 |
| | | R | 69 | 62.101 | 4.769 | 0.574 | 61.000 |
| | | C | 0 | -- | -- | -- | -- |
| **TBVO** | **1997** | **Season** | **58** | **66.759** | **5.636** | **0.740** | **65.500** |
| | | I | 47 | 66.809 | 4.933 | 0.720 | 66.000 |
| | | R | 11 | 66.545 | 8.311 | 2.506 | 62.000 |
| | | C | 1 | -- | -- | -- | -- |
| **BHIC** | **1998** | **Season** | **30** | **55.933** | **2.677** | **0.489** | **56.000** |
| | | I | 13 | 57.000 | 2.483 | 0.689 | 57.000 |
| | | R | 13 | 54.846 | 2.641 | 0.732 | 55.000 |
| | | C | 4 | 56.000 | 2.582 | 1.291 | 56.000 |
| **CHNS** | **1998** | **Season** | **59** | **58.169** | **6.760** | **0.880** | **57.000** |
| | | I | 12 | 56.500 | 2.844 | 0.821 | 56.000 |
| | | R | 47 | 58.596 | 7.401 | 1.079 | 57.000 |
| | | C | 0 | -- | -- | -- | -- |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CLNS** | **1998** | **Season** | **116** | **61.819** | **4.329** | **0.402** | **61.000** |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | I | 24 | 60.542 | 3.501 | 0.715 | 61.000 |
| | | R | 80 | 61.750 | 4.223 | 0.472 | 61.500 |
| | | C | 12 | 64.833 | 5.357 | 1.546 | 65.000 |
| **TBVO** | **1998** | **Season** | **40** | **60.975** | **6.141** | **0.971** | **60.000** |
| | | I | 20 | 61.350 | 5.412 | 1.210 | 62.500 |
| | | R | 17 | 61.176 | 7.170 | 1.739 | 58.000 |
| | | C | 3 | 57.333 | 4.933 | 2.848 | 55.000 |
| **BHIC** | **1999** | **Season** | **59** | **56.729** | **5.407** | **0.704** | **56.000** |
| | | I | 19 | 57.474 | 6.535 | 1.499 | 57.000 |
| | | R | 40 | 56.375 | 4.834 | 0.764 | 56.000 |
| | | C | 0 | -- | -- | -- | -- |
| **CHNS** | **1999** | **Season** | **35** | **61.086** | **5.868** | **0.992** | **60.000** |
| | | I | 14 | 62.143 | 5.736 | 1.533 | 62.000 |
| | | R | 21 | 60.381 | 5.987 | 1.307 | 59.000 |
| | | C | 0 | -- | -- | -- | -- |
| **CLNS** | **1999** | **Season** | **102** | **61.725** | **6.596** | **0.653** | **60.000** |
| | | I | 41 | 62.146 | 5.961 | 0.931 | 61.000 |
| | | R | 55 | 60.800 | 6.682 | 0.901 | 59.000 |
| | | C | 6 | 67.333 | 7.992 | 3.263 | 66.500 |
| **TBVO** | **1999** | **Season** | **98** | **61.439** | **6.988** | **0.706** | **59.500** |
| | | I | 46 | 62.413 | 7.277 | 1.073 | 60.000 |
| | | R | 49 | 60.857 | 6.736 | 0.962 | 59.000 |
| | | C | 3 | 56.000 | 3.606 | 2.082 | 57.000 |
| **BHIC** | **2000** | **Season** | **34** | **61.324** | **5.381** | **0.923** | **60.500** |
| | | I | 16 | 61.375 | 5.058 | 1.264 | 60.500 |
| | | R | 13 | 60.154 | 3.783 | 1.049 | 60.000 |
| | | C | 5 | 64.200 | 9.230 | 4.128 | 60.500 |
| **CHNS** | **2000** | **Season** | **38** | **65.632** | **4.103** | **0.666** | **65.500** |
| | | I | 16 | 66.625 | 4.105 | 1.004 | 66.500 |
| | | R | 17 | 64.706 | 4.647 | 1.127 | 63.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | C | 5 | 65.600 | 1.140 | 0.510 | 66.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **CLNS** | **2000** | **Season** | **99** | **67.232** | **5.251** | **0.528** | **67.000** |
| | | I | 19 | 66.737 | 7.078 | 1.624 | 65.000 |
| | | R | 68 | 67.235 | 4.810 | 0.583 | 66.500 |
| | | C | 12 | 68.000 | 4.651 | 1.343 | 69.500 |
| | | | | | | | |
| **TBVO** | **2000** | **Season** | **97** | **64.237** | **5.070** | **0.515** | **63.000** |
| | | I | 62 | 64.629 | 4.966 | 0.631 | 64.000 |
| | | R | 33 | 62.879 | 4.574 | 0.796 | 63.000 |
| | | C | 2 | 74.500 | 3.536 | 2.500 | 74.500 |
| | | | | | | | |
| **BHIC** | **2001** | **Season** | **61** | **66.459** | **46.753** | **5.986** | **60.000** |
| | | I | 20 | 62.750 | 4.898 | 1.095 | 61.000 |
| | | R | 27 | 58.370 | 3.543 | 0.682 | 57.000 |
| | | C | 14 | 61.286 | 3.646 | 0.975 | 61.000 |
| | | | | | | | |
| **CHNS** | **2001** | **Season** | **30** | **65.167** | **6.165** | **1.126** | **63.500** |
| | | I | 3 | 64.333 | 3.786 | 2.186 | 66.000 |
| | | R | 16 | 63.875 | 5.402 | 1.351 | 62.500 |
| | | C | 11 | 67.273 | 7.471 | 2.253 | 64.000 |
| | | | | | | | |
| **CLNS** | **2001** | **Season** | **62** | **64.500** | **3.929** | **0.499** | **65.000** |
| | | I | 20 | 64.800 | 4.4595 | 1.028 | 64.500 |
| | | R | 40 | 64.350 | 3.697 | 0.585 | 65.000 |
| | | C | 2 | 64.500 | 2.121 | 1.500 | 64.500 |
| | | | | | | | |
| **TBVO** | **2001** | **Season** | **76** | **61.039** | **5.010** | **0.575** | **60.000** |
| | | I | 32 | 62.781 | 6.257 | 1.106 | 61.000 |
| | | R | 44 | 59.773 | 3.416 | 0.515 | 60.000 |
| | | C | 0 | -- | -- | -- | -- |
| | | | | | | | |

Table D.4 : Mean and median values of incubation duration subdivided by beach, year, portion of nesting season (early season (ES), middle season (MS), and late season (LS)), and nest category (*in-situ* (I), relocated (R), and *in-situ* – affected by tidal inundation (C)).

| Beach | Year | Season | Nest Category | Number of Nests | Mean | SD | SE | Median |
|---|---|---|---|---|---|---|---|---|
| **BHIC** | **1997** | **ES** | -- | 10 | 60.800 | 5.473 | 1.731 | 60.000 |
| | | | I | 5 | 63.200 | 4.970 | 2.223 | 61.000 |
| | | | R | 5 | 58.400 | 5.320 | 2.379 | 56.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 39 | 58.026 | 2.670 | 0.428 | 58.000 |
| | | | I | 8 | 59.375 | 2.669 | 0.944 | 59.000 |
| | | | R | 31 | 57.677 | 2.600 | 0.467 | 58.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 17 | 63.412 | 4.583 | 1.112 | 62.000 |
| | | | I | 4 | 67.000 | 4.163 | 2.082 | 67.000 |
| | | | R | 13 | 62.308 | 4.250 | 1.179 | 61.000 |
| | | | C | 0 | -- | -- | -- | -- |
| **CHNS** | **1997** | **ES** | -- | NA | | | | |
| | | | I | | | | | |
| | | | R | | | | | |
| | | | C | | | | | |
| | | **MS** | -- | NA | | | | |
| | | | I | | | | | |
| | | | R | | | | | |
| | | | C | | | | | |
| | | **LS** | -- | NA | | | | |
| | | | I | | | | | |
| | | | R | | | | | |
| | | | C | | | | | |
| **CLNS** | **1997** | **ES** | -- | 20 | 65.750 | 7.217 | 1.614 | 63.000 |
| | | | I | 5 | 70.600 | 8.355 | 3.736 | 72.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | R | 15 | 64.133 | 6.289 | 1.624 | 62.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 44 | 60.591 | 3.500 | 0.528 | 60.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | I | 6 | 62.833 | 2.137 | 0.872 | 63.000 |
| | | | R | 38 | 60.237 | 3.560 | 0.577 | 60.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 26 | 66.308 | 4.212 | 0.826 | 66.000 |
| | | | I | 10 | 69.000 | 3.300 | 1.043 | 69.000 |
| | | | R | 16 | 64.625 | 3.897 | 0.974 | 65.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **TBVO** | **1997** | **ES** | -- | 15 | 72.000 | 7.010 | 1.810 | 71.000 |
| | | | I | 13 | 70.538 | 6.319 | 1.753 | 70.000 |
| | | | R | 2 | 81.500 | 0.707 | 0.500 | 81.500 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 27 | 63.630 | 3.065 | 0.590 | 64.000 |
| | | | I | 20 | 64.450 | 2.982 | 0.667 | 64.000 |
| | | | R | 7 | 61.286 | 1.976 | 0.747 | 61.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 16 | 67.125 | 3.649 | 0.912 | 67.500 |
| | | | I | 14 | 66.714 | 3.709 | 0.991 | 66.500 |
| | | | R | 2 | 70.000 | 1.414 | 1.000 | 70.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **BHIC** | **1998** | **ES** | -- | 16 | 56.438 | 2.756 | 0.689 | 56.500 |
| | | | I | 11 | 57.545 | 2.252 | 0.679 | 58.000 |
| | | | R | 5 | 54.000 | 2.236 | 1.000 | 54.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 14 | 55.357 | 2.560 | 0.684 | 55.000 |
| | | | I | 2 | 54.000 | 1.414 | 1.000 | 54.000 |
| | | | R | 7 | 55.375 | 2.875 | 1.017 | 55.000 |
| | | | C | 4 | 56.000 | 2.582 | 1.291 | 56.000 |
| | | **LS** | -- | 0 | -- | -- | -- | -- |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 0 | -- | -- | -- | -- |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **CHNS** | **1998** | **ES** | -- | 13 | 57.692 | 4.191 | 1.162 | 57.000 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  |  | I | 5 | 56.400 | 0.894 | 0.400 | 56.000 |
|  |  |  | R | 8 | 58.500 | 5.264 | 1.861 | 57.500 |
|  |  |  | C | 0 | -- | -- | -- | -- |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  | **MS** | -- | 32 | 56.281 | 3.466 | 0.613 | 56.000 |
|  |  |  | I | 6 | 55.833 | 3.545 | 1.447 | 55.000 |
|  |  |  | R | 26 | 56.385 | 3.511 | 0.689 | 56.500 |
|  |  |  | C | 0 | -- | -- | -- | -- |
|  |  | **LS** | -- | 13 | 59.769 | 3.539 | 0.982 | 61.000 |
|  |  |  | I | 1 | 61.000 | -- | -- | 61.000 |
|  |  |  | R | 12 | 59.667 | 3.676 | 1.061 | 60.000 |
|  |  |  | C | 0 | -- | -- | -- | -- |
|  |  |  |  |  |  |  |  |  |
| **CLNS** | **1998** | **ES** | -- | 45 | 62.311 | 4.656 | 0.694 | 61.000 |
|  |  |  | I | 19 | 60.895 | 3.770 | 0.865 | 61.000 |
|  |  |  | R | 22 | 62.500 | 4.718 | 1.006 | 61.500 |
|  |  |  | C | 4 | 68.000 | 4.546 | 2.273 | 69.000 |
|  |  | **MS** | -- | 49 | 60.673 | 3.642 | 0.520 | 60.000 |
|  |  |  | I | 3 | 59.000 | 2.646 | 1.528 | 60.000 |
|  |  |  | R | 40 | 60.650 | 3.556 | 0.562 | 60.500 |
|  |  |  | C | 6 | 61.667 | 4.803 | 1.961 | 60.500 |
|  |  | **LS** | -- | 22 | 63.364 | 4.562 | 0.973 | 62.000 |
|  |  |  | I | 2 | 59.500 | 0.707 | 0.500 | 59.500 |
|  |  |  | R | 18 | 63.278 | 4.509 | 1.063 | 62.000 |
|  |  |  | C | 2 | 68.000 | 4.243 | 3.000 | 68.000 |
|  |  |  |  |  |  |  |  |  |
| **TBVO** | **1998** | **ES** | -- | 26 | 61.500 | 5.217 | 1.023 | 63.000 |
|  |  |  | I | 17 | 61.824 | 5.703 | 1.383 | 63.000 |
|  |  |  | R | 9 | 60.889 | 4.400 | 1.467 | 59.000 |
|  |  |  | C | 0 | -- | -- | -- | -- |
|  |  | **MS** | -- | 12 | 58.750 | 7.617 | 2.199 | 56.000 |
|  |  |  | I | 3 | 58.667 | 2.309 | 1.333 | 60.000 |
|  |  |  | R | 6 | 59.500 | 10.672 | 4.357 | 55.500 |
|  |  |  | C | 3 | 57.333 | 4.933 | 2.848 | 55.000 |
|  |  | **LS** | -- | 2 | 67.500 | 0.707 | 0.500 | 67.500 |
|  |  |  | I | 0 | -- | -- | -- | -- |
|  |  |  | R | 2 | 67.500 | 0.707 | 0.500 | 67.500 |
|  |  |  | C | 0 | -- | -- | -- | -- |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **BHIC** | **1999** | **ES** | **--** | 32 | 59.281 | 4.781 | 0.845 | 59.500 |
| | | | I | 12 | 60.000 | 6.030 | 1.741 | 59.500 |
| | | | R | 20 | 58.850 | 3.964 | 0.886 | 59.500 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 25 | 53.440 | 4.592 | 0.918 | 53.000 |
| | | | I | 5 | 51.600 | 5.413 | 2.421 | 54.000 |
| | | | R | 20 | 53.900 | 4.400 | 0.984 | 53.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 2 | 57.000 | 1.414 | 1.000 | 57.000 |
| | | | I | 2 | 57.000 | 1.414 | 1.000 | 57.000 |
| | | | R | 0 | -- | -- | -- | -- |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **CHNS** | **1999** | **ES** | **--** | 19 | 64.684 | 5.334 | 1.224 | 63.000 |
| | | | I | 9 | 65.444 | 4.096 | 1.365 | 63.000 |
| | | | R | 10 | 65.444 | 4.096 | 1.365 | 62.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 16 | 56.813 | 2.834 | 0.708 | 56.500 |
| | | | I | 5 | 56.200 | 2.168 | 0.970 | 57.000 |
| | | | R | 11 | 57.091 | 3.145 | 0.948 | 56.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 0 | -- | -- | -- | -- |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 0 | -- | -- | -- | -- |
| | | | C | 0 | -- | -- | -- | -- |
| | | | | | | | | |
| **CLNS** | **1999** | **ES** | **--** | 44 | 64.545 | 4.915 | 0.741 | 64.000 |
| | | | I | 29 | 63.517 | 4.882 | 0.906 | 62.000 |
| | | | R | 15 | 66.533 | 4.486 | 1.158 | 67.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 49 | 57.204 | 3.846 | 0.549 | 57.000 |
| | | | I | 11 | 56.909 | 2.809 | 0.847 | 56.000 |
| | | | R | 35 | 56.686 | 3.046 | 0.515 | 57.000 |
| | | | C | 3 | 64.333 | 8.737 | 5.044 | 62.000 |
| | | **LS** | -- | 9 | 72.556 | 5.457 | 1.819 | 75.000 |
| | | | I | 1 | 80.000 | -- | -- | 80.000 |
| | | | R | 5 | 72.400 | 3.715 | 1.661 | 75.000 |
| | | | C | 3 | 70.333 | 7.506 | 4.333 | 70.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **TBVO** | **1999** | **ES** | **--** | 37 | 67.432 | 6.131 | 1.008 | 67.000 |
| | | | I | 25 | 67.000 | 6.739 | 1.348 | 67.000 |
| | | | R | 11 | 69.182 | 3.920 | 1.182 | 69.000 |
| | | | C | 1 | 59.000 | -- | -- | 59.000 |
| | | **MS** | -- | 54 | 56.556 | 2.982 | 0.406 | 56.000 |
| | | | I | 21 | 56.952 | 2.655 | 0.579 | 57.000 |
| | | | R | 31 | 56.419 | 3.191 | 0.573 | 56.000 |
| | | | C | 2 | 54.500 | 3.536 | 2.500 | 54.500 |
| | | **LS** | -- | 7 | 67.429 | 2.699 | 1.020 | 68.000 |
| | | | I | 0 | -- | -- | -- | -- |
| | | | R | 7 | 67.429 | 2.699 | 1.020 | 68.000 |
| | | | C | 0 | -- | -- | -- | -- |
| **BHIC** | **2000** | **ES** | **--** | 17 | 60.471 | 5.658 | 1.372 | 58.000 |
| | | | I | 7 | 61.143 | 7.081 | 2.676 | 58.000 |
| | | | R | 7 | 60.714 | 4.461 | 1.686 | 60.000 |
| | | | C | 3 | 58.333 | 6.110 | 3.528 | 57.000 |
| | | **MS** | -- | 13 | 61.308 | 4.461 | 1.237 | 61.000 |
| | | | I | 7 | 61.714 | 3.638 | 1.375 | 61.000 |
| | | | R | 5 | 58.800 | 2.864 | 1.281 | 59.000 |
| | | | C | 1 | 71.000 | -- | -- | 71.000 |
| | | **LS** | -- | 4 | 65.000 | 6.782 | 3.391 | 62.500 |
| | | | I | 2 | 61.000 | 1.414 | 1.000 | 61.000 |
| | | | R | 1 | 63.000 | -- | -- | 63.000 |
| | | | C | 1 | 75.000 | -- | -- | 75.000 |
| **CHNS** | **2000** | **ES** | **--** | 16 | 65.563 | 4.732 | 1.183 | 65.000 |
| | | | I | 8 | 67.750 | 4.432 | 1.567 | 70.000 |
| | | | R | 6 | 62.667 | 4.676 | 1.909 | 62.500 |
| | | | C | 2 | 65.500 | 0.707 | 0.500 | 65.500 |
| | | **MS** | -- | 20 | 65.700 | 3.799 | 0.849 | 66.000 |
| | | | I | 7 | 65.857 | 3.579 | 1.353 | 66.000 |
| | | | R | 10 | 65.600 | 4.624 | 1.462 | 65.500 |
| | | | C | 3 | 65.667 | 1.528 | 0.882 | 66.000 |
| | | **LS** | -- | 2 | 65.500 | 3.536 | 2.500 | 65.500 |
| | | | I | 1 | 63.000 | -- | -- | 63.000 |
| | | | R | 1 | 68.000 | -- | -- | 68.000 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  |  | C | 0 | -- | -- | -- | -- |
| **CLNS** | **2000** | **ES** | **--** | 36 | 65.444 | 3.791 | 0.632 | 65.000 |

|  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
|  |  |  | I | 7 | 64.000 | 4.546 | 1.718 | 61.000 |
|  |  |  | R | 25 | 65.400 | 3.253 | 0.651 | 65.000 |
|  |  |  | C | 4 | 68.250 | 5.123 | 2.562 | 69.500 |
|  |  | **MS** | -- | 44 | 66.568 | 4.863 | 0.733 | 65.500 |
|  |  |  | I | 7 | 64.571 | 5.159 | 1.950 | 64.000 |
|  |  |  | R | 31 | 67.065 | 4.939 | 0.887 | 66.000 |
|  |  |  | C | 6 | 66.333 | 4.227 | 1.726 | 65.500 |
|  |  | **LS** | -- | 19 | 72.158 | 5.708 | 1.310 | 72.000 |
|  |  |  | I | 5 | 73.600 | 8.620 | 3.855 | 72.000 |
|  |  |  | R | 12 | 71.500 | 4.871 | 1.406 | 71.500 |
|  |  |  | C | 2 | 72.500 | 3.536 | 2.500 | 72.500 |
| **TBVO** | **2000** | **ES** | **--** | 30 | 63.267 | 4.464 | 0.815 | 63.000 |
|  |  |  | I | 16 | 64.500 | 4.412 | 1.103 | 64.000 |
|  |  |  | R | 14 | 61.857 | 4.240 | 1.133 | 61.500 |
|  |  |  | C | 0 | -- | -- | -- | -- |
|  |  | **MS** | -- | 43 | 63.860 | 5.235 | 0.798 | 63.000 |
|  |  |  | I | 30 | 63.533 | 5.329 | 0.973 | 63.000 |
|  |  |  | R | 11 | 62.818 | 2.714 | 0.818 | 63.000 |
|  |  |  | C | 2 | 74.500 | 3.536 | 2.500 | 74.500 |
|  |  | **LS** | -- | 24 | 66.125 | 5.186 | 1.059 | 67.000 |
|  |  |  | I | 16 | 66.813 | 4.293 | 1.073 | 67.000 |
|  |  |  | R | 8 | 64.750 | 6.756 | 2.389 | 66.000 |
|  |  |  | C | 0 | -- | -- | -- | -- |
| **BHIC** | **2001** | **ES** | **--** | 16 | 62.250 | 4.480 | 1.120 | 61.000 |
|  |  |  | I | 6 | 65.667 | 4.844 | 1.978 | 68.000 |
|  |  |  | R | 9 | 60.111 | 2.977 | 0.992 | 61.000 |
|  |  |  | C | 1 | 61.000 | **--** | **--** | 61.000 |
|  |  | **MS** | -- | 35 | 69.714 | 61.761 | 10.439 | 58.000 |
|  |  |  | I | 12 | 60.417 | 3.679 | 1.062 | 59.500 |
|  |  |  | R | 14 | 56.857 | 2.316 | 0.619 | 56.500 |
|  |  |  | C | 9 | 61.556 | 3.812 | 1.271 | 61.000 |
|  |  | **LS** | -- | 10 | 61.800 | 5.673 | 1.794 | 63.500 |
|  |  |  | I | 2 | 68.000 | 4.243 | 3.000 | 68.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | R | 4 | 59.750 | 6.292 | 3.146 | 59.000 |
| | | | C | 4 | 60.750 | 4.272 | 2.136 | 62.000 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **CHNS** | **2001** | **ES** | -- | 13 | 68.615 | 6.436 | 1.785 | 68.000 |
| | | | I | 1 | 67.000 | -- | -- | 67.000 |
| | | | R | 6 | 65.500 | 4.764 | 1.945 | 67.500 |
| | | | C | 6 | 72.000 | 7.127 | 2.910 | 73.500 |
| | | **MS** | -- | 16 | 62.313 | 4.615 | 1.154 | 61.500 |
| | | | I | 1 | 60.000 | -- | -- | 60.000 |
| | | | R | 10 | 62.900 | 5.763 | 1.822 | 62.000 |
| | | | C | 5 | 61.600 | 1.517 | 0.678 | 61.000 |
| | | **LS** | -- | 1 | 66.000 | -- | -- | 66.000 |
| | | | I | 1 | 66.000 | -- | -- | 66.000 |
| | | | R | 0 | -- | -- | -- | -- |
| | | | C | 0 | -- | -- | -- | -- |
| **CLNS** | **2001** | **ES** | -- | 27 | 65.037 | 4.450 | 0.856 | 65.000 |
| | | | I | 9 | 65.556 | 5.593 | 1.864 | 64.000 |
| | | | R | 17 | 64.471 | 3.810 | 0.924 | 65.000 |
| | | | C | 9 | 70.000 | -- | -- | 70.000 |
| | | **MS** | -- | 24 | 63.625 | 3.090 | 0.631 | 65.000 |
| | | | I | 5 | 62.800 | 3.421 | 1.530 | 58.000 |
| | | | R | 18 | 63.889 | 3.142 | 0.740 | 65.000 |
| | | | C | 1 | 63.000 | -- | -- | 63.000 |
| | | **LS** | -- | 11 | 65.091 | 4.206 | 1.268 | 65.000 |
| | | | I | 3 | 62.667 | 2.887 | 1.667 | 61.000 |
| | | | R | 7 | 66.000 | 4.761 | 1.799 | 65.000 |
| | | | C | 1 | 66.000 | -- | -- | 66.000 |
| **TBVO** | **2001** | **ES** | -- | 22 | 63.636 | 6.758 | 1.441 | 62.500 |
| | | | I | 6 | 70.333 | 9.395 | 3.836 | 70.000 |
| | | | R | 16 | 61.125 | 3.138 | 0.785 | 61.500 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **MS** | -- | 38 | 60.158 | 3.949 | 0.641 | 59.500 |
| | | | I | 15 | 62.000 | 4.000 | 1.033 | 61.000 |
| | | | R | 23 | 58.957 | 3.496 | 0.729 | 59.000 |
| | | | C | 0 | -- | -- | -- | -- |
| | | **LS** | -- | 16 | 59.563 | 2.988 | 0.747 | 60.000 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | I | 11 | 59.727 | 3.069 | 0.925 | 60.000 |
| | R | 5 | 59.200 | 3.114 | 1.393 | 60.000 |
| | C | 0 | -- | -- | -- | -- |

## From the *Handbook for Sea Turtle Volunteers in North Carolina* (NEWP, 1997)

### How to Relocate a Nest

If nest relocation meets the criteria listed in section 2.5.2.1 and relocation is necessary, then the following procedure is followed to relocate the nest.

(1) Try to move the eggs within six hours after they are laid. Embryos have a better chance for developing when movement is accomplished within that time period.

(2) If moving after 6 hours is necessary, take extreme care not rotate them in any way during handling. Maintain the original orientation throughout the relocation process. It is helpful to place a small pencil mark on the top to help maintain the original orientation. Do not use ink since it may contain solvents harmful to the embryo if it permeates the egg.

(3) Resist the urge to use a probe to find a nest. Other methods will usually suffice. If probing absolutely necessary, allow only highly experienced personnel to carry it out. Once the probe starts ‘giving way’ as it is slowly pushed through the sand, extract it immediately to avoid puncturing any eggs. If any eggs are punctured, remove them and the spilled contents to prevent the clutch from rotting.

(4) Excavate the eggs by hand, not with a shovel. Place them on top of a thin layer of sand in a strong container. Used eggs cartons containing a layer of sand are useful in terms of keeping the eggs in their original orientation and for counting. Shade excavated eggs on hot, sunny days.

(5) Dig the new egg chamber with posthole diggers or a shell to the same depth and dimensions of the original nest. Round out the bottom so that the shape of the nest is similar to a round-bottomed flask.

(6) Nests should be relocated to areas above the high tide line, which are relatively free of vegetation. Invasion of the nest by roots will prevent the hatchlings from escaping.

(7) Disperse the relocated nests up and down the beach if at all possible. Concentrating nests in a small area may attract predators and/or alter natural sex ratios.

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