

NESTING SUCCESS OF THE LOGGERHEAD SEA TURTLE (Caretta caretta)  
AT CUMBERLAND ISLAND NATIONAL SEASHORE

Progress Report

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May 1986

This report has been prepared by the Center for Coastal and Environmental Studies for the National Park Service Cooperative Research Unit. It is contribution #1007 of the Center for Coastal and Environmental Studies.

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84 4640 DI NPS CRU Sea Turtles Nesting (D. Ehrenfeld)

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## Introduction

The loggerhead sea turtle (Caretta caretta) was listed as a threatened species under the Endangered Species Act of 1973. The U.S. Fish and Wildlife Service and National Marine Fisheries Service are jointly charged with the protection and recovery of this species. The beaches of the southeast U.S. from North Carolina to Texas support the world's second largest concentration of loggerheads (Ross 1982). Loggerheads nest on beaches under the jurisdiction of four National Seashores within the National Park system: Cape Hatteras, N.C., Cape Lookout, N.C., Cumberland Island, Ga., and Cape Canaveral, Fla. With the continuing commercial development of the southeast coast these beaches are becoming increasingly important as nesting sanctuaries.

A long-term intensive tagging project of loggerheads nesting within Cumberland Island National Seashore has been conducted since 1972. This project evolved as an extension of the Little Cumberland Island tagging program begun in 1964 by Dr. James Richardson. Cumberland is now considered the most significant nesting beach within the Georgia statewide population monitoring program run by the NPS Cooperative Research Unit at the University of Georgia Institute of Ecology. The 23 consecutive years of tagging data on the Georgia loggerhead population have provided invaluable information leading to the development of sophisticated models of population behavior (Richardson 1982) and estimates of adult female survivorship (Frazer 1983a). Life history parameters critical to the development of loggerhead life tables, including nest success, estimates of neonate production, and sex ratio information, have not been adequately assessed for loggerhead populations nesting within the National Seashores. This information is also necessary for the development of appropriate management guidelines for these nesting beaches.

In 1985 a project was initiated to evaluate loggerhead reproductive success and the factors that affect it on the beaches of Cumberland Island, Cape Lookout, and Cape Hatteras National Seashores. The project was conducted out of the NPS Cooperative Research Unit at the Center for Coastal and Environmental Studies, Rutgers University, New Brunswick, New Jersey.

This report presents the preliminary data on nest success and hatchling production on Cumberland Island National Seashore in 1985.

Research on the Cumberland Island population since 1972 has concentrated on the tagging of the adult nesting females and the frequency and distribution of nests. Monitoring of the nests frequently has ceased at the end of the nesting season in August, leaving many unhatched nests unsurveyed. Ruckdeschel (1977) monitored the fate of some nests during the 1977 season, and similar studies were undertaken by M. Longwater and J. McAfee in 1978 and by K. McMillen in 1980.

## Study Area

Cumberland Island is the largest and southernmost barrier island along the Georgia coast (Figures 1a and 1b). After a long history of human presence and intensive use dating back to aboriginal inhabitants from 2000 B.C. (Hillestad et al. 1975), Cumberland Island was designated as a National Seashore in 1972.

The island is 17 miles long and 3 miles across at its widest point and 0.5 miles at its narrowest. It is separated from mainland Georgia by a few miles of salt marsh, from Amelia Island, Florida, to the south by the estuary of the Cumberland Sound, and from Jekyll Island to the north by the St. Andrew Sound.

Cumberland has a tide-dominated beach with semidiurnal tides of 6+ to 8+ feet. The low relief of the island (15-25 ft), the wide, gently sloping beach, and the shallow slope of the offshore ocean floor (4 ft/mile flattening to 2 ft/mile) (Hillestad et al. 1975) accentuate the distance between the low and high tide lines, which is almost 70 m on Little Cumberland Island (Frazer 1983b). The beach slope and tidal amplitude determine how far a loggerhead must crawl after emergence if she is to lay above the high tide line.

Presently, the overall rate of beach erosion on Cumberland is similar to that of the other east coast barrier islands, and is a result of a slow rise in eustatic sea level and a reduced supply of the sediment necessary to feed and maintain the beaches. Differential erosion on a local level is correlated with the presence or absence of a foredune, which in turn depends on the extent of stabilizing dune vegetation.

Three dune communities have been identified on Cumberland (Hillestad et al. 1975). The dune grass-forb community occurs on the foredunes and low interdunes, and includes grass and herb species tolerant of salt spray, wind, burial by wind-blown sand, arid conditions, and occasional tidal inundation. This is the community that nesting loggerheads encounter most frequently. The other two dune communities, the dune shrub thicket and the dune oak-buckthorn shrub forest, occur mainly on the rear dunes, where few loggerheads nest.

## Natural History

The loggerhead sea turtle is one of six species of sea turtles in the Family Cheloniidae. The loggerhead is named for its disproportionately large head (in adults), which measures about 25 cm wide. The carapace, up to 120 cm in length, is a distinct reddish-brown color, with five pairs of lateral scutes that differentiate it from the similarly sized green turtle (Chelonia mydas).

Like most sea turtles, the loggerhead is terrestrial only at the time of hatching and when the females return to land to lay their eggs. The breeding range of Caretta is subtropical in distribution and almost all nesting occurs north of the Tropic of Cancer and south



Figure 1a. The National Seashore system of the Atlantic Coast.

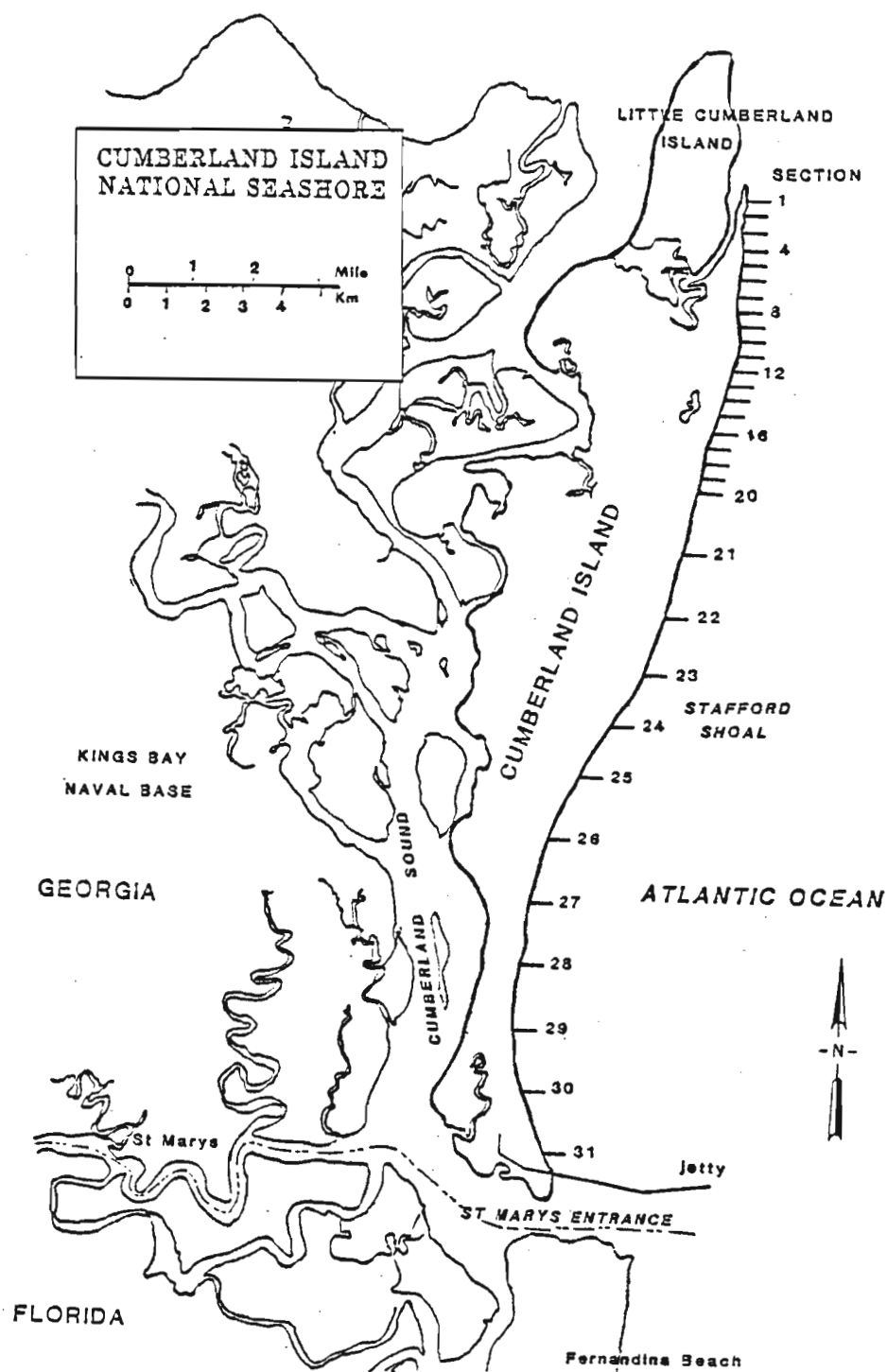


Figure 1b. Cumberland Island National Seashore. Sections 1-20 comprise the study area.

the Tropic of Capricorn (Pritchard 1979). While this species is ubiquitous in all temperate oceans, one of the largest breeding concentrations is along the coast of the southeastern United States, especially the islands of the Carolinas, Georgia, and Florida (Ross 1982).

On the U.S. coast the nesting season runs from May through August. The majority of data on loggerhead population dynamics are gathered from tagging projects and nest success studies. The females lay from one to seven clutches per season of approximately 115 eggs each on intervals of about 13 days. The great majority remigrate to nest on 2- or 3-year intervals; few nest annually.

The loggerhead is primarily carnivorous. The large head supports the jaw muscles used to crush the shells of the molluscs and crustaceans that comprise its diet in the shallow coastal waters. Adult females feed during the internesting period while off the nesting beach (Limpus 1973). Little is known of the postnesting dispersal and migration of the southeastern U.S. population, although a few Florida-tagged turtles have been recovered in Bermuda (Meylan et al. 1983) and Georgia turtles have been found in more northern waters until the fall (Bell and Richardson 1978). In winter, some turtles emigrate as water temperatures drop, whereas others have been found hibernating in the bottom mud of a Florida navigation channel (Carr et al. 1980).

#### Methods

The beach was patrolled nightly from 19 May to 7 August 1985 from 9 P.M. to 6 A.M. by the turtle tagging team and a field assistant on Honda ATCs. All nests were marked on the evening of oviposition with survey flags placed 0.5 m from the position of the egg chamber. Data recorded on the flag included the date, time of laying (or first observation), section, female tag number, and observer's initials. The assistance of the tagging team in marking these nests was invaluable. A tagging data sheet recorded additional information including nest site location and crawl diagram, curved carapace length, clutch size when observed, and weather conditions. Each nest was assigned a permanent nest number and the morning following oviposition additional data on nest site characteristics (distance from high tide line and dune, vegetative cover, slope, etc.) were obtained. Some nests at the time of laying were equipped with a thermocouple probe to monitor temperature throughout the incubation period. The results of the temperature study will not be discussed here.

For convenience and consistency of nest recording the beach is divided into sections. The northernmost 5 miles of the island, where the tagging effort is concentrated, is referred to as the study area. The sections here are 0.25 miles in length (1-20). The remainder of the island is divided into 1-mile-long sections (21-32). The 6 miles to the south of the study area were also patrolled regularly by the tagging crew. The remainder of the island was patrolled less frequently; all turtle tracks were recorded as nests or false crawls

(nonnesting emergences) but the nesting females outside the study area were not regularly observed or tagged. Nests laid in the study area were observed daily for signs of disturbance or emergence and nests outside the study area were observed every second or third day.

Raccoons (Procyon lotor) were the only mammalian predators known to open nests, though tracks of feral pigs (Sus scrofa) and armadillo (Dasypus novemcinctus) were sometimes present. Ghost crab holes (Ocypoda quadrata) within a meter of the nest site were noted, especially when pieces of turtle eggshell were seen on the surface. Whether a nest site was washed by the most recent tide was also recorded.

Upon emergence the number of hatchling tracks from the nest was counted if possible and the nest was observed for subsequent emergence for seven days. At the end of this period, or when it appeared that the turtles had completed their emergence, the nest was excavated and its contents analyzed. Early season emergences that were analyzed four and five days after the first emergence occasionally contained incubating eggs, pipping eggs, and viable hatchlings ready to emerge. For this reason and because a natural emergence success rate was desired, nests were not excavated for at least seven days.

Analysis of nest contents entailed a count of the number of successful emerged shells, live and dead hatchlings in the nest chamber and their condition, and broken and whole eggs. The unhatched eggs were opened and their contents described and any embryos were sorted by size. The presence of roots and insects in the nest chamber was also noted. The presence of crabs in the nest at any time during incubation was determined directly by observation of crabs or crab burrows into the egg chamber and indirectly based on broken eggshells that contained remains of embryos and/or egg contents. Depth to the top and bottom of the nest was recorded. Also, a sand sample from the egg chamber was taken for future analysis of edaphic characteristics of the nest site.

## Results

### Spatial Distribution of Loggerhead Nests

One hundred ninety-six loggerhead nests were laid on Cumberland Island during the 1985 nesting season (May through August). The distribution of these nests by section is shown in Figure 2. This spatial distribution by section is not indicative of relative nest density because sections within the study area are 0.25 miles long and outside the study area sections are 1 mile long. Data by section are presented to facilitate comparison with nesting data from previous years. Sixty three percent of the nests were laid within the study area (sections 1-20, n=123) and 37% outside (sections 21-32, n=73). At least one nest was laid in every section of the beach, and section 10 supported the greatest number of nests (n=17).

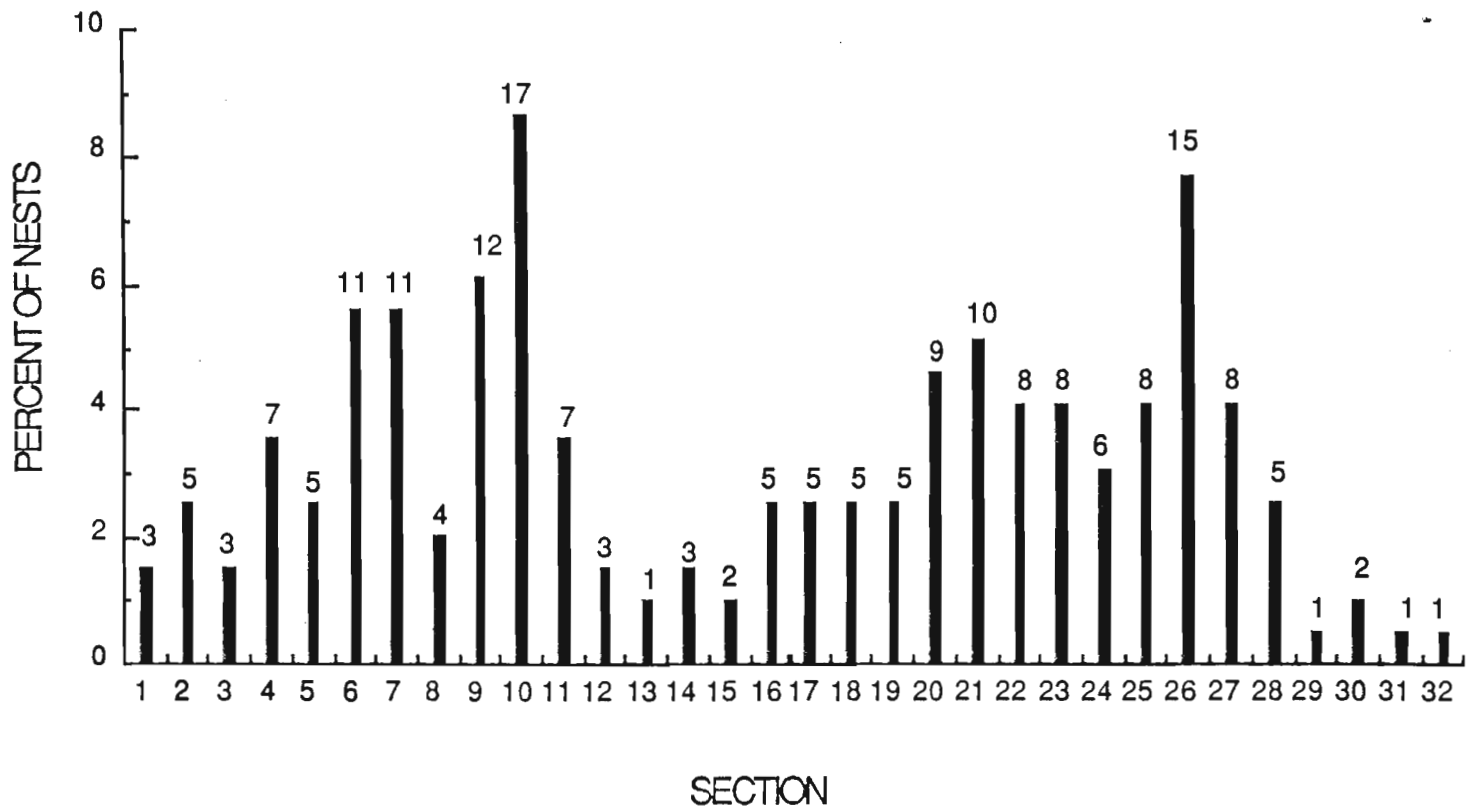


Figure 2. Percentage distribution of loggerhead nests by beach section on Cumberland Island, 1985 (N=196). Numbers above the bars represent number of nests.

To assess distribution of nest density, sections in the study area were pooled and the nest frequency data were analyzed by mile. The distribution of nests laid by mile is presented in Figure 3. Mean nest density on Cumberland Island in 1985 was 11.5 nests/mile ( $\pm 10.87$  S.D.). Nest density was skewed toward the north end of the island and gives an indication of how the study area is more heavily utilized by nesting females.

In any section nests are laid on the beach platform from the high tide line to the back side of the foredunes. Other spatial and qualitative nest site variables relating to success were measured but will not be discussed in this report.

#### Temporal Distribution of Nesting

The 1985 nesting season on Cumberland began prior to 19 May (arrival date of the tagging team) and continued through 10 August. For nests laid prior to 19 May (C. Ruckdeschel, pers. comm.) the number, locations, and dates are not known. Therefore the nesting season was a minimum of 80 days.

Individual females nest one to seven times per season. On Little Cumberland Island the average number of nests per female ranges from 2.4 to 3.4 per season with a mean internesting period of 13 days (Frazer and Richardson 1985a). On Cumberland Island in 1985 the mean number of nests laid per female was 2.5 for the 61 identified females ( $n=155$  nests) with an average of 12.5 days between subsequent nests ( $n=77$  internesting periods; periods longer than 22 days were omitted as it is believed that these represent a multiple of the internesting interval in cases when a nest was missed).

The distribution of nests by date laid is presented in Figure 4. Nesting was low in May, peaked in June, decreased slightly in July, and was lowest in August (Figure 4). The mean number of nests laid per night for the entire season was 2.5 (196 nests/80 days); nesting peaked on 7 June when 9 nests were laid.

#### Nest Characteristics

A number of nest characteristics such as clutch size, nest depth, and the presence of insects, roots, or crabs in the nest were monitored. Clutch size (the number of eggs in a nest) and frequency (the number of nests a female lays) are important indicators of female fecundity and the reproductive output of the population. Clutch sizes for all clutches of an individual nester vary less than for the population as a whole (Frazer and Richardson 1986).

Mean clutch size on Cumberland was 113.9 eggs ( $n=112$ ,  $\pm 19.53$  S.D.) and ranged from 55 to 162 eggs. One nest was omitted from the analysis because the turtle was disturbed during nesting and aborted her nest after laying only 1 egg. She returned later that evening and laid 91 eggs. Two other clutches were small (55 and 57 eggs) but there was no indication that these turtles were disturbed or induced to leave the nest before laying a full clutch. Mean clutch size

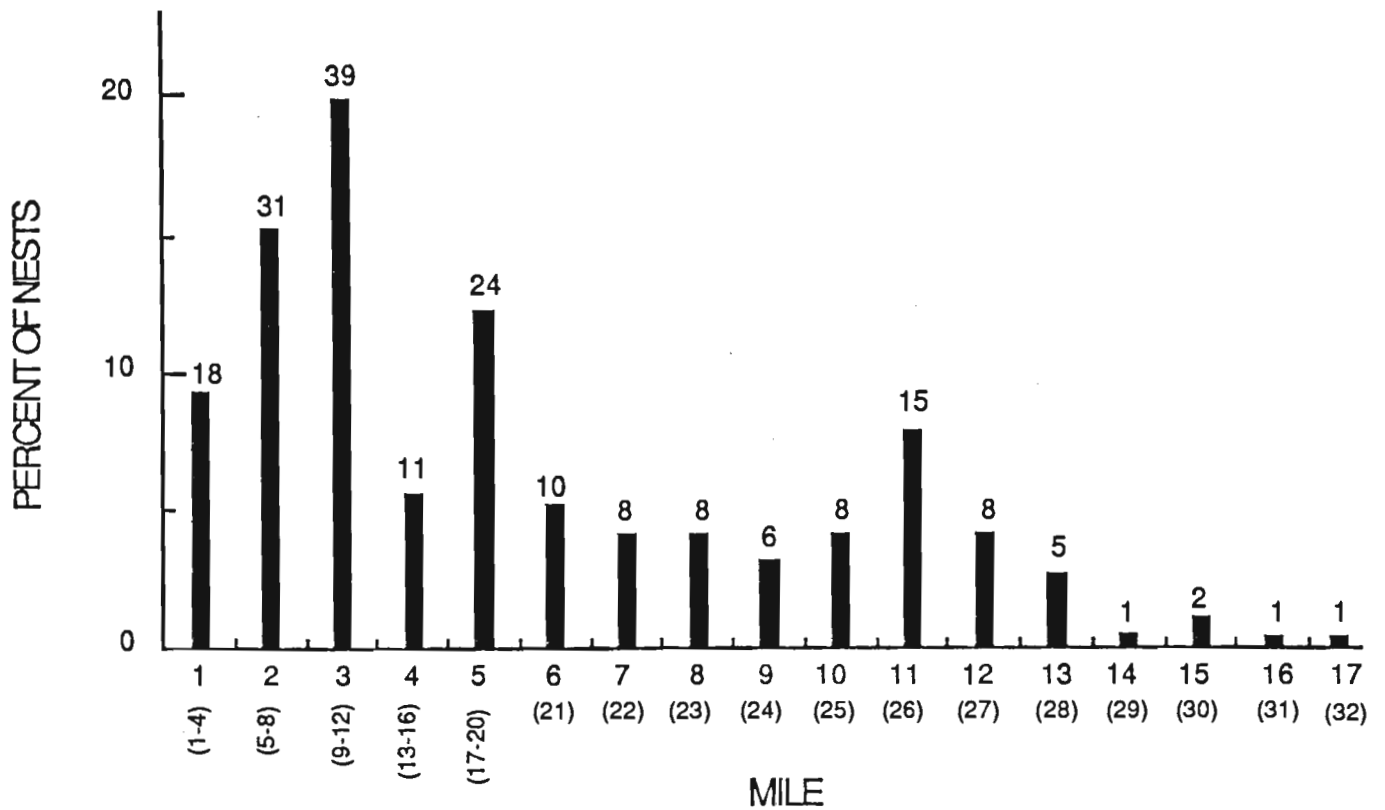


Figure 3. Percentage distribution of loggerhead nests by mile on Cumberland Island, 1985 (N=196). Numbers above the bars represent number of nests. Numbers in parentheses are beach sections.

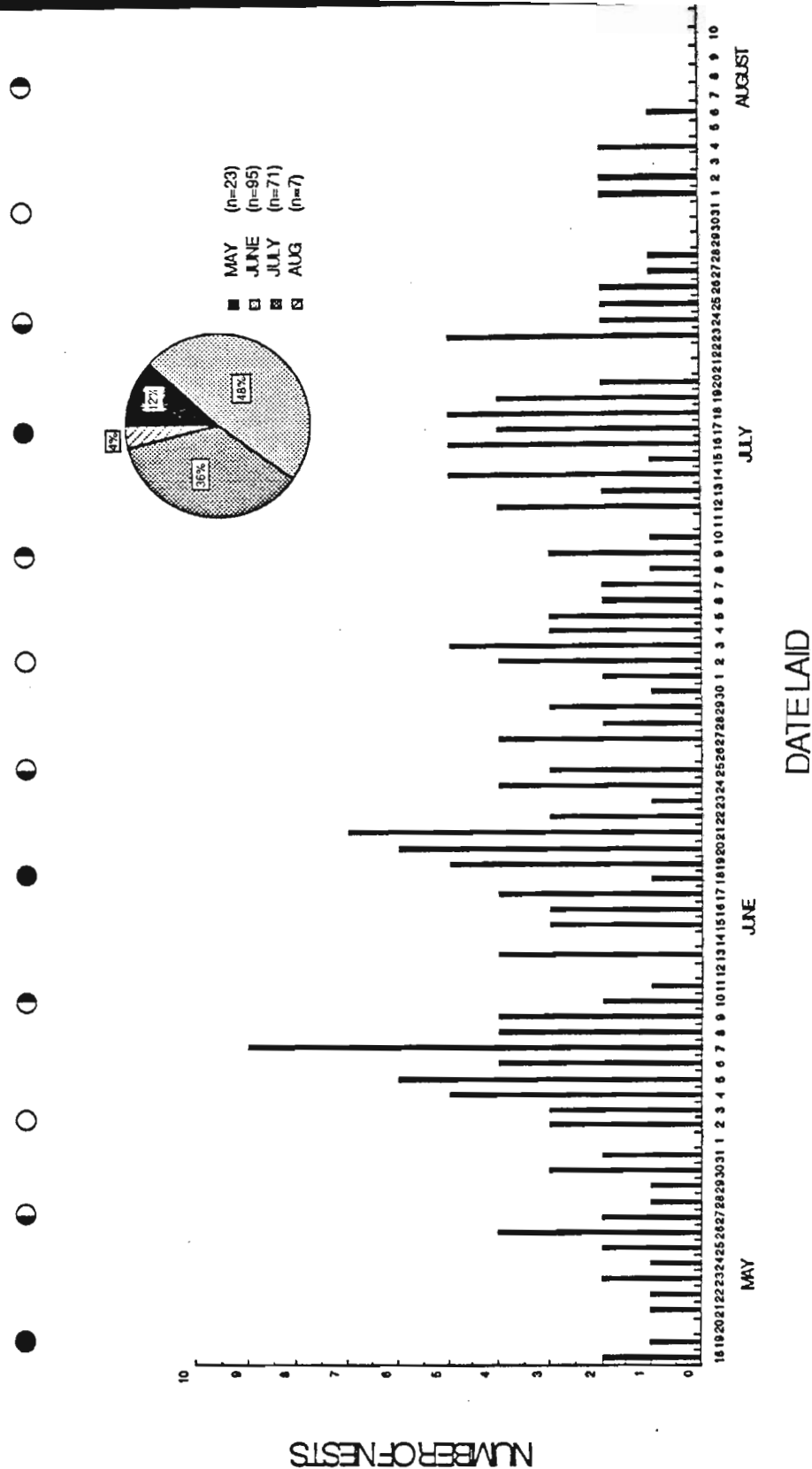


Figure 4. Distribution of loggerhead nests by date laid on Cumberland Island, 1985 (N=196). Also included are moon phase and percentage distribution of nests laid by month.

for Cumberland in 1985 falls at the lower end of the range of mean annual clutch sizes for Little Cumberland Island (114-128 eggs for 19 years of data) (Frazer and Richardson 1985a).

There are many reports in the literature of a trend of decreasing clutch size through the season either in successive clutches of individual nesters or for the population as a whole. Frazer and Richardson (1985b) have pointed out that the majority of these reports are anecdotal with few supporting statistics. In their work on Little Cumberland Island they found that mean clutch size in the population as a whole as well as for females laying multiple clutches per season was smallest at the end of the nesting season, but no steady decreasing seasonal trend was detected. A linear regression of clutch size by date laid, in 1985 on Cumberland Island (n=112), also indicated no significant increase or decrease in clutch size over the season for the population as a whole. Successive clutches by nesting females have not yet been analyzed.

The depth of the nest influences its thermal regime, which in turn determines the incubation period: incubation period decreases as temperature increases and sand temperature decreases with depth but becomes more stable over a diurnal cycle. Nest depth is partly determined by female size (because she digs the nest with her rear flippers) and is adaptive. Nests laid too shallowly undergo large diurnal fluctuations in temperature and may be more readily detected by predators, yet very deep nests develop slowly, increasing the incubation period and thus the time the nest is susceptible to predators.

One very large female (affectionately named the "Cumberland Queen" by the tagging team) rarely dug an egg chamber deep enough to accommodate all of her eggs. As a result she inevitably broke a number of eggs while covering, and on occasion had to be assisted because eggs were backed up in her cloaca as the nest overflowed on the surface. Clutch size is positively correlated to body size for loggerheads in Georgia and Florida (Frazer and Richardson 1986, Ehrhart 1980, p. A-296); rear flipper length is also correlated with carapace size, thereby enabling a large turtle to construct an egg chamber that will hold her clutch. It is interesting to note that the "Queen" is known to have laid at least seven clutches on Cumberland this season.

Mean depth to the center of the clutch was 44.2 cm (n=99,  $\pm 10.30$  S.D.) and was not significantly different between successful and unsuccessful nests. Mean depth to the top of the clutch was 34.9 cm ( $\pm 12.00$  S.D.) and mean depth to the bottom was 53.3 cm ( $\pm 9.75$  S.D.). These depth measurements were made at the time of nest analysis and therefore may not be identical to the original depth because of sand accretion or erosion from the nest site during incubation. The shallowest nest was only 7 cm below the surface (bottom = 35 cm) and was not successful. One of the deepest nests extended from 57 (top) to 83 cm (bottom) and successfully emerged. Loggerhead nest depth on Cumberland is similar to that on Little Cumberland Island, where mean depth is 42 cm (Kraemer 1976).

## Fates of Nests

The fates of 151 of 196 nests laid on Cumberland in 1985 were determined (Figure 5): 40.8% (n=80) were successful, 27.0% (n=53) were unsuccessful because of inundation/erosion, and 9.2% (n=18) were lost to mammalian predators. A successful nest is defined as a nest from which at least one hatchling emerges.

The remaining 45 nests were of undetermined fate because either the nest marker was lost during a high tide or storm event or in some cases the marker remained but the egg chamber could not be located despite extensive searching. It is also possible that some of these nests may have been false crawls.

The spatial distribution of the fates of nests by mile is presented in Figure 6. To determine whether different areas of the beach were more successful than others, a chi-square test was done comparing fates of nests (excluding those of undetermined fate) by their location (mile). When predated nests were included in the analysis, nest fates differed significantly between miles ( $X^2=42.33$ ,  $p < .012$ ), but significant differences were not found when the predated nests were omitted. In other words, the distribution of predated nests was highly localized.

The majority of successful nests were located at the north end of the island; miles 1-3 (section 1-12) contained 45% of the nests laid on Cumberland but 61% of the successful nests (Figure 6). Forty-nine percent of the inundated nests also occurred in miles 1-3. Predated nests were less evenly dispersed than nests of the other fates; 44% were from mile 5.

The data were also analyzed to determine whether nest fate differed in relation to date laid during the nesting season. For this the nests were divided into six cohorts (Table 1). Cohorts differed significantly regarding the fate of their nests ( $X^2=31.86$ ,  $p < .001$ ). Figure 7 depicts the percentage distribution of nest fates from each cohort. Nests laid prior to July (cohorts 1-3) were more successful than later cohorts. Cohorts 4-6 (laid during July and August) had disproportionately more nests lost to inundation. Thus, for the successful and inundated nests, date laid appeared to influence fate more than their location along the beach. Where the nest was located on the beach platform in relation to the tide line and dune also affected its likelihood of inundation and will be discussed later. The probability of predation, however, was more dependent on nest location than on date laid.

— BASED ON ONLY SEASON OF DATA.

## Successful Nests

A successful nest is defined as a nest in which at least one hatchling successfully emerges. Eighty nests were known to be successful, and the fates of all eggs in 72 of these nests are summarized in Table 2.

■ SUCCESSFUL (n=80)  
▨ UNDATED (n=53)  
▩ PREDATED (n=18)  
□ UNDETERMINED (n=45)

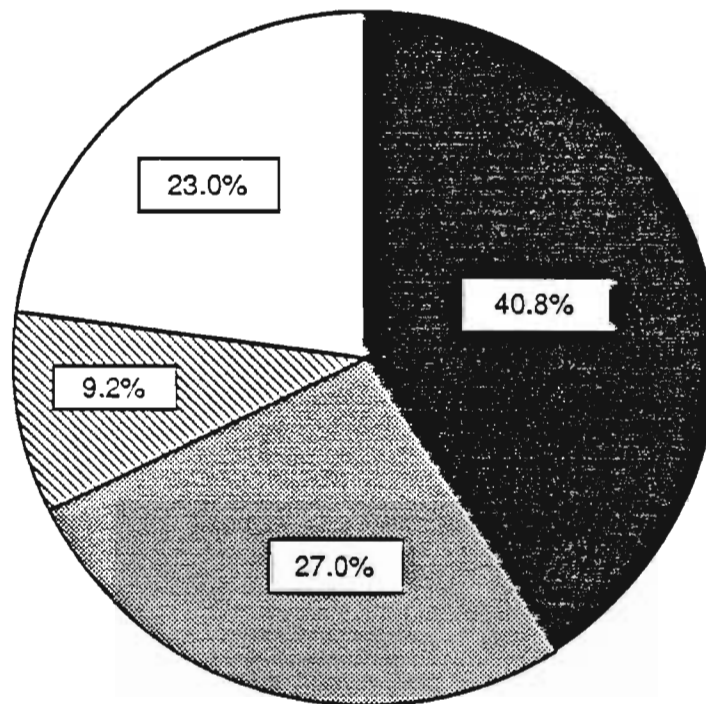


Figure 5. Percentage distribution of fates for all nests laid on Cumberland Island, 1985 (N=196).

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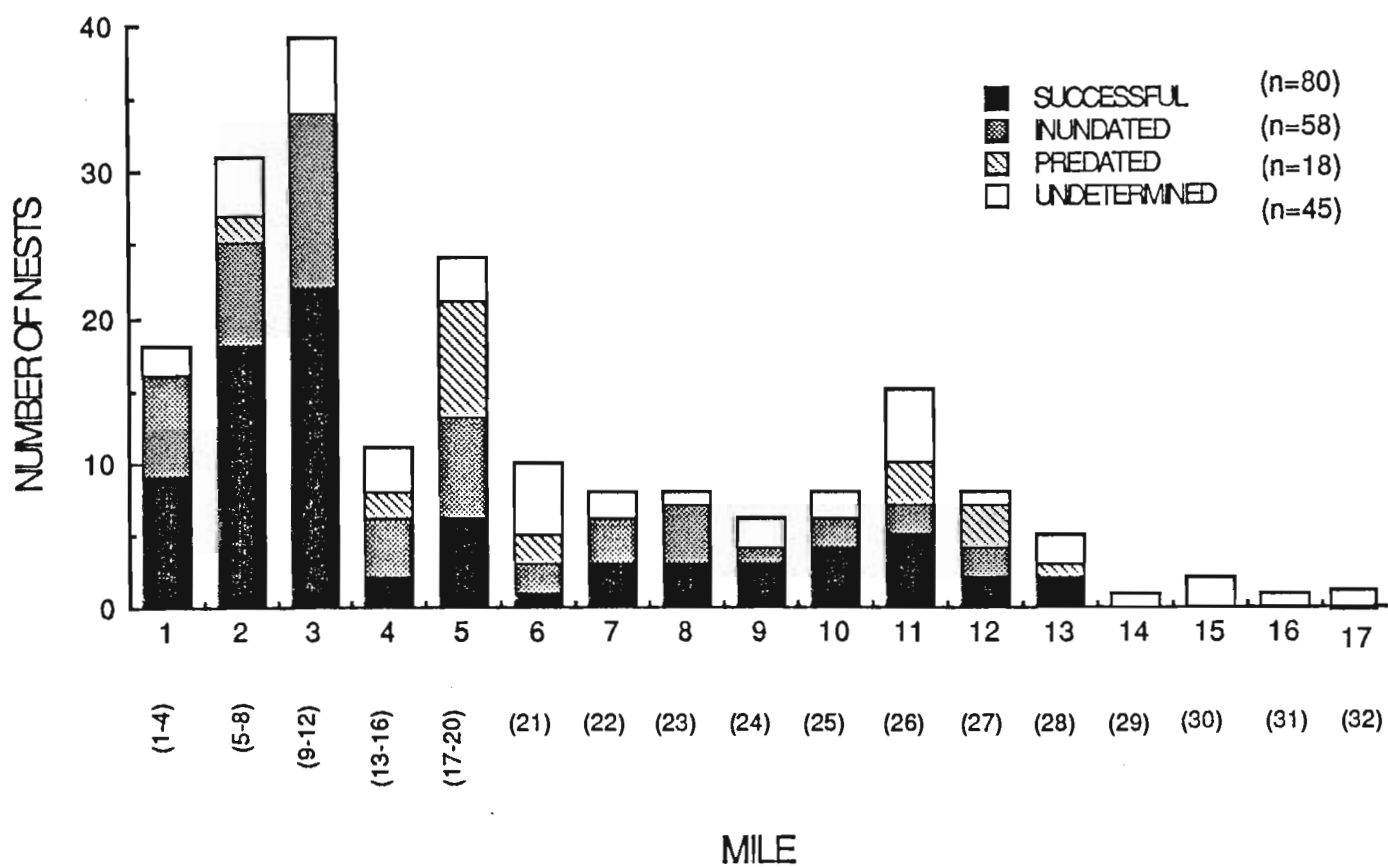


Figure 6. Fates of loggerhead nests by mile on Cumberland Island, 1985 (N=196). Numbers in parentheses represent beach sections.

Table 1. Nest cohorts laid on Cumberland Island, 1985. Cohorts represent approximately two-week periods.

| Cohort | Lay date           | Number<br>of nests | Percent<br>of nests |
|--------|--------------------|--------------------|---------------------|
| 1      | Up to 1 May        | 23                 | 11.7                |
| 2      | 1 June to 15 June  | 48                 | 24.5                |
| 3      | 16 June to 30 June | 47                 | 24.0                |
| 4      | 1 July to 15 July  | 38                 | 19.4                |
| 5      | 16 July to 31 July | 33                 | 16.8                |
| 6      | After 1 August     | 7                  | 3.6                 |

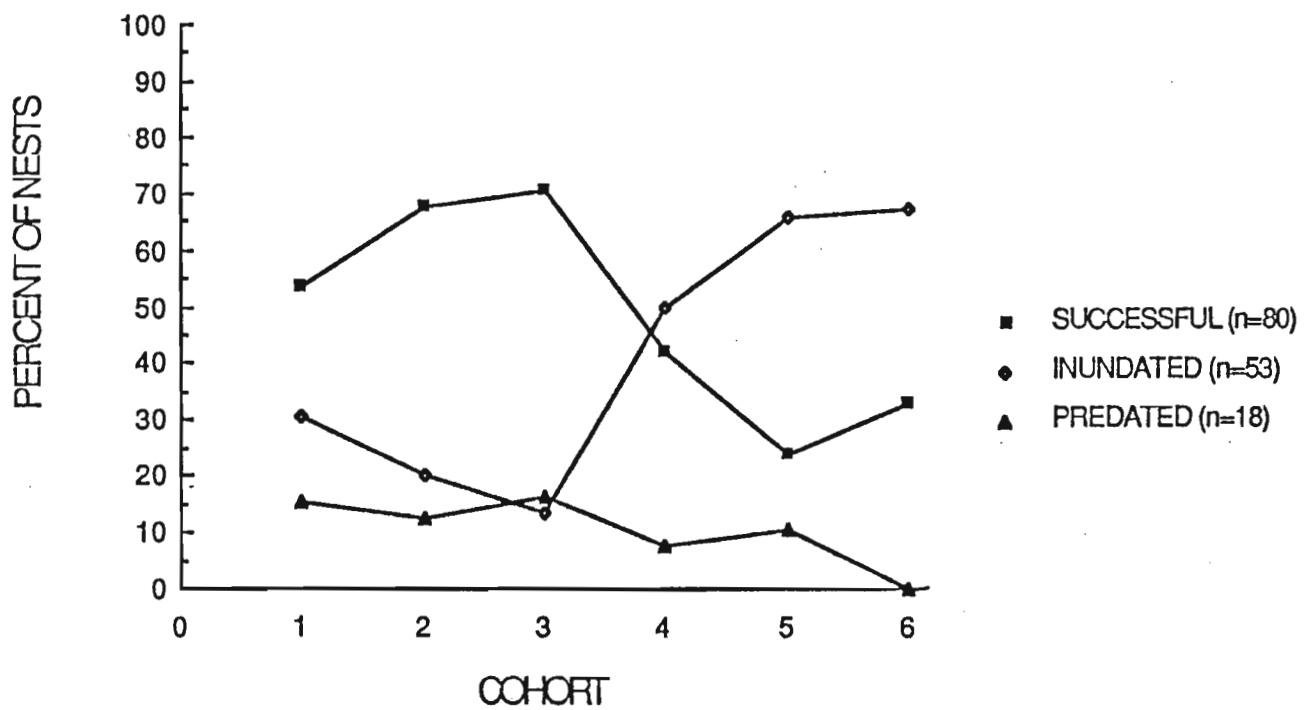


Figure 7. Percentage distribution of nest fate by cohort (date laid). Percentages sum to 100% for each cohort.

Table 2. Fates of eggs in successful analyzed nests (n=72).

| Egg fate                 | Number<br>of eggs | Percent<br>of total<br>eggs | Number<br>of nests | Percent of<br>successful<br>nests |
|--------------------------|-------------------|-----------------------------|--------------------|-----------------------------------|
| Hatched                  | 6430              | 79.2                        | 72                 | 100.0                             |
| Emergед                  | 6035              | 74.3                        | 72                 | 100.0                             |
| Dead in nest             | 357               | 4.4                         | 38                 | 52.8                              |
| Live in nest             | 38                | 0.5                         | 7                  | 9.7                               |
| Pipped                   | 52                | 0.6                         | 13                 | 18.1                              |
| Unhatched                | 1627              | 20.0                        | 72                 | 100.0                             |
| Undeveloped*             | 911               | 11.2                        | 71                 | 98.6                              |
| Normal embryos           | 699               | 8.6                         | 53                 | 73.6                              |
| White embryos            | 15                | 0.2                         | 6                  | 8.3                               |
| Broken eggs\$<br>(crabs) | 440               | 5.4                         | 45                 | 62.5                              |
| Total                    | 8121              | 100.0                       | 72                 | 100.0+                            |

\* Unfertilized eggs were not distinguished from undeveloped eggs.

\$ Broken eggs are included in the undeveloped and normal embryo categories.

+ 72 of 80 successful nests were analyzed.

Hatching success, the percentage of eggs that produce hatchlings, was 79.2%. Not all of these hatchlings made their way to the surface, and therefore overall success is based on the emergence success, or the percentage of hatchlings that successfully emerge from the nest. On Cumberland, 6035 hatchlings emerged from the 8121 eggs in the successful analyzed nests for a 74.3% emergence success.

This success rate is only for successful nests and does not include the 124 other clutches laid during the 1985 season. It is known that no hatchlings emerged from the 53 inundated nests and the 18 predated nests. Eight other successful nests were not analyzed, but if the mean emergence success is the same for these nests an additional 672 hatchlings would have emerged. Thus, a total of 6707 hatchlings from the 22,325 eggs laid (196 nests x 113.9 eggs/nest) gives an overall emergence success of 30.0% on Cumberland for 1985. Because the fates of 45 nests were undetermined (some may have been successful), 30% represents a minimum overall success rate.

A number of hatchlings made it out of the shell but died before emerging from the nest (n=357). Some of these may have hatched after the majority of the clutch left the nest. Emergence requires a cooperative effort among hatchlings, and Carr and Hirth (1961) found that the fewer the number of hatchlings trying to escape at any one time, the lower the emergence success. For this reason, when live hatchlings were found in the nest during analysis, their position in the egg chamber and their physical condition were noted. If they were found on the bottom of the nest and/or looked very weak, they were tallied as dead in the nest, because they probably would not have emerged successfully on their own. All of the live hatchlings were released on the beach. Less than 1% of the hatchlings died while pipping (breaking their way out of the eggshell).

Some of the dead hatchlings in the nest were infested with maggots of the stable fly (Stomoxys calcitrans) (Ruckdeschel 1977), which enter the nest through crab burrows, and others had their eyes eaten out by ghost crabs. In most cases it could not be determined whether these parasites or predators actually caused the death of the hatchling or attacked only after the hatchling died.

Twenty percent of the eggs in the successful nests neither hatched nor pipped. The majority of these eggs (56%, 911/1627) showed no signs of development. It is not possible to determine without microscopic analysis whether these eggs were infertile or whether death of the embryo had occurred very early during development (Ewert 1979).

Embryos, the majority near full term and hatching, were found in 43% (699/1627) of the unhatched eggs. The cause of death of these embryos is not known, but the death of 5% (440/1627) of the unhatched eggs, all broken and showing embryonic development, is attributed to crabs. Signs of crabs were evident in 63% of the successful nests.

Most of the embryos left in the nest appeared normal. Some deformities were noted, such as abnormal flipper length, but none was more obvious than the "white turtle complex." Fifteen white embryos were found in six successful nests. These embryos were white, lacking pigment in their carapace and appendages, but were not considered albino because they had dark eyes. Gross facial and head deformities often accompanied the white color, including cyclops and total loss of eyes. The white turtles never hatched out of the eggs but were often still alive long after the remainder of the nest had emerged. White turtles have also been found in the Little Cumberland hatchery nests and will be studied in greater depth in 1986 by J. Fleetwood and Dr. F. Smith of the College of Veterinary Medicine, UGA.

The mean incubation period (date laid to date of emergence) was 65.7 days ( $n=66$ ,  $\pm 4.89$  S.D.) and varied from 54 to 74 days. Length of incubation is influenced by the temperature of the sand: as nest temperature increases, the incubation period decreases. Nest temperature is determined by the location of the nest on the beach, its depth, and the time of season it is laid.

Length of incubation on Cumberland varied significantly between nests (ANOVA,  $F=3.92$ ,  $p < .0038$ ). Nests laid on the front slope or top of the foredunes have shorter incubation periods than those laid on the open beach platform. Nests laid under or partly shaded by vegetation are cooler than nests exposed to full sunlight. Incubation period was positively correlated with the mean depth of the nest: as depth increased so did the incubation period (ANOVA,  $F=5.937$ ,  $p < .0179$ ).

Nests also showed seasonal differences in incubation length. As expected, early and late season nests (cohorts 1 and 2 and cohorts 5 and 6, respectively) had longer incubation periods than midseason nests (cohorts 3 and 4). Reducing the incubation period decreases the time a nest is exposed to such threats as storm tides and predation, but the minimum period is determined by the time necessary for a fertilized egg to develop into a full-term embryo.

#### Inundated Nests

All the unsuccessful nests that were not lost to predation were included in the inundation/erosion category. In these nests it was evident that inundation had caused its failure: most eggs in these nests died at the same stage of development, developmental stage at death corresponded with the flood tides associated with storm events, it was recorded that the high tide had washed over the nest site, and on analysis the sand in some nests was very wet and at times saturated. Some of the flood tides occurred in conjunction with hurricanes or major rainstorms that caused extensive flooding on the upper beach platform near the dunes. Many of the nests in this area may have failed as a result of freshwater inundation and eventual suffocation from extended periods of saturated sand. Therefore, nests included in this fate failed because of water effects - either

saltwater flooding by the high tide or freshwater saturation from rainfall.

The contents of 27 of the 53 inundated nests were analyzed. Only 53 of 3126 eggs hatched (1.7% hatching success) but none emerged (Table 3). Fifty (all from one nest) died while trying to emerge; they were found in layers above the egg chamber. In this nest the sand was saturated and the high tide had washed the nest site. The remainder of the eggs contained full-term embryos about ready to pip.

As in successful nests, less than 1% of the eggs in inundated nests died while pipping. Almost 98% of the eggs in the inundated nests did not hatch. Of these, 36% (1101/3047) showed no sign of development and 64% (1946/3047) contained normal embryos of various sizes. Many of these nests were excavated in layers to determine embryo position within the nest. In nests laid low on the beach platform, where the high tide was most likely the cause of death, the smallest embryos, sometimes detectable only by the pigmented eyespot, and eggs with no sign of development were usually at the bottom of the nest; embryos got larger toward the surface, indicating that the death of the eggs occurred over a period of time and proceeded from bottom to top.

The sand in many of these unsuccessful nests, especially low beach nests, was often wet or saturated. The unhatched eggs were often highly discolored. In many, the outer shell as well as the contents of the egg were black and frequently contained embryos 2 mm and larger. Black eggs were especially prevalent in very wet nests, where anaerobic conditions were likely. Less common were eggs of bright fuchsia and orange, some of which contained embryos. It is not definitely known what causes these discolorations, although bacteria of the genera Pseudomonas and Aeromonas have been isolated in the black eggs and bacteria of the genus Serratia have been found in association with the pink eggs (J. Wyneken, pers. comm.). Whether these are pathogenic and cause the death of the eggs or invade after nest death is not known. Fungal infections have also been found in loggerhead nests.

The likelihood of nest death caused by inundation was related to temporal and spatial components. On the southeast coast of the U.S., September is the beginning of the hurricane season. At this time nests laid in July and August are still incubating. In 1985, hurricanes Elena and Gloria threatened Cumberland enough to justify closing the park to visitors. Elena brought three days of heavy rain and strong winds (30 August - 1 September). As a result there was standing water everywhere on the beach, especially near the dunes. It is believed that the pools were from freshwater rainfall rather than tidewash, although the salinity of the water was not measured. One of the nests excavated immediately after the hurricane was saturated and had standing water 30 cm below the surface. Hurricane Gloria came late in the season (24-25 September) and did not hit Cumberland directly, so it did little damage to the beach and the remaining incubating nests. More significant was the northeaster of 13 September, which was unusual for this time of year as they

Table 3. Fates of eggs in analyzed nests lost to inundation (n=27).

| Egg fate             | Number of eggs | Percent of total eggs | Number of nests | Percent of inundated nests |
|----------------------|----------------|-----------------------|-----------------|----------------------------|
| Hatched              | 53             | 1.7                   | 2               | 7.4                        |
| Emerg                | 0              | 0                     | 0               | 0                          |
| Dead in nest         | 53             | 1.7                   | 2               | 7.4                        |
| Live in nest         | 0              | 0                     | 0               | 0                          |
| Pipped               | 26             | 0.8                   | 4               | 1.5                        |
| Unhatched            | 3047           | 97.5                  | 27              | 100.0                      |
| Undeveloped*         | 1101           | 35.2                  | 26              | 96.3                       |
| Normal embryos       | 1946           | 62.3                  | 24              | 88.9                       |
| White embryos        | 0              | 0                     | 0               | 0                          |
| Broken eggs§ (crabs) | 44             | 1.4                   | 5               | 18.5                       |
| Total                | 3126           | 100.0                 | 27              | 100.0+                     |

\* Unfertilized eggs were not distinguished from undeveloped eggs.

§ Broken eggs are included in the undeveloped and normal embryo categories.

+ 27 of 53 unsuccessful nests due to inundation were analyzed.

are more common during the winter months (K. Kacer, pers. comm.). Because these northeast winds coincided with the highest tides of the season (8 m), the tide washed up onto the dunes and dramatically reshaped the beach. The sand that had accumulated to build the summer profile was displaced and the beach took on the form of a winter profile: the soft berm was gone, the beach sloped evenly from surf to dune, and many of the dunes were scarped and breached by the tide. Many late season nests were washed repeatedly by these tides and some nests were buried deeply under the shifted sand.

Because of the seasonal nature of hurricanes and northeasters, late season nests run higher risks. As seen in Figure 7, 50-70% of cohorts 4-6 (all laid after 1 July) were unsuccessful as a result of inundation. Ragotzkie (1959) also found that loggerhead nests on Sapelo Island laid after 1 July ran a high probability of mortality as a result of excessive rainfall in September. Kraemer and Bell (1980) point out that the amount of rainfall in September is not significantly greater than in other months during the turtle season, but excessive rainfall events (>100 mm) are more common in September; these events cause the flooding and sand saturation that impede oxygen flow and drown nests (Packard et al. 1977).

The closer a nest is to the dunes the less susceptible it is to fluctuation in the tide and nests laid on top of the dunes generally escape tidewash. Also, because of the nature of dune sands, rainwater quickly percolates through the dune (Salisbury 1952) and evaporation rates are high. Therefore, even during extended periods of rain dune nests will not be subjected to saturated conditions.

Spatial and environmental correlates of nest success (including moisture content and salinities) will be further investigated during the 1986 nesting season.

#### Predated Nests

Raccoons appeared to be the predators of all nests lost to this cause. Feral hogs, a potential nest predator, were seen on the beach on a number of occasions but none of the predated nests showed signs of hog rooting. A hog removal program by the Park Service has effectively reduced the population so that at the present time hogs do not pose a threat to the loggerhead population on Cumberland, although they are still relatively abundant on Little Cumberland.

Once a nest was opened by raccoons it eventually failed. Raccoons rarely ate all the eggs in the nest in one night, but would return on subsequent nights. On one occasion a nest (instrumented with a thermal probe) opened by raccoons was protected by a wooden board the following morning; it remained in place for a couple of days. As only a small portion of the nest was disturbed, it was hoped that the remainder of the clutch would incubate successfully. Nest temperature during incubation indicated that the clutch was not successfully developing, suggesting that once a nest is opened by raccoons and eggs are broken in the nest, the whole nest, or at least the majority of the eggs, will be unsuccessful (McMurtray 1986).

Raccoon predation on Cumberland accounted for the loss of 18 nests (9.2%). No other species was known to take whole nests although crabs entered nests and destroyed individual eggs and hatchlings. Predation was highly localized, 12 of the 18 predated nests being taken in a 3-mile stretch (miles 4-6) and 8 of these from mile 5 (sections 17-20). This area is distinguished by the high dunes that begin their abrupt rise to about 10 m in height only a short distance above mean high tide line. The dune oak-buckthorn shrub forest abuts the landward side of this dune and may explain why predation rates are highest for this part of the island. Raccoon tracks at nest sites indicated that the raccoons came over the dunes rather than laterally along the beach. This localized pattern of predation seems to indicate that one or two individuals were responsible for the predation rather than an islandwide overpopulation of raccoons.

It is believed that raccoons primarily use olfactory cues to locate nests. Freshly laid nests are the most vulnerable because smells associated with the eggs and nesting female dissipate with time. The mean incubation period before these nests were predated was 7.7 days ( $n=12$ ,  $\pm 2.24$  S.D.). This mean period is skewed by two nests that incubated 21 and 24 days before being eaten. In one of these nests it is known that crabs entered the nest first, leaving turtle eggshells scattered about the surface. These visual and olfactory signs may have alerted a foraging raccoon to the presence of a nest that otherwise may have gone undetected. When these two nests are not included, mean incubation prior to predation drops to 4.7 days.

A second wave of predation occurs at nest emergence. At this time the exit tunnel made by the first emerging hatchlings serves as a visual cue and possibly an olfactory cue to the location of the nest. Six nests (7.5% of the successful nests) were predated by raccoons at the end of their incubation periods, all after the initial hatchling emergence. Because at least some of the hatchlings successfully escaped to the sea, these nests were considered successful rather than predated, but only two were included in the egg fate analysis.

The social facilitation mechanism (Carr and Hirth 1961) that enables the hatchlings to dig their way out of the nest is also critical in lessening the impact of postemergence predators including raccoons, crabs, birds, predatory fish, and sharks. By emerging all at once, the hatchlings "swamp" the predators, thereby assuring that at least some of the hatchlings escape predation. This predator satiation strategy is especially important to a species that has no parental care of young and suffers high mortality rates early in life.

Predation on Cumberland Island is quite low compared to other loggerhead beaches in the southeast. Nests laid on beaches of Cape Canaveral National Seashore, Florida, suffer 98% predation by raccoons, and Hopkins et al. (1978) reported a loss of 56% of the nests laid on four barrier island beaches in South Carolina.

## Conclusions

On Cumberland Island in 1985, 41% of the loggerhead nests of known fate were successful. This hatching success is significantly higher than the natural success rates reported for other nesting beaches in the southeastern United States. In recent years, Cape Canaveral National Seashore has had a 1% success of natural nests due to excessive raccoon predation (McMurtray 1986), and predation, inundation, and poaching reduced the overall hatch on four South Carolina islands to 6% (Hopkins et al. 1978). Although the nesting population on Cumberland (approximately 60 females nested in 1985) is smaller than on these other beaches, the relatively high success rate suggests that Cumberland may contribute significantly to recruitment in the loggerhead population of the southeastern U.S.

Predation is a minor cause of mortality of loggerhead nests on Cumberland Island. On some South Carolina and Florida beaches, raccoons destroy 55 to 98% of the nests (Stancyk et al. 1980, Hopkins et al. 1978), whereas only 10% were taken on Cumberland in 1985. Hopkins et al. (1978) noted that on four South Carolina islands raccoons were ubiquitous and predation closely followed the spatial distribution of nests. Talbert et al. (1980) found that predation on Kiawah Island, S.C., was significantly lower in areas heavily patrolled by the tagging team than in areas less patrolled, although they offered no direct evidence that patrol frequency was the cause of this difference. Raccoon predation on Cumberland follows neither of these patterns. In 1985, predation was highly localized and was probably indicative of the spatial distribution of the raccoons rather than of the nests. One area of heavy predation occurred near the high dunes backed by forest, which provides cover near the beach, and the other predation area was near the Sea Camp and Stafford camping areas, which are heavily utilized by raccoons. Patrol coverage did not deter predation, as the heaviest predation was in a part of the study area where the tagging team rested between hourly runs.

The majority of unsuccessful loggerhead nests on Cumberland in 1985 were lost to inundation (27% of all nests). Freshwater and saltwater inundation has consistently been cited as a significant cause of nest mortality for loggerhead turtles nesting in the southeastern U.S. (Ragotzkie 1959, Hopkins et al. 1978, Kraemer and Bell 1980, Ferris 1985). Developing turtle eggs require a constant supply of oxygen. As moisture content increases in the nest, gas exchange is impeded and the eggs suffocate (Ackerman 1981).

In some areas of the nesting range severe beach erosion is also a cause of nest mortality; often nests are completely washed out to sea (Hopkins et al. 1978). Beach profile and tide regime, as well as the incidence of major storm events, are important determinants of the likelihood of nest loss to erosion. Cumberland Island is a low-energy beach of gentle slope, and erosion is generally not severe. Notable erosion and scarping of the dunes occurred on two occasions in association with northeasters; nests laid in the saddle between

dunes were the most susceptible to both wind and water erosion but no nest is known to have been washed out to sea.

On a beach of such gentle slope, small increases in tide and wave amplitude associated with storm events can greatly increase the extent of tide wash up the beach platform. As a result, even nests laid high on the berm well above the mean high tide line are subjected to occasional tidal overwash. Nests on the dune are the least susceptible to inundation because of their elevation and the porous nature of dune sands. As might be expected, the majority of nests lost to inundation were located low on the beach, yet it is not known whether saltwater percolation from tide overwash, freshwater percolation from excessive rainfall, or a rise in the ground water table was the major cause of failure. In 1986, sand moisture content and salinity will be monitored to determine the source of water responsible for nest mortality.

The nesting season on Cumberland extends from mid-May to mid-August. Late season nests, however, have a greater risk of mortality because of the frequency and severity of storm events in September (Ragotzkie 1959, Kraemer and Bell 1980). On Cumberland in 1985, more than 50% of the nests laid after 1 July failed from inundation. Because 40% of the season's clutches were laid after this date, there does not appear to be selection for a shorter nesting season by favoring early nesting. The hurricane season in this region has probably overlapped the loggerhead nesting season throughout its evolutionary history and the limits of the nesting season may be dictated more by sand temperatures than by storm occurrence. Weather patterns vary and in some years hurricanes and tropical storms occur later or are less severe than in others. Hence, late season nests in years characterized by delayed or mild storms may contribute a significant proportion of that season's hatchling production, which may be sufficient to maintain late season nesting in the population. Sea turtles, which are long-lived and have a long reproductive life span, may be better able to average out the effects of short time scale environmental fluctuations (annual variations in the environment, such as annual weather patterns) than animals with short generation times, and therefore do not have to track these variations as closely (May 1976, Southwood 1976).

The results presented in this report represent preliminary data analysis. Monitoring of the environmental and biotic factors associated with nest success, as well as the thermal regime of the nesting beach, will continue in 1986. Management recommendations for reducing nest loss to inundation and predation will be presented in the final project report.

#### Threats to Cumberland Island Loggerheads

##### Incidental Catch

Sea turtle mortality resulting from incidental catch in commercial fishery nets is currently one of the greatest threats to sea turtles in the southeastern Atlantic and Gulf waters. It is

estimated that more than 12,000 sea turtles die in nets, especially shrimp trawls, each year (Oravetz 1986). The majority of these are loggerheads whose feeding grounds coincide with productive shrimping areas or who are attracted to these areas by the large quantities of bycatch discarded from the shrimping vessels (Shoop and Ruckdeschel 1982). In Georgia waters the majority of these turtles tend to be large, prereproductive immatures (Ruckdeschel and Zug 1982).

The National Marine Fisheries Service in conjunction with representatives of the commercial shrimp industry has developed a turtle excluder device, or TED, that effectively reduces the incidental catch of sea turtles by 97% (Hopkins and Richardson 1984). After a number of design changes the device is safe, lightweight, and collapsible. NMFS is now at the stage of convincing the shrimp industry to widely and voluntarily adopt the TED, which is also known as the trawler efficiency device because while maintaining or slightly increasing the shrimp catch it greatly reduces the finfish bycatch (representing billions of pounds per year lost to other fisheries) and jelly balls that clog the nets. The TED also reduces damage to the shrimp and the time required to sort the catch on deck. It is unfortunate that NMFS is meeting with so much resistance, and a number of government agencies and environmental groups are beginning to push for mandatory use of the TED on all U.S. commercial shrimping vessels.

As reported by the Georgia Marine Turtle Stranding Network of the Georgia DNR, 29 turtles stranded on Cumberland Island from May to September 1985: 2 in May, 2 in June, 13 in July, 4 in August, and 8 in September. The jump in stranded turtles in July corresponds to the opening of the nearshore waters to shrimping operations. The majority of turtles caught in shrimp trawls in Georgia waters are juveniles and subadults (Hillestad et al. 1977). On Cumberland, most of these DOBs (dead on beach) were large, immature females, just below the reproductive size class: the mean over-the-curve carapace length was 67 cm (n=19, range 55-87 cm). Two of the eight turtles stranded in September were immature Kemp's ridleys (Lepidochelys kemp), the most endangered sea turtle species.

Population models indicate that pre- and newly reproductive individuals have the greatest reproductive potential of all age classes in the population. Therefore, any chronic threat to these recruits can have serious long-term consequences, especially in a species that is long-lived and takes between 15 and 30 years to reach sexual maturity (Mendonca 1981, Frazer and Ehrhart 1985).

Little can be done from the nesting beach to reduce the number of Cumberland turtles incidentally caught in shrimp trawls, other than to press for the implementation of the TED by local fishermen. It has been suggested that inshore waters near the nesting beaches be closed to shrimping during the nesting season as incidence of capture is high in nearshore waters especially early in the season, whereas mortality associated with shrimp vessels 3 miles offshore is low (Hillestad et al. 1977). This would undoubtedly cause resentment

toward sea turtles by the shrimp industry, and it is felt that use of the TED would avoid such a conflict.

### Lighting

Cumberland Island is a National Seashore with limited development and few resident homes. There are no major artificial sources of light originating from Cumberland Island and no direct illumination of the beach. Two point sources of light that may affect both adult nesting females and emerging hatchlings are the paper mill directly south of the island near Ft. Clinch, Florida, and Kings Bay Naval Base to the west of Cumberland in St. Marys. Both of these are very brightly lit and remain lit throughout the evening. The paper factory is mainly visible from the southern end of the island, whereas the Kings Bay "glow" can be seen to the west from all beach points, particularly on foggy evenings.

The effect of these lights on females nesting on Cumberland is not known. In fact, the effect of reflected light, emanating from a city or source such as Kings Bay, on turtle orientation has not been well studied. Mann (1978) found that stationary bright lights on developed beaches did not deter nesting females, but that moving lights near the beach may induce turtles to make false crawls (emerge on the beach without laying) more than usual. Hopkins and Murphy (1985) have shown that as the number of induced false crawls increases the quality of the nest site used when the turtle finally lays goes down, thereby reducing nest success.

Cumberland Island, by nature of its National Seashore status and low resident population, has little beach traffic at night, the majority of the vehicles being the ATCs used by the turtle tagging patrol. Most of the local residents are aware of the disturbance that vehicle lights cause the turtles. It is recommended that brochures or notices be posted in the rental homes informing transient vacationers of the nesting turtles and how to observe them without disturbing them. Programs educating campers about sea turtle ecology can teach them how to find and watch nesting turtles without flashlights. It is also suggested that the tagging crew or any vehicle regularly using the beach at night shield their headlights with red filters, provided they do not reduce safety.

Hatchlings emerge from the nest at night to avoid the lethal sand temperatures and diurnal predators. The comparative brightness of the seaward horizon (because of the low profile of dunes and vegetation in that direction) is the primary stimulus that orients the hatchlings toward the ocean (Daniel and Smith 1947, Ehrenfeld and Carr 1967). Bright artificial lights disorient hatchlings: as they emerge from the nest hatchlings will head in the direction of bright lights that are visible on the horizon from the nest. It is the intensity or brightness of the light that is important (Ehrenfeld 1968, Mrosovsky 1972). If these lights originate over land the hatchlings will head toward them rather than the sea. Wandering on the beach increases the time exposed to predators and uses up stored food reserves. Although most hatchlings eventually find their way to the sea, some may get lost behind the dunes. Those left on the beach

the following morning will inevitably die from dehydration, lethal sand temperatures, or as breakfast for a diurnal predator. Artificial lights can also disorient hatchlings already swimming away from the nesting beach, and can even draw them back to land (Carr and Ogren 1960).

In the majority of successful nests in 1985, hatchlings were not disoriented by artificial lights, however, tracks indicated that three nests were affected. Because the ocean horizon is dark to hatchlings emerging from nests on the back slope of dunes especially on moonless nights, light sources from the mainland to the west draw hatchlings into the dunes; this occurred on two back slope nests. Tracks from another nest that emerged on a foggy night, on the beach toward the south end of the island, headed directly south for over 200 m. Lights from the paper mill probably caused this disorientation; most hatchlings eventually made it to the surf and a few ended up in crab burrows. Ferris (1986) found that the lighthouse on Cape Lookout as well as mainland lights affected hatchling movement, but the extent depended on the distance and visibility of the light source from the nest and the position and phase of the moon at emergence.

Eliminating the problem light sources affecting Cumberland's hatchlings is unlikely, but another measure can be taken to decrease hatchling disorientation. Implementing a technique suggested by Ehrenfeld (1968), Ferris (1986) erected black, opaque screens 1 m high and 3 m long adjacent to the nest site to block the disorienting light from the hatchlings' view and direct them toward the surf. Although this technique was tried only once, it was successful.

Because sea turtles are one of the main attractions on Cumberland during the summer months, visitors need to be educated about the effect flashlights can have on hatchlings making their way to the sea. If flashlights must be used to watch hatchlings (and this should be discouraged) observers should stand between the hatchlings and the surf: this will draw the hatchlings toward the water without impeding their progress. Also, because it is believed that the initial trip down the beach may be crucial to imprinting, visitors should be told not to handle the hatchlings or "help" them to the sea.

Finally, although Cumberland is well protected from the commercial development currently under way along the southeast coast, a good review of hatchling orientation and the effect of beachfront lighting (including management recommendations) is available from the Center for Environmental Education, Washington, D.C. (Raymond 1984).

#### Dredging and Kings Bay

The U.S. Navy and Army Corps of Engineers have been conducting dredging operations in the Cumberland Sound Inlet to open the Kings Bay Naval Submarine Base to Trident nuclear sub operations. This will require extensive dredging of the channel. Under the provisions of the Endangered Species Act (1973), the Navy conducted an

assessment of the potential impact that dredging operations could have on threatened and endangered species in the Cumberland Sound and St. Marys Entrance. Potential for impact on loggerhead sea turtles was determined to be considerable because turtles are common in these waters during the reproductive season.

The Navy recognizes the fact that hopper dredge operations could disturb female emergence and nesting on the southern end of Cumberland Island, but the impact would likely be greatest on the juvenile turtles and neophyte breeders that rest and feed in these waters during the summer. The Navy acknowledges that such an impact could be reduced by eliminating dredging in the nearshore and channel regions during the nesting season.

The possible direct and indirect impacts of channel dredging operations on loggerhead turtles are discussed below.

#### Direct impacts:

1. The hopper dredge may take up and pulverize turtles that are feeding or resting in the inlet waters during the nesting season.
2. Although loggerhead strandings occur year-round, it is not known whether turtles overwinter in local waters, as no hibernacula have been found. However, turtles may be induced to overwinter in the soft sediment that accumulates in the channel bottom subsequent to the dredging operations. This would increase their susceptibility to disturbance and mortality during future dredging operations. This has been found to be a problem associated with the maintenance of the Cape Canaveral Ship Channel (P. Raymond, pers. comm.).

#### Indirect impacts:

1. Dredging may affect food availability to turtles directly by removing the crustacean populations, or indirectly by altering the physicochemical characteristics of the waters, which may in turn influence the entire biotic food web and the "nursery" status of the estuarine waters.
2. Given the depth and extent of the dredging operation, the sediment budget in the area may be severely altered and may accelerate the beach erosion rate. This would not only reduce the availability of nesting beach but may alter the offshore topography, influencing where females emerge to nest.
3. Increased erosion rates may be compensated for by a beach nourishment program, but not without other negative impacts. If done during the nesting season, sands pumped onto the beach risk covering existing nests, which could change the thermal and hydric characteristics of the nests and ultimately reduce their success. Even in nests that successfully hatch, increased sand depth may prevent hatchlings from emerging. This can be avoided by conducting beach nourishment programs at times other than the nesting season.

Care must be taken to match the grain size of the dredge material to that of the natural beach to prevent changing the physical and microclimatic characteristics of the beach. Sand compaction resulting from beach nourishment by the hydraulic pumping method reduces the ability of adult turtles to dig nests. On a restored beach in Florida loggerhead nesting rate declined, false crawls increased, females nested in less successful sites (often in areas washed by the tides), and hatching success was lower (Raymond, 1986).

Changes in sediment parameters and the sediment budget may also cause profound changes in the coastal geomorphology and beach profile. Because it is not known what factors loggerheads use as cues for beach recognition and site selection, it is best to take a conservative approach toward the physical alteration of the nesting beach.

4. Artificial lighting onshore is known to disorient adult and hatchling sea turtles. Lighted dredges could have a similar effect and should be positioned at night in an area that will not be visible to nesting females or emerging hatchlings.

It is imperative to keep a close watch on the loggerhead population status in the Cumberland Sound and St. Marys Entrance during all seasons. Dredging operations may modify the habitat and make it favorable for overwintering. Trawling to monitor turtle presence should be conducted at regular intervals and contingency plans enacted to mitigate impact if turtles are found.

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