Sea turtle nesting in the Ten Thousand Islands of Florida

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ABSTRACT

Loggerhead sea turtles (*Caretta caretta*) nest in numerous substrate and beach types within the Ten Thousand Islands (TTI) of southwest Florida. Nesting beach selection was analyzed on 12 islands within this archipelago. Numerous physical characteristics were recorded to identify the relatedness of these variables and determine their importance for nesting beach selection in *C. caretta*. These variables were chosen after evaluating the islands, conducting literature searches and soliciting personal communications. Along transects, data were collected, on the following: height of canopy, beach width, overall slope (beach slope and slope of offshore approach) and sand samples analyzed for pH, percentage of water, percentage of organic content, percentage of carbonate and particle size (8 size classes). Data on ordinal aspect of beaches and beach length were also recorded and included in the analysis. All of the variables were analyzed by tree regression, incorporating the nesting data into the analysis. In the TTI, loggerheads appear to prefer wider beaches ($p < 0.001$; $R^2 = 0.56$) that inherently have less slope, and secondarily, wider beaches that have low amounts of carbonate ($p < 0.001$). In addition, *C. caretta* favors nest sites within or in close proximity to the supra-littoral vegetation zone of beaches in the TTI ($p < 0.001$).

Aerial surveys were flown over the TTI region during June and July of 1996. Twenty-nine of the possible 34 islands with potential nesting beaches were chosen for the study. Ground surveys were conducted on 8 islands to provide a correction factor between ground and aerial counts. All crawls counted on the ground were counted from the air. This technique resulted in estimates of 906 nests and 997 false crawls in 1996 for the 29 islands. It appears that sea turtles (*Caretta caretta* and *Chelonia mydas*) nest in relatively high numbers in an area (TTI) not previously known to support significant sea turtle nesting activity.

Predation by raccoons (*Procyon lotor*) is the primary factor in nest success for sea turtles in the TTI archipelago. Eight islands within or adjacent to the Ten Thousand Islands National Wildlife Refuge (TTINWR) have been surveyed for sea turtle nesting activity from 1991-96. Raccoon trapping was conducted during the 1992 nesting season and in 1995-96 from January through April, removing 21, 15 and 2 raccoons, respectively. Removals in 1992 (21) resulted in continued high predation, indicative of a high raccoon population and insufficient removals (nests= 42, 95% predation). Although fewer raccoons were removed prior to the 1995 and 1996 nesting seasons (15, 2), no nest predation occurred during either year (1995, nests= 41; 1996, nests= 62). These figures are in contrast to 76-100% nest predation for the previous four years. Eight raccoons were also trapped, tagged and released on Gullivan Key in 1995 (276 trap-nights, 3.2% trap success). The following year only 1 raccoon was trapped and removed (114 trap-nights, 0.9% trap success) resulting in no significant decrease in nest predation (nests= 33, 97% predation). The results from the TTI indicate that raccoon removal may be an effective management tool for increasing sea turtle nest success on relatively remote barrier islands, although some raccoons may become sensitized to traps if exposed to traps prior to removal work. More work is needed to provide conclusive evidence that sufficient and cost-effective trapping and removal can be conducted on these barrier island beaches in order to increase sea turtle hatching success.

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CHAPTER 1

INTRODUCTION

Sea turtles have been the subject of much scientific and public attention due to their imperiled status and prominent role on beaches of the world. The direct contact with the public has heightened awareness and concern for sea turtle conservation. Understanding distribution, nesting and habitat preferences, and sources of mortality is critical to management of sea turtles and their habitats.

The Ten Thousand Islands (TTI) extend roughly 40 kilometers from Marco Island to Pavilion Key along Florida's southwest coast (Edwards, 1991). Located approximately 25 kilometers southeast of Naples, these largely undeveloped islands are utilized by the public year-round, primarily for fishing (Cheng, 1996). The climate is subtropical with 110 to 160 centimeters of average annual precipitation, two-thirds of which occurs between May and October (Cheng, 1996). Average annual temperature is 23 degrees Celsius, with occasional freezing temperatures in the winter and regular mid-thirties in the summer (Cheng, 1996).

The mangrove ecosystem of the TTI supports a wide range of invertebrates, fishes, amphibians, reptiles, birds, and mammals. Roughly eighty-six species of fish and over eighty species of birds have been documented in the area (Cheng, 1996). The waters serve as a rich nursery ground and an important foraging area for many marine creatures. Red (*Rhizophora mangle*) and black (*Avicennia germinans*) mangroves dominate most of the islands. Where they exist, beaches are usually narrow and interspersed with mangroves. Some of the most seaward islands have one or two long stretches (several hundred meters) of uninterrupted beach. These islands are characterized by a pioneer zone where vegetation meets the beach. A variety of grasses, herbaceous plants, and vines are found in this zone, including seashore saltgrass (*Distichlis spicata*), sea oats (*Uniola paniculata*), sea purslane (*Sesuvium portulacastrum*), and railroad vine (*Ipomoea pescaprae*) (Cheng, 1996).

The loggerhead sea turtle (*Caretta caretta*), is a member of the family Cheloniidae. It is known to nest in Florida, particularly on the east coast, in the largest nesting aggregation in the world. Various techniques have been developed to estimate sea turtle population characteristics. These include a description of techniques for studying sea turtle population dynamics (Bustard, 1979), a study of population dynamics of green turtles based on nesting females and hatching (Thompson, 1980) and estimation of population dynamics for the southeastern United States based on netting of sea turtles (Henwood, 1987). Chaloupka and Musick (1997) describe the latest techniques for assessing population dynamics of sea turtles, discussing in detail the numerous variables that have to be considered when attempting to create a population estimate. Several researchers have based population estimates on nesting loggerhead females that were tagged over the course of a 20-year period in Georgia (Crouse et al., 1987; Frazer, 1983; Frazer, 1984; Richardson et al., 1978; Richardson, 1982).

Numerous studies have been conducted pertaining to sea turtles in Florida, with some work conducted in southwest Florida. LeBuff & Beatty (1971) and LeBuff (1990) reported on the nesting status of *C. caretta* on the Gulf coast of Florida, and LeBuff (1969) discussed the status of marine turtles at Sanibel and Captiva islands along the southwest coast of Florida. The studies mentioned above refer to basic descriptions of the nesting status in southwest Florida in predominantly urban areas. Addison (1994) commented on the nesting behavior of *C. caretta* on beaches in the Naples, Florida area, conducting some work on uninhabited beaches similar to the TTI. LeBuff and Hagan (1978) assessed the effectiveness of aerial survey as a means of documenting sea turtle nesting activity on the beaches of the Ft. Myers-Naples, Florida area, with incidental flights over the TTI included in the study. However, little is known of *C. caretta* in the TTI of the west coast of Florida. The TTI have been neglected, with annual ground surveys conducted by the U.S. Fish and Wildlife Service the only indicator of sea turtle activity in the TTI. Further down the coast of southwest Florida, Klukas (1967) reported on the status of marine turtles in Everglades National Park (ENP), while Davis and Whiting (1977) created a nesting estimate for ENP lands and reported on sources of mortality for sea turtle nests. Kushlan (1986) repeated the aerial methodology utilized by Davis and Whiting (1977) in order to create an updated nesting estimate for ENP lands. The flights over ENP did not cover the TTI in either of the previously mentioned aerial studies in the TTI. Due to the lack of information concerning sea turtles, it became important to develop techniques for assessing the nesting status of sea turtles in the TTI. Included in these techniques are methods for assessing nesting preferences and distribution of nesting by sea turtles, as well as conservation (i.e. predator control) methodology.

Once a sea turtle has navigated to its natal area, it may exhibit nesting preferences. Only a few researchers directly attempted to clarify reasons for nesting beach selection in sea turtles. Among these possible factors are an open offshore approach, sediment type, vegetation, lighting, salinity and area of nesting beach (Mortimer, 1990, 1995; Johannes and Rimmer, 1984). However, these factors may not have inter-specific applications, and may differ from study area to study area around the world. Furthermore, these particular characteristics have been treated individually by these researchers; they were not subjected to multiple variable analysis.

Miller (1995) reported that sea turtles tend to renest in relatively close proximity (0-5 km) during subsequent nesting attempts, while a small percentage may utilize more distant nesting sites. Carr et al. (1978) found that green sea turtles select the same beaches year after year for nesting, while avoiding other seemingly almost identical beaches. Melucci et al. (1991) found evidence that hawksbill turtles also exhibit a significant degree of site-fixity on Antigua. Bjorndal et al. (1985) also found evidence that the hawksbill turtle exhibits a significant degree of site-specificity at Tortuguero, although a greater degree of site-fixity existed between seasons rather than within seasons. Mortimer and Portier (1989) found that green turtles exhibit a high degree of nest site fidelity at Ascension Island. Tagging data showed that 70 percent of observed renesting emergences occurred in the same beach cluster as the initial observed emergence (Mortimer and Portier, 1989). In Chapter 2, I use tree regression to evaluate numerous physical characteristics of the beaches in the TTI in order to establish loggerhead sea turtle nesting beach preferences for a particular characteristic or combination of characteristics. I also discuss nest placement and/or selection by *C. caretta* in the TTI.

Aerial surveys have been employed to assess wildlife throughout the United States and the world. The value of this type of assessment is dependent upon the species or activity of the species being evaluated. Aerial surveys have been utilized to census sea turtles and dugongs by several researchers (Marsh and Sinclair, 1989; Bayliss, 1986; Irvine et al., 1981; Fritts et al., 1983). Marsh and Sinclair (1989) and Bayliss (1986) reported success in counting dugongs from the air, but reported that due to the diving behavior of sea turtles, it was difficult to assess their abundance. Fritts et al. (1983) reported numerous sightings of a variety of species in the TTI region, including large numbers of loggerheads, and lesser numbers of leatherback, Kemp's Ridley, and green sea turtles. However, their counts may have coincided with weather and water conditions that were favorable to spotting sea turtles, as was indicated by Mourao et al. (1994). Mourao et al. (1994) clearly state that population estimates derived from aerial surveys are subject to a host of sampling errors. In Chapter 3, I assess the problem of sea turtle nesting distribution in the TTI. I discuss the possibility of creating a seasonal nesting estimate for the TTI archipelago based on an aerial survey technique adapted from Hopkins-Murphy and Murphy (1983).

Raccoons are known to prey on the eggs of numerous species, including: American crows (Kilham, 1986), waterfowl (Urban, 1970), painted turtles (Christens & Bider, 1987), wading birds (Frederick & Collopy, 1989), yellow mud turtles (Christiansen & Gallaway, 1984), coastal burrow-nesting birds (Hartman, 1993) and diamondback terrapins (Seigel, 1979). The impacts of raccoons on sea turtles are well known throughout the United States, particularly in areas where continuous studies have been conducted. The Georgia Department of Natural Resources assessed the impacts of raccoons, as well as feral hogs on sea turtle nests on several barrier islands for six seasons. Raccoons have been shown to have definitive impacts on the success of sea turtle nesting over the six-year period (Harris and Maley, 1990; Maley and Harris, 1991, 1992; Maley and Murphy, 1993, 1994; Maley, 1995). Raccoons have been determined to be a major factor in the success of sea turtle nesting in the TTI of southwest Florida (L. Richardson, pers. comm.). The TTI are inhabited by the Ten Thousand Islands raccoon (*Procyon lotor marinus*), a subspecies of *P. lotor* which was first identified by Nelson (1930). *P. l. marinus* is characterized by a smaller stature than the mainland subspecies, as well as cranial differences (Nelson, 1930; Bigler et. al., 1977). Due to the high incidence of depredation of sea turtle nests by raccoons (ranging from 59-85% for 1991-1994) (Garmestani, 1995), a better understanding of raccoon re-population trends, movement patterns and effects of removal on sea turtle hatch success in the Ten Thousand Islands National Wildlife Refuge was necessary to create a more comprehensive sea turtle management strategy (Shabica et al., 1978). I discuss this research in Chapter 4 and offer management suggestions for raccoons in regard to sea turtle conservation.

Finally, in Chapter 5, I suggest management options for the TTI with respect to sea turtle conservation.

CHAPTER 2

EVALUATION OF PHYSICAL PARAMETERS AS INDICATORS OF NESTING BEACH SELECTION FOR THE LOGGERHEAD SEA TURTLE (*CARETTA CARETTA*)

Introduction and Background

The Ten Thousand Islands (TTI) have been neglected when assessing sea turtle populations in southwest Florida. No accurate estimates have been made for the region because surveys conducted in the archipelago have been incomplete. Only the area encompassed by the Ten Thousand Islands National Wildlife Refuge (TTINWR) has been effectively monitored. TTINWR accounts for approximately 20% of the possible turtle nesting beaches in the archipelago; the remainder is already under the ownership of Everglades National Park (ENP) and the Florida Department of Environmental Protection.

The TTI are characterized by undeveloped mangrove islands with low human activity, predominantly fishermen and campers (fall, winter and spring). The islands are not subject to the kind of nesting disruption due to human usage that affects distribution of loggerhead nests in other research areas (e.g., North Carolina; Fangman and Rittmaster, 1994). Fangman and Rittmaster (1994) found that loggerhead sea turtles tended to abort nesting attempts with the increased presence of humans (e.g., camping, night-walking, parties). With the continued protection of these islands by the federal government (National Park Service, U.S. Fish and Wildlife Service) and the Department of Environmental Protection (Rookery Bay National Estuarine Research Reserve), the relatively unspoiled turtle nesting beaches offered a unique opportunity for study. Because of the potential significance of the TTI for sea turtle nesting, further exploration of these islands and accurate predictions on sea turtle nesting was necessary to determine the status of turtle populations in this area.

Information gathered for eight monitored islands in the refuge indicated that the total nesting effort for the Ten Thousand Islands could be significant (Table 2-1).

Table 2-1. Total TTINWR turtle survey data (1991-1995)

Year	# of crawls	# of known nests	# of depredated nests	% of depredated nests
1991	194	157	128	82
1992	255	139	118	85
1993	189	93	61	66
1994	232	157	92	59
1995	364	206	85*	41*

*- includes raccoon removal island (Panther Key)

Sea turtles exhibit three basic behaviors when returning to natal areas to nest: homing behavior, nesting beach selection and nest-site selection. Homing behavior is discussed as a means of inter-connecting these behaviors, although it was not examined in this study. Nesting preferences are discussed in detail, with nesting beach selection the focus of this research.

Homing behavior

Sea turtles are known to exhibit varying degrees of site-specificity to their natal areas. Grassman et al. (1984) found evidence that sea turtles detect differences in water samples when exposed to different samples in a laboratory setting. In laboratory experiments, the researchers found that sea turtles preferred to spend time in water solutions in which they had been artificially imprinted. This research suggests that sea turtles may have the ability to identify their natal areas by imprinting on olfactory cues specific to that particular area. Lohmann (1992) commented that tagging studies at Ascension Island have shown that green turtle females remain faithful to their nesting site; no turtle seen at Ascension has ever been found nesting elsewhere. Loggerhead turtles also exhibit some nest site-fixity (Lund, 1986), as evidenced by the 49% return of tagged female turtles over ten years at Cumberland and Little Cumberland Island, Georgia (Richardson et al., 1978). The methods by which sea turtles orient and return to natal areas has been the subject of much debate and research. Lohmann (1992) has suggested that cues utilized by other migratory animals such as the position of the sun or stars, polarized light, odors, wind direction, infrasound and/or the earth's geomagnetic field may play a role in navigation for sea turtles. Lohmann (1992) does not rule out the possible reliance upon chemosensory factors, as suggested by Grassman et al. (1984), or other as of yet unidentified cues, but hypothesizes that they are not a primary factor in navigation.

Lohmann (1992) suggested that adult sea turtles appear to fix their position with respect to their destination. Furthermore, he discounted the use of stars as an orientation cue based on anatomical studies of sea turtle eyes that revealed them to be extremely myopic when their heads are above water (Ehrenfeld and Koch, 1967; Koch et al., 1969). He further suggested that adults may have a "map sense", that allows them to orient according to the magnetic field line inclination, or by detecting pathways along the ocean floor created by magnetic maxima and minima. As with hatchlings, wave direction may be a possible cue, due to the independence of swell direction from local weather patterns, for adult turtles migrating back to nesting areas.

The idea of "social facilitation", suggested by Owens et al. (1982), was refuted by conducting mtDNA analyses on three different sea turtle species (*Chelonia mydas, Caretta caretta* and *Eretmochelys imbricata*) (Allard et al. 1994; Bowen et al., 1992; Bowen et al., 1993; Broderick et al., 1994; Meylan et al., 1990). Bowen (1995) stated that the mtDNA evidence suggests that nesting populations are distinct demographic units, and depletion of nesting aggregates will not be compensated by recruitment from other populations. What this evidence suggested is that sea turtles are fixed upon a particular natal area and return to that area utilizing a navigation mechanism that is not yet understood. These aforementioned studies dealt with some of the possible mechanisms sea turtles may use to return to their natal area, in this case the TTI and/or southwest Florida, but further exploration was necessary to indicate preferences for particular beaches.

Nesting beach selection

Shoop et al. (1985) made the observation that a high-density loggerhead sea turtle nesting beach was abandoned over the course of a five-year period due to, in their estimation, a mud flat that developed on the ocean side of the island. This sort of drastic change in a suitable nesting habitat does not necessarily affect the homing behavior of sea turtles to a particular area, but it would drastically affect nesting beach selection. Therefore, it appears that certain chemical and/or physical factors influence loggerhead sea turtle nesting beach selection. Mortimer (1995) has conducted the most comprehensive research dealing with nesting beach preferences in sea turtles. She conducted research on green turtles at Ascension Island, analyzing numerous components of the island in an attempt to determine nesting beach preferences for *C. mydas*.

Mortimer (1995) commented that there are some basic requirements indicative of a good nesting beach. Among these characteristics are: easy accessibility from the sea, a beach platform that is high enough to not be inundated by high tides or the water table, and beach sand that facilitates gas diffusion, but moist enough and fine enough to prevent excess slippage during nest construction (Mortimer, 1995). Taking these factors into account, Mortimer (1995) evaluated beach length, rock cluttering the foreshore, rock obstructing the offshore approach and artificial light visible on the shore as possible indicators of nesting beach selection.

Sea turtle nesting preferences for *C. caretta* in the TTI were assessed by evaluating each nesting beach based on a subset of physical characteristics of the islands. These characteristics included: height of canopy (Bustard, 1972); beach width, overall slope (beach slope and slope of offshore approach) (Mortimer, 1995; Shoop et al., 1985) and sand samples analyzed for pH, percentage of water, percentage of organic content, percentage of carbonate and particle size (8 size classes) (Mortimer, 1995; Mortimer, 1990; Stancyk and Ross, 1978; Hughes, 1974). Data on ordinal aspect of beaches and beach length (Mortimer, 1995) were also recorded and included in the analysis. These factors were based upon characteristics of the islands, past research and personal communications (R. Carthy, A. Bolten, K. Rice and H. Percival). Although green sea turtles were known to nest in the TTI, they were not included in this study.

Nest-site selection

Numerous studies have been conducted on nest-site selection in sea turtles, addressing various factors as potential indicators of nest-site selection. Johannes and Rimmer (1984) found that nest sites for the green turtle were on beaches that had lower salinity at nesting depth, lower salt content at the surface of the sand and were sheltered from prevailing winds. Stoneburner and Richardson (1981) found that sea turtles cross a temperature gradient after they have landed on a nesting beach. A nesting female will lay her eggs once she has passed over a zone of the beach where a rapid rise in temperature is encountered. However, Hays et al. (1995) were critical of the latter study, indicating that the sand temperatures Stoneburner and Richardson (1981) recorded were from disturbed sand at *C. caretta* nest sites. Hays et al. (1995) suggested that the abrupt temperature increase at nest sites may be a result of deeper, warmer sand being brought to the surface. They were also critical of the lack of explanation for this abrupt temperature increase (i.e. no correlation with any of the features of the beach topography). Hays et al. (1995) compared nest-sites for loggerhead turtles in southwest Florida, and green turtles on Ascension island, and found that loggerheads clump their nesting attempts close to vegetation backing nesting beaches, while green turtles appear to cue on uneven beach topography when choosing nesting sites. Stancyk and Ross (1978) found no correlation between sand characteristics of the beaches at Ascension Island and nesting frequency of green turtles. Mortimer (1990) also conducted a study at Ascension Island and found no preference for a particular sand type based on clutch survival, and concluded that factors other than the physiognomy of the sand on nesting beaches may be more important in nest-site selection for the green turtle. Bjorndal and Bolten (1992) concluded that annual factors may have a greater effect on nest placement than individual nesting patterns for green turtles at Tortuguero. This lack of consistent nest distribution may result from environmental uncertainty and low predictability of nest success (Bjorndal and Bolten, 1992). Mrosovsky (1983) was unable to explain the poor nest-site selection of leatherback turtles in Guianas and Malaysia. In addition, Camhi (1993) conducting research at Cumberland Island, Georgia found that loggerhead turtles did not show strong site preferences, even though certain areas of the beach were more likely to produce hatchlings. Whitmore and Dutton (1985) found that leatherbacks nested more in open, sandy areas, while green turtles nested in predominantly vegetated areas. Daud and deSilva (1987), found that leatherbacks preferred to nest in fine sand on steep sloped beaches, while green turtles preferred to nest in coarser sand on broad, flat beaches.

Nest-site selection was also evaluated for *C. caretta* utilizing nesting data from the 1996 field season. No attempt was made to evaluate the possible cues indicating nest-site selection.

Objectives

The primary objective of this research was to establish if the loggerhead sea turtle exhibits preferences for a particular physical characteristic, or combination of characteristics when selecting nesting beaches. The secondary objective of this research was to document the overall distribution of loggerhead sea turtle nests and determine if there was a significant trend of nest placement for the TTI.

Materials and Methods

Study Area

The TTI extend roughly 40 kilometers from Marco Island to Pavilion Key along Florida's southwest coast (Edwards, 1991). Located approximately 25 kilometers southeast of Naples, Florida, these largely undeveloped islands are utilized by the public year-round, primarily for fishing (Cheng, 1996). The climate is subtropical with 110 to

160 centimeters of average annual precipitation, two-thirds of which occurs between May and October (Cheng, 1996). Average annual temperature is 23 degrees Celsius, with occasional freezing temperatures in the winter and regular mid-thirties in the summer (Cheng, 1996).

The study area included 12, low-relief mangrove islands, further broken down into 35 beaches based on the ordinal aspect of the individual beaches. Islands in the study area directly face the Gulf of Mexico and were known to support sea turtle nesting. These islands included: Brush, B, Turtle, Gullivan, White Horse, Hog, Panther and Round Keys, located in the Cape Romano Aquatic Preserve and Ten Thousand Islands National Wildlife Refuge, and Kingston, Indian, Picnic, and Tiger Keys in Everglades National Park. These islands are located to the southeast of Marco Island, and are part of the western delta of Florida's Everglades. Beaches are made up of differing substrate types that are usually backed by a variety of supralittoral vegetation (Table 2-2). The 35 beaches examined totaled 7.404 kilometers in total length.

Field Sampling Techniques

Twelve (12) islands were selected for study based on logistical constraints and supporting agencies' (TTINWR and ENP) preferences. This included the 8 islands covered in the five-year monitoring period for TTINWR (Edwards, 1991) and 4 additional islands within ENP. Although these islands do not represent a random sample of possible islands in the TTI, they are representative (Garmestani, pers. observ.) of the range for each of the variables selected for analysis. The 12 islands are a sample of the 19 northernmost keys, with 10 other keys in the TTI also included in the generalization of the results of this research.

Sea turtle surveys were conducted from May 13, 1996 until August 15, 1996. Surveys were conducted twice a week for each island. This strategy was developed by the U.S. Fish and Wildlife Service, due to the remoteness of the TTI and lack of personnel. A total of 252 loggerhead nests was used in the analysis for nesting beach

Table 2-2. List of plant species sampled within quadrats at transect points

Common Name	Scientific Name
Sandwort	*Arenaria lateriflora*
Black mangrove	*Avicennia germinans*
Saffron plum	*Bumelia celastrina*
Gray nickerbean	*Caesalpinia bonduc*
Sea rocket	*Cakile edentula*
Bay bean	*Canavalia rosea*
Australian pine *	*Casuarina equisetifolia*
Sandspur	*Cenchrus incertus*
Beach spurge	*Chamaesyce mesembrianthemifoluim*
Coco-plum	*Chrysobalanus icaco*
Sea grape	*Coccoloba uvifera*
Latherleaf *	*Colubrina asiatica*
Buttonwood	*Conocarpus erectus*
Flatsedge	*Cyperus retrorsus*
Seashore saltgrass	*Distichlis spicata*
Water grass	*Echinochloa walteri*
Devil's potato	*Echites umbellata*
Black torch	*Erithalis fruticosa*
Finger grass	*Eustachys petraea*
Spider lily	*Hymenocallis latifolia*
Wild potato vine	*Ipomoea pandurata*
Railroad vine	*Ipomoea pes-caprae*
Morning glory	*Ipomoea trichocarpa*
White mangrove	*Languncularia racemosa*
Seedbox	*Ludwigia alterniflora*
Trailing ludwigia	*Ludwigia palustris*
Melanthera	*Melanthera nivea*
Poorman's patch	*Mentzelia floridana*
Prickly pear	*Opuntia compressa*
Bahia grass	*Paspalum notatum*
Passion-flower	*Passiflora suberosa*
Painted leaf	*Poinsettia heterophylla*
Red mangrove	*Rhizophora mangle*
Cabbage palm	*Sabal palmetto*
Inkberry	*Scaveola plumieri*
Sea purslane	*Sesuvium portulacastrum*
Cord grass	*Spartina patens*
Bay cedar	*Suriana maritima*
Sea oats	*Uniola paniculata*
Spanish bayonet	*Yucca aloifolia*
Dildoe cactus	*Cereus pentagonus*

* Exotic species

selection, while a subset of 236 nests was used in the analysis for nest-site selection. Crawls were described and data were collected from each nest site. Included in the data set were species of turtle, vegetation (if any), distance of nest from mean high tide line (MHTL), distance of nest from the vegetation (calculated as a percentage of the beach width for each nest), distance of nest from the nearest transect and status of nest (e.g., depredated, inundated).

Island characteristics were measured in April and May of 1996, prior to sea turtle nesting season. Each of the 12 islands was assessed for a subset of physical characteristics that might influence loggerhead nesting beach selection along 82 transects that were placed at 100m intervals along nesting beaches. Each transect was run perpendicular from the beach/vegetation transition (i.e. starting point) to a point 100m offshore using a compass to maintain the perpendicular vector of the transect, and a survey tape to record distance. The beach/vegetation transition was defined by the first occurrence of vegetation on the open beach and marked with a stake along the transects. Data were collected on the following characteristics:

1) **Beach width** - Beach width was defined as the distance from the MHTL to the beach/vegetation transition, and measured in meters along the transects using a distance measuring wheel.

2) **Slope** - Slope was assessed along the transects from each of the individual stakes. Sample point distances were taken in meters with a survey tape. Depth measurements were made in meters using a laser transit and survey pole, or in the case of deeper areas, a Lowrance sonar (X-16 paper graph unit; Lowrance Electronics, Inc., Tulsa, OK, USA). Measurements were taken in increments based upon the rate of change of the slope. Least squares technique was used to estimate slope based on linear, quadratic or cubic models.

3) **Height of canopy** - Canopy height was defined as the height of the vegetation taken while standing at MHTL, and observing the canopy with a clinometer. This

characteristic was assessed along each transect using the clinometer and a survey tape, and measured in meters.

4) **Nesting substrate -** Nesting substrate samples were taken at MHTL along each transect (i.e. shell content, particle size, organic content, water content and pH levels). Samples were taken at MHTL, because after landing a sea turtle may exhibit a preference for a particular nesting beach based on factors in the sand with which she comes in contact as she initially leaves the surf for the open beach. The nesting substrate samples were collected by digging vertically and taking a 300 gm sample, placing the sample in a ziplock bag and storing the sample on ice, to preclude chemical changes in the samples. The samples were maintained on ice as they were transported to the field headquarters in Everglades City and refrigerated until they were taken to Gainesville on ice. After arriving in Gainesville, the samples were refrigerated until they were analyzed in the laboratory.

5) **Ordinal aspect -** Ordinal aspect is defined by the angle of the vector running parallel to a nesting area. This feature was assessed with US Geological Survey, Collier County and NOAA maps, and compass measurements. The 12 islands were divided into 35 "beaches" based on the ordinal aspect of their nesting areas.

6) **Beach length** - Beach length was defined as the horizontal cross-section distance of each beach, and was measured in meters using a distance measuring wheel along MHTL.

7) **Vegetation** - Nesting area vegetation was classified according to common name and scientific name at each transect starting point in a $1m^2$ quadrat.

Laboratory analysis

Sand samples were assessed for pH, particle size, water content, organic content and carbonate content. For pH analysis, two 5g sub-samples were taken. Since sea turtles would come into contact with wet sand, one was assessed directly, while the other was processed in a drying oven at 105 degrees Celsius for 12-16 hours as per standard soil science technique. Each sample was mixed with de-ionized and distilled water in a 1:2 mixture, and allowed to sit for one hour. Then the mixture was stirred and a pH reading was taken and recorded.

For particle size, a 50cc. sub-sample was air-dried for 72 hours and was shaken through 8 sieves (< 0.246mm, 0.246, 0.351, 0.495, 0.701, 0.991, 1.397, 1.981mm). Each size class was weighed and the results recorded. For water, organic and carbonate content, one 25cc. sub-sample was taken and subjected to analysis outlined in Dean (1974) and Schulte (1988). The 25 cc. sub-sample was dried in a drying oven at 105 degrees Celsius for 12-16 hours, allowed to cool to room temperature in a desiccator and then weighed to determine water content. The dried sub-sample was tested for organic content by heating in a muffle furnace for 24 hours at 360 degrees Celsius and weighing after cooling to room temperature in a desiccator. The resulting sample was processed by heating in a muffle furnace at 850 degrees Celsius for 4 hours, and weighing after it had cooled to room temperature in a desiccator, to determine carbonate content.

Sand samples for organic and carbonate content were assessed in triplicate in order to validate consistent laboratory technique, as well as account for variability among sub-samples. The average values obtained from the laboratory analysis were utilized for statistical analysis.

Statistical analysis

The multi-dimensional data which resulted from the field measurements and laboratory analysis were plotted in their first two principal components to detect obvious clustering of transects. The relationship between beach utilization for nesting and beach characteristics was examined using a robust tree regression technique (Portier and Anderson, 1995). The final tree regression model was used to indicate which characteristics should be considered important in predicting beach use by nesting turtles. A binomial test was used to compare nest counts on the beach to nest counts in the vegetation. A Chi-square goodness-of-fit test was used to determine if nesting occurred uniformly across the width of the beach.

Computations associated with the formal statistical tests and computations of beach slope were performed in SAS (SAS Institute, Inc, 1989) on a personal computer. The tree regression and principal components analysis computations were performed using S-PLUS (Statistical Sciences, 1993; Venables and Ripley, 1994) on a UNIX workstation.

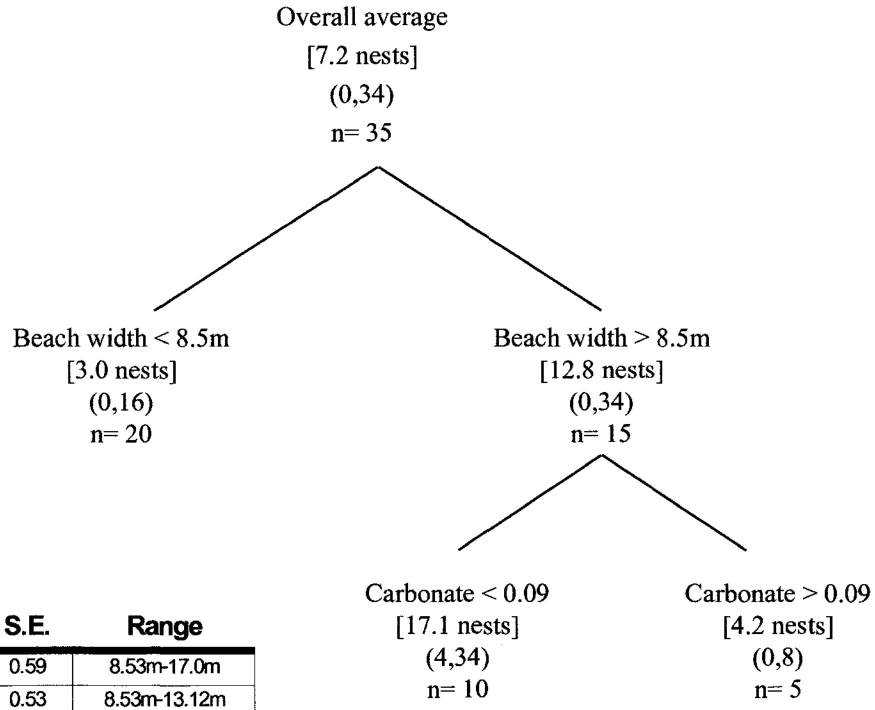
Results

Nesting beach selection

The principal components plots did not demonstrate significant clustering within the data. A more formal cluster analysis using the average linkage method also failed to demonstrate clustering.

The final regression tree (R^2= 0.56; Figure 2-1) identified beach width ($p< 0.001$) as the primary factor affecting nesting beach selection for *C. caretta*. Beaches that are wider (>8.5m; n= 15) on average have much higher nesting than narrower beaches (<8.5m; n= 20). Beach width was negatively correlated ($r= -0.6$) with beach slope, wider beaches having inherently less slope. For wider beaches (> 8.5m) the regression tree indicated a further split using percentage of beach carbonate ($p< 0.001$). On wide beaches loggerheads preferred less than 9% carbonate (n= 10) (i.e. function of the shelliness of a beach), over beaches that had over 9% carbonate (n= 5). Wider beaches having low carbonate levels will be expected to have the highest nesting. The percentage of carbonate (i.e. shelliness) was also positively correlated ($r= 0.88$) with the three largest particle size classes (0.991mm, 1.397mm, 1.981mm). Narrow beaches (n= 20) (< 8.5m beach width) had 153 crawls, of which 60 (39%) resulted in nests. Wide beaches (n= 5) (> 8.5m beach width) with high levels of carbonate (> 9% carbonate), received 50 crawls,

$R^2 = 0.56$



Beach width	Carbonate	N	Mean	S.E.	Range
> 8.5m		15	10.81m	0.59	8.53m-17.0m
	< 9%	10	10.46m	0.53	8.53m-13.12m
	> 9%	5	11.51m	1.48	9.3m-17m
< 8.5m		20	5.83m	0.39	3.0m-8.5m

Figure 2-1. Regression tree for beach nesting counts: condition; [average # of nests]; (minimum observed, maximum observed); number of beaches in the condition. All conditions significant at the p< 0.001 level.

of which 21 (42%) resulted in nests. Finally, beaches that were wide (> 8.5m) and had less than 9% carbonate (n= 10), had a total of 292 crawls, of which 171 (59%) resulted in nests. The number of nests on beaches increased dramatically in conjunction with increased beach width (Figure 2-2). The nesting to non-nesting emergence ratio was decidedly higher on beaches possessing the favored characteristics (Figure 2-3). All of the beach data are summarized in Table 2-3.

The other variables included in the analysis were not as highly correlated to loggerhead sea turtle nesting beach selection as were the primary and secondary components. Although these variables may be of tertiary importance in nesting beach selection, there influence will be much less than the two characteristics identified in the regression tree. With a larger data set it might be possible to determine which of these variables further discriminate nesting beach selection.

After running the duplicate analyses on the sand sub-samples, it was determined that there was greater than 2% variability between several of the samples. Therefore, it was necessary to run a third sample set in order to get an average of the three samples and alleviate concerns over variability between the samples. Overall, the triplicate samples had a 9.2% coefficient of variation.

Nest-site selection

There were 236 loggerhead nests used in the analysis, 111 of which were located in the vegetation and 125 on the open beach (Figure 2-4). No significant preference between open beach and vegetation was detected for *C. caretta* nest placement (p= 0.82, binomial test). However, location of nests was not uniformly distributed in relation to the vegetation and vegetation lines on beaches (p< 0.001, Chi-square test; Figure 2-5). Of these nests (n= 236), 127 were depredated, 106 hatched and 3 were inundated. For the depredated nests (n= 127), there was no significant difference in depredation rates detected for nests in the vegetation (n= 59) or nests on the open beach (n= 58) (p= 0.14).

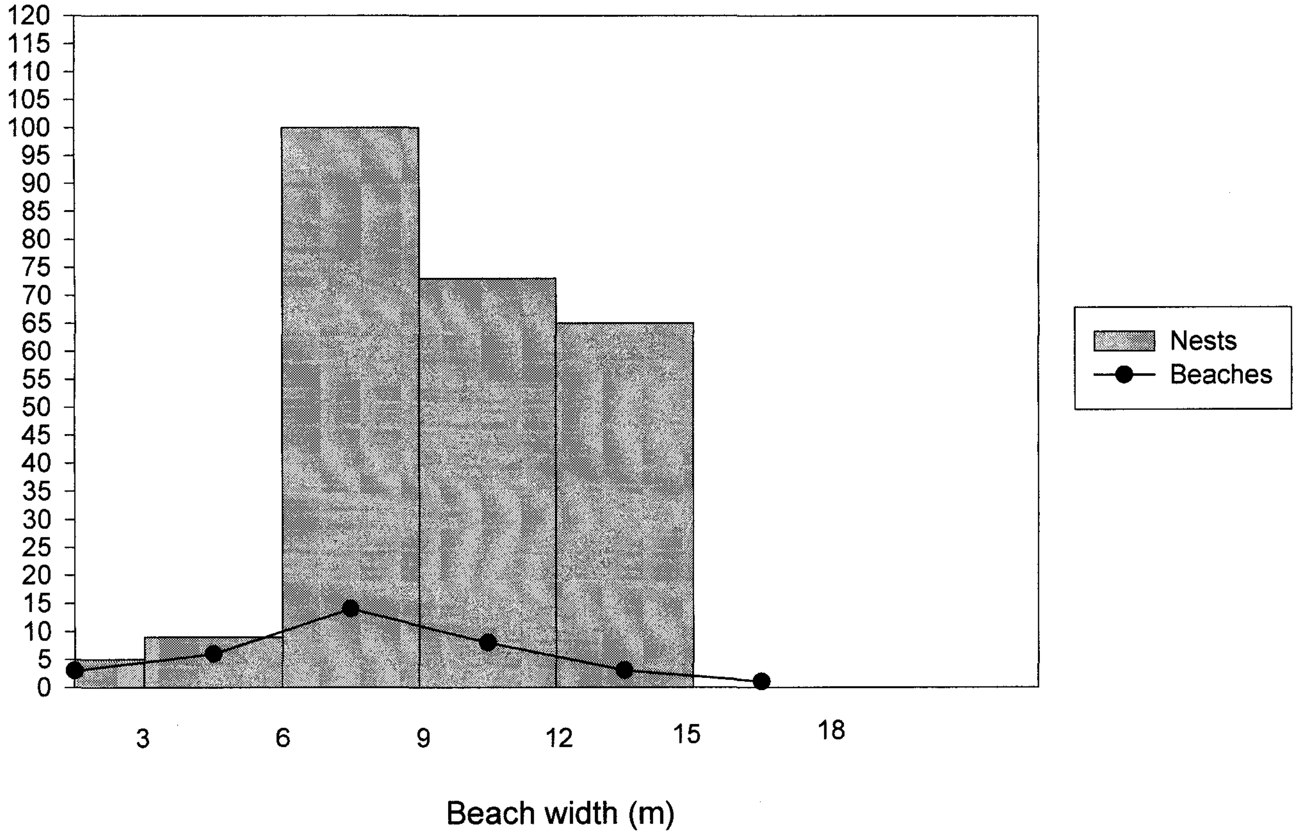


Figure 2-2. Number of nests on TTI beaches in relation to beach width

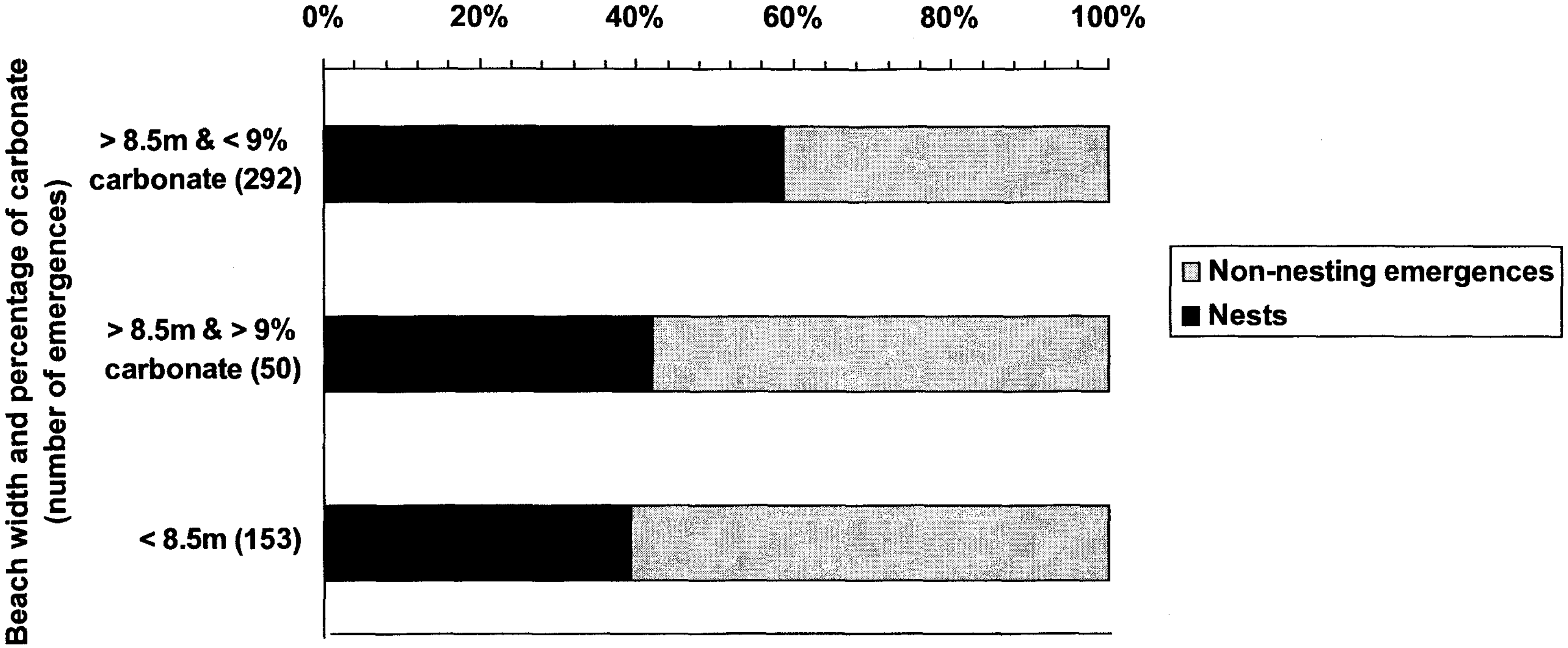


Figure 2-3. Percentages of nesting and non-nesting emergences on beaches with both the primary and secondary characteristic, the primary characteristic and those without the primary characteristic

Table 2-3. Index of physical components for Ten Thousand Islands beaches

Variable	N	Mean	S.E.	Range
Beach slope	82	0.0722	0.0043	.0039-.2304
Offshore slope	82	0.0151	0.0014	-0.002-0.0591
Beach width	82	8.789m	0.4008	2-21
Height of canopy	82	5.834m	0.407	0-18.84
pH (wet)	82	7.038	0.0331	6.461-8.392
pH (dry)	82	7.306	0.0366	6.772-8.664
% H20	82	0.1151	0.0068	0-0.253
% Organic material	82	0.0035	0.0002	0.005-0.0124
% Carbonate	82	0.0805	0.0056	0.0011-0.2040
% Sand 1 (1.981mm)	82	0.1632	0.0204	0-0.9972
% Sand 2 (1.397mm)	82	0.0389	0.0036	0-0.1683
% Sand 3 (0.991mm)	82	0.037	0.0031	0.0003-0.1695
% Sand 4 (0.701mm)	82	0.0412	0.0036	0.0003-0.1719
% Sand 5 (0.495mm)	82	0.0823	0.0078	0.0005-0.3827
% Sand 6 (0.351mm)	82	0.3118	0.0199	0.0003-0.7826
% Sand 7 (0.246mm)	82	0.1833	0.0104	0.0002-0.4612
% Sand 8 (<0.246mm)	82	0.1418	0.0124	0.0005-0.6118
Beach length	35	208.943m	19.6367	50-815
Ordinal aspect	35	5.242	0.2236	1-8

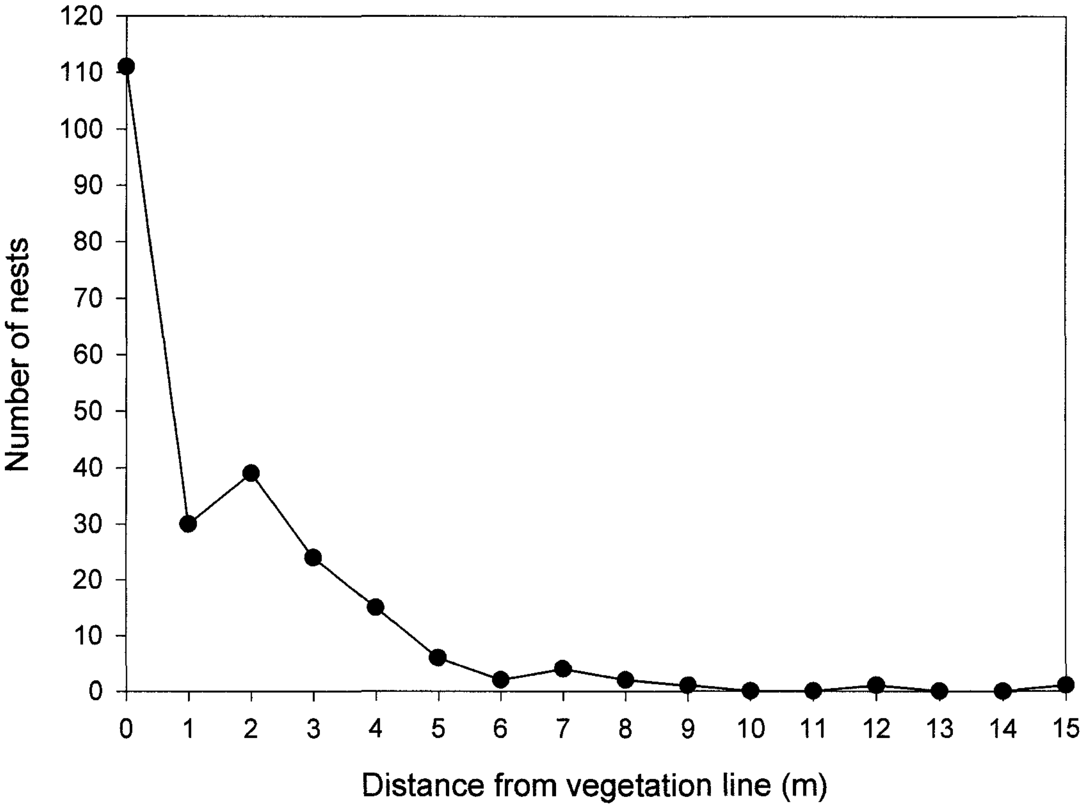


Figure 2-4. Distance (m) of loggerhead nests to supra-littoral vegetation line

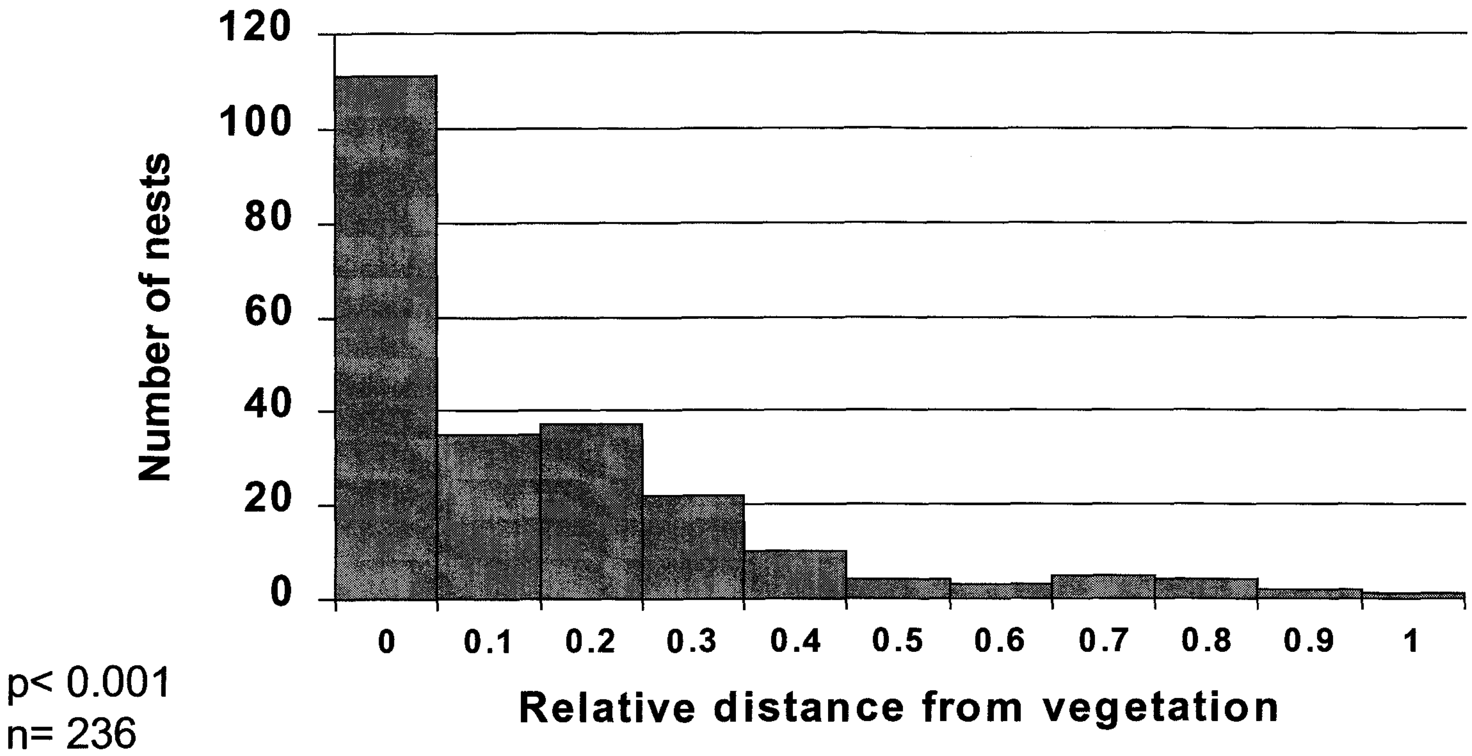


Figure 2-5. Proportional distance of loggerhead sea turtle nests from supra-littoral vegetation line

There was no significant difference in the hatch rate for the hatched nests (n= 106) whether they were in the vegetation (n= 51) or on the open beach (n= 55) (p= 0.39).

Discussion

It is now widely accepted that sea turtles have the ability to home to particular areas of the world's seas for feeding, mating and nesting. Lohmann (1992) has described mechanisms of navigation utilized by hatchling sea turtles, and has hypothesized about the possible mechanisms that adults use to home to their natal areas for nesting. The distinctiveness of sea turtle populations as demographic units indicates that sea turtles are programmed to home to natal areas (Bowen, 1995). Meylan et al. (1990) concluded that social facilitation to non-natal sites was rare due to evidence of mtDNA sequences for turtles sampled. Allard et al. (1994) supported the results found by Meylan et al. (1990) by conducting a study on green turtles at Tortuguero, Costa Rica and the southeast coast of Florida. They found evidence, in the form of mtDNA sequences, that the Costa Rican and Florida populations were significantly different (Allard et al., 1994).

On a finer scale, Murphy and Hopkins-Murphy (1990) conducted research on the homing behavior of gravid loggerhead turtles in South Carolina. Of the 27 radio-tagged turtles they collected data from, 23 (85%) showed evidence of returning to their home or primary beach (Murphy and Hopkins-Murphy, 1990). They found that there is a plasticity to site selection which allowed for the acceptance of suitable alternate nesting beaches for one or more nesting events for several of the turtles (Murphy and Hopkins-Murphy, 1990). They hypothesized that loggerhead sea turtles may select beaches according to offshore topography and/or the suitability of the beaches for nesting at the translocation site (Murphy and Hopkins-Murphy, 1990). They suggest that loggerhead sea turtles may be exhibiting preferences when selecting nesting beaches. Carr and Carr (1972) reported that green turtles showed strong site fixity, although some re-nesting attempts stray up to 7 km from previous nesting attempts. They suggest that colony expansion might occur in this manner (Carr and Carr, 1972). Another possible explanation for this phenomenon is that green turtles have a preference for particular beach characteristics. After homing to natal areas, sea turtles may have several beach types from which to choose, and select nesting beaches according to criteria specific to their natal area.

Nesting beach selection

Mortimer (1995) reported that the heaviest nesting by green turtles on Ascension Island occurred on beaches that were unlighted, with open offshore approaches and foreshores relatively free of rock clutter. In addition, most nesting occurred on stretches of beach where the offshore approach was deepest (Mortimer, 1995). For the beaches that met these criteria, the correlation between beach length and the estimated number of clutches laid per season was highly significant (Mortimer, 1995). Mortimer (1995) found no relationship between beach vegetation or beach sand characteristics and density of nesting. Johannes and Rimmer (1984) reported that no relationship has been found between nesting beach selection and pH, calcium carbonate content, water content, organic content and particle size. However, they found beaches favored by the green turtle in Australia had lower salt content and less exposure to prevailing winds (Johannes and Rimmer, 1984). Although Johannes and Rimmer (1984) found a positive relationship between these characteristics and green turtle nest density, there is no evolutionary explanation for the observed phenomenon. While sea turtles could possibly detect elevated levels of salinity upon immediate landing on a nesting beach and choose another nesting beach, there is no clear relationship between elevated levels of salinity and sea turtle nesting beach selection. There is no literature referring to the potential impacts of increased salinity on egg development in sea turtles. One of the only references in the literature to salinity and its effects on development, deals with its impacts on egg development in Baltic cod (Westin and Nissling, 1991). Therefore, the connection between salinity and nesting beach selection is questionable. Furthermore, the connection between prevailing winds and nesting beach selection is not clear. This point is reinforced by the fact that prevailing winds in the study area frequently ceased at night, making them a non-factor in nesting beach selection (Johannes and Rimmer, 1984).

The tree regression approach was used in the analysis because it is very flexible, allowing the data to specify complex interactions where justified, and very simple to interpret. This approach is also less concerned with underlying distributional assumptions than are traditional linear regression approaches. Tree regression models expected nest counts as a binary decision process, which is a result of comprehensive examinations of all levels of each characteristic in a hierarchical model-building process. The process involves constructing a large binary tree, then pruning the tree back to a size which is consistent among sub-samples of the complete data set.

For the loggerhead sea turtle, a positive relationship was found between beach width, which is highly correlated with slope (i.e. wider beach=decreased slope), and the number of nests (n= 192; 76%) laid on beaches. On these wider beaches, loggerheads preferred those with a lower shell content, which is highly correlated with the three largest particle size classes analyzed. The fact that the number of non-nesting emergences increased on beaches that do not possess the favored criteria only lends strength to the tree model.

Loggerheads may prefer wider beaches because the loss of nests from tidal inundation or erosion decreases with distance from the surf (Fowler, 1979). Choosing beaches that are relatively wide may be the only alternative for a sea turtle attempting to produce a successful clutch in a region like the TTI, where beaches are narrow and subject to wide variation in tidal fluctuation from season to season and year to year. Slope may simply be a construct of beach width in the area, or *C. caretta* may be cueing on the slope of the beach. This makes sense, because the gradient of the beach determines the distance a turtle must crawl overland in order to reach a nest site (Pritchard, 1971; Schulz, 1975). Loggerheads may prefer more gently sloping beaches because they afford the quickest and easiest approach and means of escape after laying a nest. Bjorndal and Bolten (1992) have suggested that in long-lived species that cannot accurately assess the nesting environment, it may be better to select to nest on the basis of the survivorship of the adult female rather than on the survivorship of the clutch.

C. caretta may choose to nest on wide beaches that are relatively free of large shell fragments because the shells may make it more difficult for the turtle to create an adequate nest cavity. Digging in shells is difficult, even for a creature as large and powerful as a loggerhead sea turtle. Furthermore, nesting cavities made up of shells will be more prone to collapse as the turtle excavates the chamber. Considering that the quality of beach sand can so strongly influence reproductive success, one would expect turtles to use sand textures as a criteria in selection (Mortimer, 1990). Data gathered by Mortimer (1995) at Ascension Island suggest otherwise. There was no correlation between the average percent hatchling emergence at Ascension Island beaches and nesting density (Mortimer, 1995). It appears that the choice of nesting beach is primarily determined by the ease with which a nest site can be reached and excavated, with little choice exhibited for more favorable reproductive substrates.

No significant relationship was found between pH, percentage of water, percentage of organic content, or the 5 smallest classes of the 8 particle size classes and the number of nests laid on beaches in the TTI. From these data, it appears that *C. caretta* does not select nesting beaches according to the height of the canopy immediately adjacent to nesting beaches, the beach length, the slope of the offshore approach, or the ordinal aspect of the beaches. Although some of these factors could potentially affect the reproductive success of sea turtles, none affected the nesting beach selectivity of *C. caretta*.

Nest-site selection

Nest-site selection has been the subject of much sea turtle research (Bjorndal and Bolten, 1992; Camhi, 1993; Carr and Carr, 1972; Daud and deSilva, 1987; Miller, 1995; Mrosovsky, 1983; Whitmore and Dutton, 1985). Numerous theories have been suggested as possible explanations for this critical process in sea turtle ecology, with multiple variables assessed as potential indicators of nest-site selection. Among these are salinity (Johannes and Rimmer, 1984), temperature (Stoneburner and Richardson, 1981), particle size, pH, water content, organic content, shell content, substrate conductivity (Mortimer, 1990; Stancyk and Ross, 1978) and vegetation (Hays and Speakman, 1993). A connection has been made between temperature, salinity and nest-site selection (Johannes and Rimmer, 1984; Stoneburner and Richardson, 1981), and some researchers have suggested the vegetation zone backing beaches as a potential cue for sea turtles to select nest sites (Hays and Speakman, 1993). The importance of this process on the reproductive success of the turtle is critical, however, sea turtles often choose nest sites that do not maximize their reproductive output, and therefore their fitness. When it is apparent that certain beach types drain better, provide better gas and water exchange and are more favorable for maintaining a nest cavity (Pollock and Hummon, 1971), it is hard to imagine that sea turtles are not programmed to detect these obvious advantages in selecting certain nest sites over others (Mortimer, 1995). Bolten and Bjorndal (1992) have suggested that a female may have a limited ability to assess the current nesting environment when selecting a nest site, and unpredictable changes in the nesting environment over a 60-day incubation period. They believe this environmental uncertainty and the inability of female turtles to assess the nesting habitat in terms of ultimate hatching success may be responsible for the lack of any consistent patterns in nest distribution for green turtles at Tortuguero (Bjorndal and Bolten, 1992). Hays and Speakman (1993) found that loggerheads tended to lay nests away from the sea, and close to, but not beyond the vegetation line. The increase in the distance turtles laid from the sea when the vegetation line was further from the water suggests that the vegetation may have constrained the length of the turtle's inland crawl (Hays and Speakman, 1993). Some researchers have suggested that loggerhead sea turtles simply crawl a random distance above the most recent MHTL prior to digging a nest site (Hays et al., 1995). They constructed a random-crawl-distance model that closely reproduced the observed spatial pattern of nests (Hays et al., 1995). Hays et al. (1995) stated that the distribution of nests on Sanibel and Captiva islands in southwest Florida can be explained by the random-crawl-distance model without implicating micro-habitat cues.

Although it has been suggested that supra-littoral vegetation backing nesting beaches may act as a cue for nesting sea turtles (Hays and Speakman, 1993), documentation of nest placement by *C. caretta* in the TTI indicates that no such relationship exists. Of the nests analyzed for 1996 (n= 236), 111 were laid within the supra-littoral vegetation backing nesting beaches, while 125 were laid on the open beach at varying lengths from the vegetation line. The majority of the 125 nests laid on the open beach were clumped in close proximity to the vegetation line. Furthermore, nests laid in the vegetation suffered nearly equal depredation rates when compared to nests laid on the open beach, and therefore no appreciable difference in hatch rates. Since no micro-habitat cues were analyzed for this research, it is difficult to explain why *C. caretta* nests in this manner in the TTI. The most obvious explanation for this phenomenon is that loggerheads may select nest sites that will lessen the chance of tidal inundation or inundation of nests by the water table (Fowler, 1979). The possibility exists that they simply crawl a random distance beyond the last MHTL and lay their clutch, as has been suggested by Hays et al. (1995). No attempt was made to verify the theory proposed by Hays et al. (1995); the theory only exists as one possible explanation for nest placement by the loggerhead sea turtle in the TTI.

Conclusion

The TTI is a unique ecosystem, and results from this study are unlikely to be directly applicable to other loggerhead nesting areas. The same is true of the green turtle work conducted by Mortimer (1995) at Ascension Island. Therefore, the conclusions reached about green turtles and loggerhead turtles may be specific to the environments evaluated. Without testing these methodologies on turtles in other parts of the world, there is no way of validating the results. Therefore, the only way of commenting on loggerhead nesting beach selection in other parts of the world is to replicate this methodology in another part of the world where *C. caretta* nests.

Loggerhead sea turtles in the TTI appear to have chosen nesting beaches according to the width of the beach, preferring relatively wide beaches. Secondarily, *C. caretta* preferred wider beaches according to the shelliness (i.e. carbonate content) of the beach. *C. caretta* also selected nest-sites in the TTI that are in or close to supra-littoral vegetation.

From a management perspective, this means that biologists/conservationists in the TTI could concentrate their efforts for loggerhead sea turtle conservation on beaches that meet the criteria for favorable nesting beach selection. Beach width measurements could be taken, and sand from the beaches could be shaken through a series of sieves in order to assess the quality of a particular beach. Beach width could be assessed quickly and easily; beaches that are on average greater than 8.5 meters in width should be selected. After these wide beaches were selected, the resource manager could judge the amount of shells (i.e. carbonate content) that remains in the three largest sand classes (0.991mm, 1.397mm, 1.981mm) after the sample has been shaken through the sieves. If there is a large proportion of shells (> 9%) in the sample, then the manager has the ability to make decisions about allocation of time, money and personnel to particular islands and/or beaches, based on the quality of the particular nesting area for *C. caretta*.

This management option is presented as a possibility for application in the TTI. However, at least one more year of data would need to be collected in order to determine if the nesting beach selection observed in 1996 represented a trend in the behavior of *C. caretta*. If the replicate study re-affirms the findings of this study, then the suggested management scheme could be implemented on a trial basis.

CHAPTER 3

EVALUATION OF AERIAL SURVEY FOR ESTIMATION OF SEA TURTLE NESTING EFFORT FOR THE TEN THOUSAND ISLANDS: APPLICATION OF A SURVEY TECHNIQUE

Introduction and Background

The remoteness of the Ten Thousand Islands (TTI) provided a unique opportunity to conduct biological research in a relatively undisturbed setting. However, this desirable characteristic (i.e. remoteness) of the TTI limits access to the area, requiring large expenditures of personnel, time and expenses to effectively monitor and protect sea turtle nests. Numerous researchers have used aerial surveys to assess large areas of sea turtle nesting beaches. These include an assessment of sea turtle nesting in the southeastern United States (Shoop et al., 1985), North Carolina (Crouse, 1984), South Carolina (Stancyk et al., 1979), Baja California (Fritts et al., 1982), Panama (Meylan and Meylan, 1985) and a survey of Pacific Mexico coupled with a new estimate of the world's leatherback (*Dermochelys coriacea*) turtle population (Pritchard, 1982). Pritchard (1982) used aerial surveys to assess an area of Mexico that resulted in discovery of a large, previously unknown leatherback rookery. With this new information, Pritchard (1982) was able to create a crude estimate of the world's population of mature, female leatherback turtles. Sarti et al. (1996) followed up the work of Pritchard (1982) and other researchers, and found this large Mexican conglomeration of nesting leatherbacks to be in serious decline from previously documented numbers. Crouse (1984) conducted aerial surveys in North Carolina in conjunction with ground truthing, allowing for a conversion factor to create a seasonal estimate for the state of North Carolina. Unfortunately, differential crawl retention on individual beaches precluded any season-long estimate.

Aerial surveys have been flown over the TTI area, but documentation of sea turtle nesting was not the primary objective of the flights. Irvine et al. (1981) flew fixed-wing manatee and dolphin surveys over the TTI, documenting incidental observations of sea turtle crawls in the area. LeBuff and Hagan (1978) flew fixed-wing aerial surveys over the beaches of Cape Romano and Marco Island, and reported missing approximately 50% of the nests documented by surveyors on the ground. Fixed-wing aerial surveys by Davis and Whiting (1977) over the Cape Sable region extended into the southern portion of the Ten Thousand Islands archipelago, encompassing Pavilion and Rabbit Keys, included in the current study. Kushlan (1986) repeated Davis and Whiting's surveys 8 years later, and found results similar to the previous work.

The objective of this study was to develop a seasonal nesting estimate for the TTI using an aerial survey coupled with ground truth counts. The estimate developed depended upon two basic assumptions: nesting activity on the 8 ground-truth islands is similar to activity on the other study islands and the nest-to-non-nesting emergence ratio on other islands in the TTI is similar to that experienced on the 8 ground-truth islands.

Materials and Methods

Study Areas

The Ten Thousand Islands (TTI) extend roughly 40 kilometers from Marco Island to Pavilion Key along Florida's southwest coast (Edwards, 1991). Located approximately 25 kilometers southeast of Naples, these largely undeveloped islands are utilized by the public year-round, primarily for fishing (Cheng, 1996). The climate is subtropical with 110 to 160 centimeters of average annual precipitation, two-thirds of which occurs between May and October (Cheng, 1996). Average annual temperature is

23 degrees Celsius, with occasional freezing temperatures in the winter and regular mid-thirties in the summer (Cheng, 1996).

These islands are dominated by mangrove trees, with some invasion by Australian pine (*Casuarina equisetifolia*). Beaches are characterized by sand, false coral, or oyster shells, either individually or in some combination on each island. Characteristically, beaches of these islands face the Gulf of Mexico from many different aspects and are much shorter and narrower than the long, ribbon-like beaches on the east coast of Florida or in Naples, Florida.

Sampling Techniques

From aerial photographs and fly-overs prior to initiation of the study, 29 keys in the TTI were identified that could potentially support sea turtle nesting. From this information, a flight plan was developed that allowed observation of all 29 keys for sufficient numbers of days to create an overall seasonal nesting estimate for the TTI in 1996. To assess the accuracy of the aerial counts for the 29 islands, 8 of these islands were chosen as ground truth islands for this study. Sea turtle nesting surveys were conducted from May 13, 1996 until August 15, 1996 for the 8 ground-truth islands. Ground surveys were conducted twice a week for each island, providing a seasonal nesting total. This strategy was developed by the U.S. Fish and Wildlife Service due to the remoteness of the TTI and lack of personnel.

Aerial surveys were conducted in a U.S. Coast Guard Sikorsky Jayhawk helicopter at an altitude between 46.9 to 62.5 meters and a speed of 30 to 40 knots over the surf zone. This placement of the helicopter afforded the best view of the narrow TTI beaches. Flights were made on two successive mornings after new moons in June (June 19 and 20) and July (July 9 and 10) and on two successive mornings after full moons in June (June 26 and 27) and July (July 25 and 26). The flight on June 19 was a training flight, and the flight on June 27 was canceled due to mechanical problems with the helicopter.

The full moon/new moon flight plan provided the greatest proportion of "fresh" crawls (i.e. crawls made the night prior to aerial survey), since the tides following these lunar cycles erase most old crawls from the beaches. In addition, all old crawls on the ground-truth beaches were erased by raking prior to aerial survey. Crawls were ground-truthed by assistants conducting daily surveys to provide the basis for a visibility index and an accurate nest/false crawl ratio. Aerial surveys were begun between 0800 and 0900 h, usually concluding within two hours, beginning at Coon Key at the northwest end of the study area, and ending at Pavilion Key at the extreme southeastern end. The survey was conducted from the port side of the helicopter. This methodology was adapted from research conducted by Hopkins-Murphy and Murphy (1983) in South Carolina.

Formula

The following formula was used to calculate a nesting estimate for the entire study area:

If the total ground and aerial counts for ground-truth islands are not equal, then a correction factor has to be calculated:

G = ground count of crawls for ground-truth islands

A_g = aerial count of crawls for ground-truth islands

C = correction factor

$= (A_g/G)$

The correction factor can then be applied to the observed number of aerial counts to create a corrected estimate ($\hat{a}$) of the total number of aerial counts at all sites:

T_a = total aerial count of crawls at all sites

$\hat{a}$ = total corrected # of aerial counts at all sites

$= (T_a/C)$

If a correction factor is necessary then the total aerial estimate ($\hat{a}$) would then be substituted for the total aerial count (T_a) in subsequent calculations. The percentage of total nesting activity on the ground-truth islands observed during the aerial survey is calculated in order to obtain a seasonal nesting estimate:

T_g = total seasonal ground count of crawls for ground-truth islands
P = % of total seasonal crawl activity for ground-truth islands
= (G/T_g)

Once the percentage of the total seasonal nesting activity (P) has been calculated, a total seasonal nesting estimate can be calculated:

$\hat{e}$ = total seasonal crawl estimate for TTI
= (T_a/P)

After the total seasonal nesting estimate has been calculated, the number of total nests can be calculated based on the nest-to-total-crawl ratio for the 8 ground-truth islands:

N_g = # of nests observed on ground-truth islands during aerial survey
$\hat{u}$ = total # of nests for all sites
= $\hat{e}(N_g/T_g)$

Results

A total of 26 crawls was observed in both ground and aerial surveys during the study period on the ground-truth islands (Table 3-1). Although the total counts were identical, the overall aerial survey failed to detect one crawl on one occasion and recorded one when it did not exist on another occasion. In addition, the ground and aerial counts for individual islands exhibited a much higher degree of variability when compared to the total count for the entire survey period (Table 3-2).

Table 3-1. Ground and aerial counts of sea turtle crawls on 8 islands in TTI for June-July 1996

Date	Ground count	Aerial count
6/20/96	5	5
6/26/96	8	8
7/9/96	5	4
7/10/96	4	4
7/25/96	3	4
7/26/96	1	1
TOTAL	26	26

Table 3-2. Aerial and ground counts on ground-truth islands for each survey by island

Date	Key	Ground	Air	Date	Key	Ground	Air
6/20/96	Brush	0	0	7/10/96	Brush	0	0
	B	1	2		B	0	0
	Turtle	0	0		Turtle	0	0
	Gullivan	1	0		Gullivan	2	2
	WH	1	1		WH	0	0
	Hog	0	0		Hog	2	2
	Panther	1	1		Panther	0	0
	Round	1	1		Round	0	0
6/26/96	Brush	1	1	7/25/96	Brush	0	0
	B	1	1		B	0	0
	Turtle	0	0		Turtle	0	0
	Gullivan	0	1		Gullivan	0	0
	WH	0	0		WH	2	2
	Hog	0	0		Hog	1	1
	Panther	5	5		Panther	0	1
	Round	1	0		Round	0	0
7/9/96	Brush	0	0	7/26/96	Brush	0	0
	B	0	0		B	1	1
	Turtle	0	0		Turtle	0	0
	Gullivan	3	2		Gullivan	0	0
	WH	0	0		WH	0	0
	Hog	0	0		Hog	0	0
	Panther	1	1		Panther	0	0
	Round	1	1		Round	0	0

The total number of crawls observed based on ground surveys conducted twice a week throughout the 1996 nesting season (Figure 3-1), does not accurately represent the levels of activity on the 8 ground truth islands on any given night. Figure 3-2 depicts the estimated numbers of nests that were laid on the 8 ground truth islands, based on the twice-a-week ground surveys. These nightly estimates were calculated by totaling the number of nests laid during lapses in ground surveys and dividing that total by the number of nights in the interval between ground surveys. The average obtained was then applied to each of the nights that fell between the interval between ground surveys. This graph (Figure 3-2) represents a trend in the amount of nightly nesting activity that occurred on these islands during the 1996 season.

An estimate was derived utilizing the formulas described previously in this paper. There were 26 crawls (G) counted on the 8 ground-truth islands during the aerial survey. For these 8 ground-truth islands, there were a total of 422 crawls (T_g) in 1996. Thus, the aerial observations accounted for 6.2% (P) of the seasonal crawl activity for these 8 islands. Since there were 118 aerial observations (T_a) at all sites, a total seasonal crawl estimate ($\hat{e}$) of 1903 crawls was derived. By calculating the % of nests for the 8 ground-truth islands ($N_g/T_g = 47.6\%$) for the entire nesting season, the total number of nests at all sites ($\hat{u} = 906$) was calculated. It is estimated that 906 nests and 997 non-nesting emergences occurred on the 29 study islands during the 1996 nesting season.

Discussion

Aerial surveys have been used in many sea turtle studies (Shoop et al., 1985; Crouse, 1984; Stancyk et al., 1979; Fritts et al., 1982; Meylan and Meylan, 1985; Pritchard, 1982) as a technique for covering large areas of coastline, reaching remote areas and reducing costs of conducting season-long daily or nightly surveys. Aerial surveys have been employed on several occasions in the area immediately adjacent to the

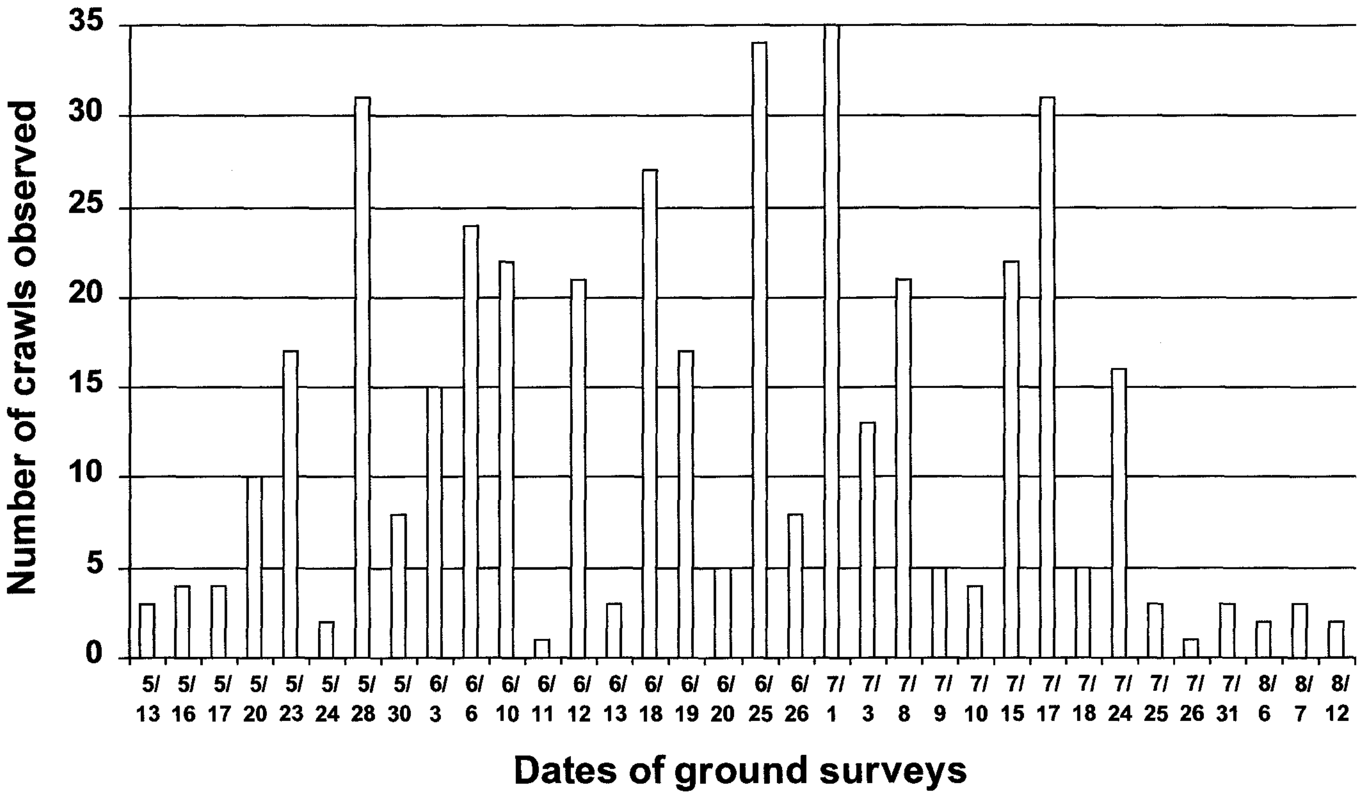


Figure 3-1. Sea turtle nesting activity on the 8 ground-truth islands for the 1996 nesting season (Based on 2 surveys per week)

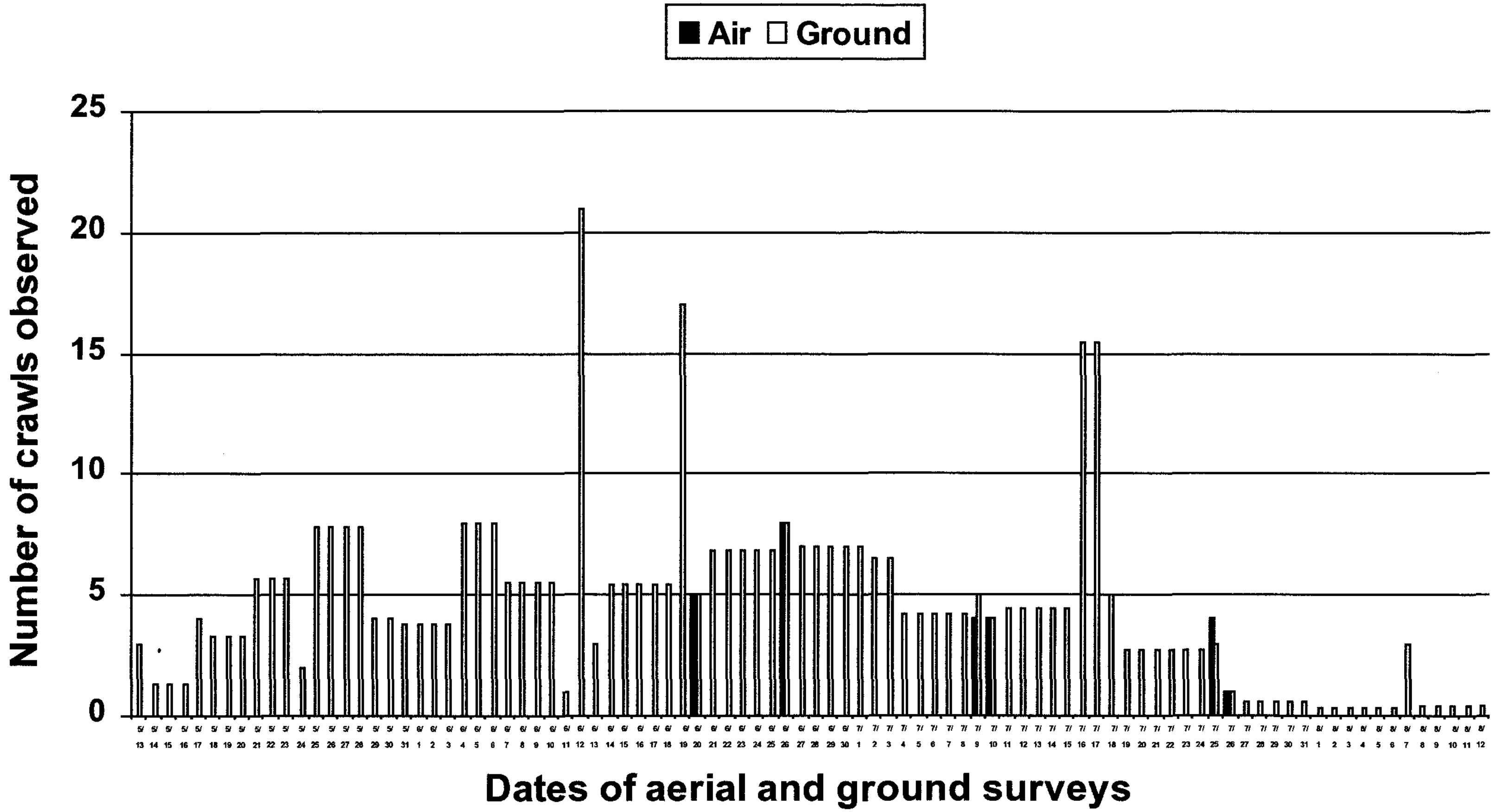


Figure 3-2. Ground and aerial sea turtle nesting activity on the 8 ground-truth islands for the 1996 nesting season. Daily counts for the ground surveys are estimates from surveys conducted twice a week. See text.

TTI (Davis and Whiting, 1977; LeBuff, Jr. and Hagan, 1978; Irvine, 1981; Kushlan, 1986), reporting varying degrees of success at documenting sea turtle activity.

The most efficient means of gathering data on marine turtle nesting activity over a large area appears to be aerial survey (Hopkins-Murphy and Murphy, 1983). But, aerial survey is only useful if it is effective, that is, producing accurate and reproducible estimates (Hopkins-Murphy and Murphy, 1983). There are a number of factors that influence the effectiveness of aerial survey nesting estimates. LeBuff and Hagan (1978) reported that strong westerly or northwesterly winds in conjunction with high tides often caused beach erosion and shifting sands, and that severe weather left marine vegetation upon beaches that concealed crawls. Hopkins-Murphy and Murphy (1983) discuss the importance of aerial sampling parameters associated with aerial surveys such as: speed of the aircraft, height of the aircraft, position of the aircraft, angle of view (beach), skill of the pilot and observer experience on estimator accuracy. Other factors that could potentially bias aerial estimates, include: amount of turtle activity, the type of beach, the amount of sunlight, human activity on the beach, location of crawls on the beach and in the case of the TTI, the ordinal aspect of the islands. LeBuff and Hagan (1978) noted that crawls in close proximity to each other or crawls partially hidden caused problems when attempting to assess nesting activity from the air. Not all factors can be controlled or accounted for in creating nesting estimates.

Crouse (1984) identified one of the inherent difficulties with creating estimates from aerial survey, is that a limited number of aerial surveys are used to extrapolate to a total seasonal nesting estimate. Crouse (1984) is critical of the use of a conversion factor as a means of creating nesting estimates via aerial survey. She noted that variability of crawl retention and visibility from beach to beach adversely affects conversion indices. These factors may vary from beach to beach depending upon characteristics of the nesting substrate and prevailing tides (Crouse, 1984). She also stated that weather patterns could affect crawl retention, both geographically and temporally, and that changes in beach profile due to erosion or accretion may affect crawl retention over time (Crouse, 1984).

The TTI are used minimally in the summer months by humans, therefore, that impact on crawl retention is minimal. In addition weather patterns and the type of nesting substrate can cause differential crawl retention on TTI beaches temporally; these factors can be controlled by only documenting "fresh" crawls. Recognizing these limitations of aerial survey, efforts to reduce potential sources of bias and make corrections prior to the beginning of the flight schedule, were taken. For example, a test flight was conducted where fine-tuning of the aerial survey technique to the TTI took place (i.e. adjusting speed, altitude and angle of observation of the helicopter). Another problem associated with aerial survey is detecting all crawl activity after nights of high nesting activity or storm activity. One of the methods of dealing with this problem is the creation of a conversion factor. Although the overall accuracy of a seasonal estimate will suffer if aerial and ground counts are not in fairly close agreement, the conversion factor still allows for an estimate to be made. The accuracy of this sort of estimate would be debatable, although it would provide managers with a good idea of the trends in sea turtle nesting activity for their study area. The usefulness of such data cannot be discounted.

Since the survey technique suggested here has numerous limitations, it is necessary to describe methods that could improve upon the protocol used for the 1996 season. One of the key limitations of this particular study is the fact that we conducted 6 flights. After assessing the data, it was determined that in order to accurately create a nesting estimate that is worthy of application for threatened and endangered species, several years of flights would need to be flown, with the flights occurring no less than a daily basis for at least the first year. After collecting this data, it would be possible to determine the minimum number of flights needed to create estimates that can limit the variability in the data. By adding many more flights to the protocol, a more accurate picture of sea turtle nesting trends could potentially be developed for the TTI.

Although the technique applied in the TTI for the 1996 nesting season is not the answer to developing an accurate nesting estimate for the TTI, it did provide answers about the difficulties associated with aerial survey in the TTI. Therefore, the technique served as the first step in potential development of a method for accurately assessing sea turtle nesting activity in the TTI. Furthermore, the nesting estimate suggested in this paper should not be viewed as a hard estimate of the total activity in the TTI. In fact, due to the variability of crawls observed, the estimate should be cautiously viewed as an indicator of the amount of sea turtle nesting that is occurring in the TTI. This preliminary research should be expanded upon by implementing the changes to the methodology suggested in this paper.

Davis and Whiting (1977), in work that is now over 20 years old, found an estimated 1553 loggerhead nests in 1972 and 919 loggerhead nests in 1973 for nesting beaches stretching from Cape Sable northwest to Morman Key, just southeast of the furthest extent (Pavilion Key) of my study area. Kushlan (1986) conducting aerial surveys in the same area and employing the same methodology as Davis and Whiting (1977) found 1362 nests in 1980. Taking into account the estimate I made for the TTI, this portion of coastline, long thought to be fairly insignificant in terms of overall nesting effort by sea turtles, could potentially host between two to three thousand sea turtle nests in a given year. These nesting numbers identify the significance of this coastline as a high use area for sea turtles, particularly the loggerhead sea turtle. Furthermore, I was unable to differentiate crawls by species of sea turtle from the aerial survey, therefore, it is not possible to say how many of the nests in the TTI are from green turtles (*Chelonia mydas*), which are known to nest in the islands.

This technique may be used as an indicator of nesting activity in the TTI although, there are several additional changes in the methodology used in this study that could potentially increase the accuracy of aerial surveys. The use of two observers is a strategy used in the work conducted by Murphy and Hopkins-Murphy (1983) in South

Carolina. They found no significant difference in the number of crawl identifications between two separate observers. By using two observers, like Murphy and Hopkins-Murphy (1983), a basic mark-recapture study could be created, and the results could be subjected to statistical analyses to lend strength to any aerial estimates. Since aerial observations are conducted by helicopter in the TTI, there is greater flexibility with regard to how flights could be conducted. It may be possible to safely reduce the speed at which the helicopter flies, based on the discretion of the pilot. It may be beneficial to hover over beaches at the discretion of the observer(s). Hovering might allow for more accurate documentation of crawl activity. The observer(s) may request additional fly-bys of beaches in order to get more accurate counts of crawl activity.

The methodology suggested here is imperfect. Although the estimates for 1996 appear to be sound, these results cannot predict the accuracy of aerial surveys for future years in the TTI. Therefore, when implementing this strategy, the conclusions drawn from the results presented should be considered cautiously.

Conclusion

Aerial survey, in conjunction with seasonal ground surveys, appears to be a useful tool for evaluation of sea turtle activity in the Ten Thousand Islands. In order to develop low-cost methods for assessing trends in sea turtle nesting in the TTI, natural resource managers may consider annual aerial surveys with partial ground-truth counts punctuated with aerial survey corrected by season-long ground surveys. Detailed information on the accuracy of aerial survey, as well as the trends in sea turtle nesting in the TTI may allow for the development of a lower-cost method for evaluating nesting activity. However, before any protocol can be established, at least several more years of aerial surveys need to be conducted, before nesting trends can be more clearly understood.

CHAPTER 4

MOVEMENT PATTERNS OF THE TEN THOUSAND ISLANDS RACCOON (*PROCYON LOTOR MARINUS*), AND THE EFFECT OF ITS REMOVAL ON SEA TURTLE HATCH SUCCESS

Introduction and Background

Raccoons (*Procyon lotor*) have been the subject of considerable study pertaining to various aspects of behavior, feeding ecology, and population dynamics. In addition, several studies have dealt directly with the Ten Thousand Islands raccoon (*Procyon lotor marinus*). This subspecies was identified by Goldman (1950), and later confirmed by Hall and Kelson (1959). This spurred further study, including descriptions of morphometric characteristics (Bigler et al, 1977), and population characteristics of *P. l. marinus* (Bigler et al, 1981).

Raccoons are effective predators of sea turtle nests in Florida (Ratnaswamy, 1995; McMurtray, 1986; Lewis et al., 1994; Kushlan, 1986; Klukas, 1967; Davis & Whiting, 1977), Georgia (Anderson, 1981), and South Carolina (Stancyk et al., 1980; Andre & West, 1979; Hopkins & Murphy, 1980; Hopkins et al., 1977). Raccoon depredation rates of sea turtle nests ranged from 49-87% annually at Cape Sable, FL (Davis & Whiting, 1977) and from 59-85% annually from 1991-1994 for Ten Thousand Islands National Wildlife Refuge (TTINWR), FL (Garmestani, 1995). Raccoons have been identified as the primary predator of sea turtle nests with humans, fire ants, ghost crabs and bobcats as possible secondary predators in TTINWR (L. Richardson, pers. comm.).

Due to the imperiled status of sea turtles, various means of decreasing raccoon depredation of sea turtle nests have been explored. Numerous studies have been conducted to evaluate the effectiveness of conditioned taste aversion (CTA) and its impacts on consumption of eggs by raccoons. Linhart et al. (1991) formulated baits that were readily taken by raccoons, tested the baits in the field, and found that 31-53% of the baits were taken by non-target species (Linhart et al., 1994). Conover (1990) reported that emetine dihydrochloride was determined to have some effectiveness in reducing egg depredation. Nicolaus (1987) and Semel & Nicolaus (1992) found CTA using estrogen-injected eggs can be an effective strategy to reduce raccoon depredation of eggs. However, Nicolaus et al (1989), found mixed results when treating eggs with estrogen, and researchers in South Carolina found CTA using lithium chloride to be completely ineffective at reducing depredation of sea turtle nests (Hopkins & Murphy, 1982). One study conducted in South Dakota concluded that raccoons could be baited into ingesting chemosterilants, thereby inhibiting reproduction (Nelson, 1970). CTA techniques were rejected by TTINWR because of their mixed results, combined with the likelihood of ingestion by non-target species.

Other methods of sea turtle nest protection have been attempted. McMurtray (1986) concluded that the most effective means of turtle nest protection was flat screens left on nests until hatchlings emerged. Ratnaswamy (1995) supported the claim that screens are the most effective form of nest protection from predators, and claimed that CTA and predator removal were ineffective. Several researchers argue the effectiveness of nest transplantation as an effective means of decreasing turtle egg mortality (Andre & West, 1979; Stancyk et al., 1980). Hopkins and Murphy (1982) concluded that the most effective form of nest protection includes nest transplantation and predator removal, thereby decreasing chances of inundation and depredation. This conclusion was supported by the findings of researchers at St. Vincent's National Wildlife Refuge (Lewis et al., 1994). However, the U.S. Fish and Wildlife Service has recently determined that nest transplantation should only be considered when a nest is threatened by potential inundation (MacPherson, personal comm.). Klukas (1967) reported a 25% reduction in nest destruction using predator elimination as a management tool on Cape Sable in Everglades National Park (ENP).

Raccoons depredated nests on the eight continuously surveyed islands in TTINWR at varying rates (Garmestani, 1995). Although the literature indicated that other forms of nesting management may be more effective, particularly screening in conjunction with predator removal (Hopkins & Murphy, 1982; Lewis et al., 1994), lack of personnel and the remoteness of TTINWR precluded any attempt at labor-intensive or season-long nesting management. Due to these constraints, the effectiveness of short-term raccoon control was assessed as a possible management strategy for the Ten Thousand Islands.

Materials and Methods

Study Areas

Study areas were 4 low-relief mangrove islands located within TTINWR and the Cape Romano-Ten Thousand Islands Aquatic Preserve in southwest Florida. This rich estuary, which supports breeding and feeding grounds for a multitude of species, consists of a labyrinth of tidal creeks, bays, and passes. The 4 study islands were dominated by red (*Rhizophora mangle*), black (*Avicennia germinans*), and white (*Laguncularia racemosa*) mangrove trees, interspersed with sandy and/or shelly beaches. These beaches are of varying lengths (50m-815m) and widths (1.4m-18.3m), and support beach vegetation that varies with the substrate and elevation of the particular island and/or beach. Study islands were of varying sizes, in close proximity (< 2 km) and interconnected by the observed motility of raccoons: Panther (54.8 ha), White Horse (39.3 ha), Hog (26.7 ha), and Gullivan (19.6 ha). These 4 islands (Panther, Hog, White

Horse, and Gullivan Keys) were known to support sea turtle nesting and to suffer varying rates of raccoon depredation of sea turtle nests (Garmestani, 1995). White Horse was the site of 75 documented sea turtle nests from 1991 through 1994, and had an average depredation rate of 46% for those four years; Gullivan was the site of 124 documented sea turtle nests from 1991-1994, with a 91% depredation rate for that time period; Hog Key had a total of 21 documented sea turtle nests for the years 1991-1994, with an average depredation rate of 72%.

Sampling Techniques

Live traps (91.44cm X 27.94cm X 27.94cm [2-door]; 81.28cm X 30.48cm X 25.4cm [1-door]; Havahart, Inc., Lititz, Pennsylvania, USA; 121.92cm X 30.48cm X 30.48cm [1-door]; custom traps, South Carolina Wildlife and Marine Resources Department, Georgetown, South Carolina, USA) were placed in a randomly spaced array in the vicinity of nesting beaches, utilizing vegetation as camouflage. Raccoons were attracted into live traps using a variety of baits, including sardines, a sardine/cat food mixture, mullet, marshmallows, and chicken eggs coated with fish oil. After a raccoon was captured, it was compressed within the live trap using either a homemade plunger or stakes. The animal was then injected intramuscularly with 8-10 mg/kg of ketamine (100 mg/ml; Fort Dodge Laboratories, Inc., Fort Dodge, Iowa, USA). Once the animal was anesthetized, one of two things then occurred: 1) if the animal was part of the mark-recapture study it received a Monel (National Band and Tag Co., Newport, KY, USA) ear tag in each ear and a Passive Integrated Transponder (PIT) (Avid Co., Norco, CA, USA) which was placed in the scruff of the neck, and a 4 cc sample of blood (1995) was taken from the heart and placed on ice; 2) if the animal was part of the removal study, blood was drawn (1995), and the animal euthanized with an intercardiac injection of euthasol

(Delmarvia Laboratories, Inc., Midlothian, VA, USA). Next, numerous aspects of the anatomy of the raccoon were measured and evaluated, including: sex, testes lengths, baculum length, evidence of lactation, weight, age (Grau et al., 1970), canine lengths, total length (head-body and tail), right hind-foot, right ear, length of vibrissae, neck, head and chest circumference, pelage, and physical condition. Euthanized raccoons were then buried in three-foot deep holes on the beach. Tagged raccoons were released by placing them in the shade, covering their eyes with horseshoe crab shells to alleviate the potential damage from sunlight. Raccoons were captured and removed on Panther Key in January, February, May, June, and July for 1995, and in January for 1996; sampled by mark-recapture on White Horse Key in March of 1995 and 1996, and on Hog Key in April of 1995 and 1996; Gullivan Key was sampled by mark-recapture in March and April of 1995, and removal in March and April of 1996.

1995 Field Season

On January 11th, 1995, raccoon trapping commenced on Panther Key in the TTINWR. A 100 mile round trip drive, and a 12 mile round trip boat ride were required each day in order to arrive at the field site in the TTINWR. Initially, 12 Havahart one-door live traps were used to capture raccoons on the west beach of Panther Key. However, after compiling 8 nights using only the one-door traps, 12 Havahart two-door live traps were deployed on the east beach of Panther Key for an additional 15 nights, for a total of 23 nights on Panther Key. Only one door was opened on the two-door traps each night. Beginning May 1, 12 one-door and 10 custom live traps on loan from South Carolina Wildlife and Marine Resources Department (SCWMRD) were re-set on Panther Key. After 5 nights of trapping, the 10 custom traps were removed, and the remaining 12 live traps were run until July 14, 1995. Raccoons were enticed into traps with a variety of baits including sardines, a sardine/cat food mixture, marshmallows and mullet.

Beginning March 3, 1995, raccoon trapping commenced on White Horse Key. A total of 33 traps was initially deployed on White Horse, including 12 Havahart one-door traps, 11 Havahart two-door traps, and 12 custom traps on loan from Phillip Wilkinson of SCWMRD. Six of the two-door traps were closed after two nights of trapping, because of time constraints. All raccoons captured were marked and released. Mullet was used exclusively to bait traps on White Horse Key.

Beginning March 28, 1995, raccoon trapping commenced on Gullivan Key. Twenty-two traps were set on Gullivan, including 12 Havahart one-door traps, and 10 of the custom traps on loan from SCWMRD. Mullet was used exclusively as bait, and all raccoons were tagged and released.

Beginning April 17, 1995, 7 one-door Havahart traps were set on Hog Key. This number was upgraded the following day, by adding 5 more Havahart one-door traps, and 10 of the custom traps on loan from SC Wildlife. A total of 8 nights were run on Hog Key from April 17 through April 28. Mullet and marshmallows were used as bait, and all captured raccoons were tagged and released.

1996 Field Season

Raccoon trapping for the 1996 field season was based upon the rate of first-time captures for the 1995 field season (Table 4-1).

Table 4-1. Initial raccoon capture rates for TTINWR (1995) initial trapping regime

Island	new captures	# of nights	%new captures
Panther	13	8	100
White Horse	18	5	100
Gullivan	8	6	100
Hog	10	5	100

In addition, the study methodology was further altered from the 1995 field season by adding Gullivan Key as a removal island, along with Panther Key. Gullivan Key was selected due to its distance from Panther Key and high depredation rate. Also, during 1996, mark-recapture efforts were conducted on White Horse and Hog Keys, in order to accumulate data on changes in raccoon population characteristics of the two islands.

Raccoon trapping commenced on Panther Key beginning on January 18, 1996, running traps for 8 nights. Twenty-one traps were deployed on the island, including 11 Havahart one-door and 10 Havahart two-door live traps. Each of these traps was baited with chicken eggs scented with fish oil. This bait was devised as a method of targeting egg-depredating raccoons. All raccoons captured were euthanized and buried on site.

On March 5, 1996, trapping began on White Horse Key, running 5 nights. Twenty traps were originally deployed on White Horse, including 20 Havahart live traps (e.g. ten one-door, ten two-door). But, after two nights, one of the two-door traps was stolen, so the remaining three nights were run with 19 traps. All traps were baited with the chicken egg/fish oil bait, and all raccoons were marked and released.

On March 30, 1996, trapping commenced on Gullivan Key, running 6 nights. Nineteen Havahart live traps were deployed on Gullivan, including 10 one-door and 9 two-door traps. All traps were baited with egg/oil, and all raccoons were eliminated and buried on site.

On April 18, 1996, trapping was initiated on Hog Key, running 5 nights. Eighteen Havahart live traps were deployed on Hog Key, including 10 one-door and 8 two-door traps. All traps were baited with egg/oil, and all raccoons were marked and released.

Results

1995 Field Season

Panther Key (PK), an island continuously surveyed for the past 5 years at TTINWR, was chosen as a test island for raccoon removal because of its high incidence of sea turtle nests and raccoon depredation. In addition to the limited success with live trapping, baiting the beach with piles of mullet was completely unsuccessful for spot-lighting and shooting of raccoons. There were a total of 15 captures on Panther Key, including one escape. So, a total of 14 raccoons was removed from Panther Key in 750 trap nights for the 1995 season. Traps were reset on Panther Key in May to determine whether raccoons will move from adjacent islands to exploit an open niche and a plentiful seasonal food resource (i.e. sea turtle nests). However, only 1 unmarked raccoon was captured after the start of sea turtle nesting. Raccoon tracks were observed on numerous occasions on Panther Key during turtle nesting season, but no depredation occurred in 1995 (Table 4-2).

Table 4-2. Sea turtle nesting and depredation on Panther Key for the1991-1995 nesting seasons

Year	total nests	# depredated	% depredated
1991	63	63	100
1992	42	40	95
1993	36	29	81
1994	38	29	76
1995*	41	0	0

* post-removal

Even with the elimination of raccoon depredation as a factor in sea turtle nest mortality for Panther Key in 1995, overall hatch success did not significantly improve due to the high rate of inundation of nests (Table 4-3). This high rate of inundation was due to an extreme aberration in the occurrence of tropical storms and hurricanes for the 1995 storm season.

Table 4-3. Sea turtle hatch success on Panther Key for the 1995 nesting season

# of nests	# hatched	# of eggs evaluated	# of emerged hatchlings	# unhatched
41	14 (34%)	1664	903 (54%)	761 (46%)

In addition to the animals trapped on Panther Key, raccoons were marked and released on Gullivan (n=8), White Horse (n=18), and Hog (n=10) Keys. All 3 of these islands are in close proximity to Panther Key, and all have turtle nesting beaches that have been documented for the past 5 years.

Ten nights of trapping were run on White Horse Key with 18 initial captures, and a total of 30 captures for White Horse Key. Raccoons were tagged and released, accounting for the 12 recaptures (Table 4-4). A total of 12 nights of trapping was run on Gullivan Key, with 8 initial captures and 1 recapture (Table 4-4). Ten initial captures were recorded on Hog Key in 8 nights of trapping (Table 4-4).

Table 4-4. Results of raccoon trapping activity on the four study islands for the 1995 trapping season

Island	# of trap nights	Initial captures	Total recaptures	# of captures per night	% of successful traps
Panther	750	14	0	0.33	2.0
White Horse	286	18	12	3.00	10.5
Gullivan	264	8	1	0.75	3.4
Hog	161	10	1	1.38	6.8
TOTAL	**1461**	**50**	**14**	**0.67**	**3.4**

Of these 50 captures, 36 were males, ranging in size from 1.4 kg to 4.8 kg, with mean weight and standard error of 3.55 +/- 0.136 kg. Fourteen were females ranging in size from 1.4 kg to 3.6 kg, with mean weight and standard error of 2.83 +/- 0.151 kg. Age class distribution for males (n=36) captured in 1995 was fairly even (Figure 4-1), but age class distribution was slightly skewed towards young (Class 1) and middle-aged (Class 3) females (n=14) (Figure 4-1). Although a population estimate could not be created, raccoon densities were calculated for the period of trapping on a particular island (Table 4-5).

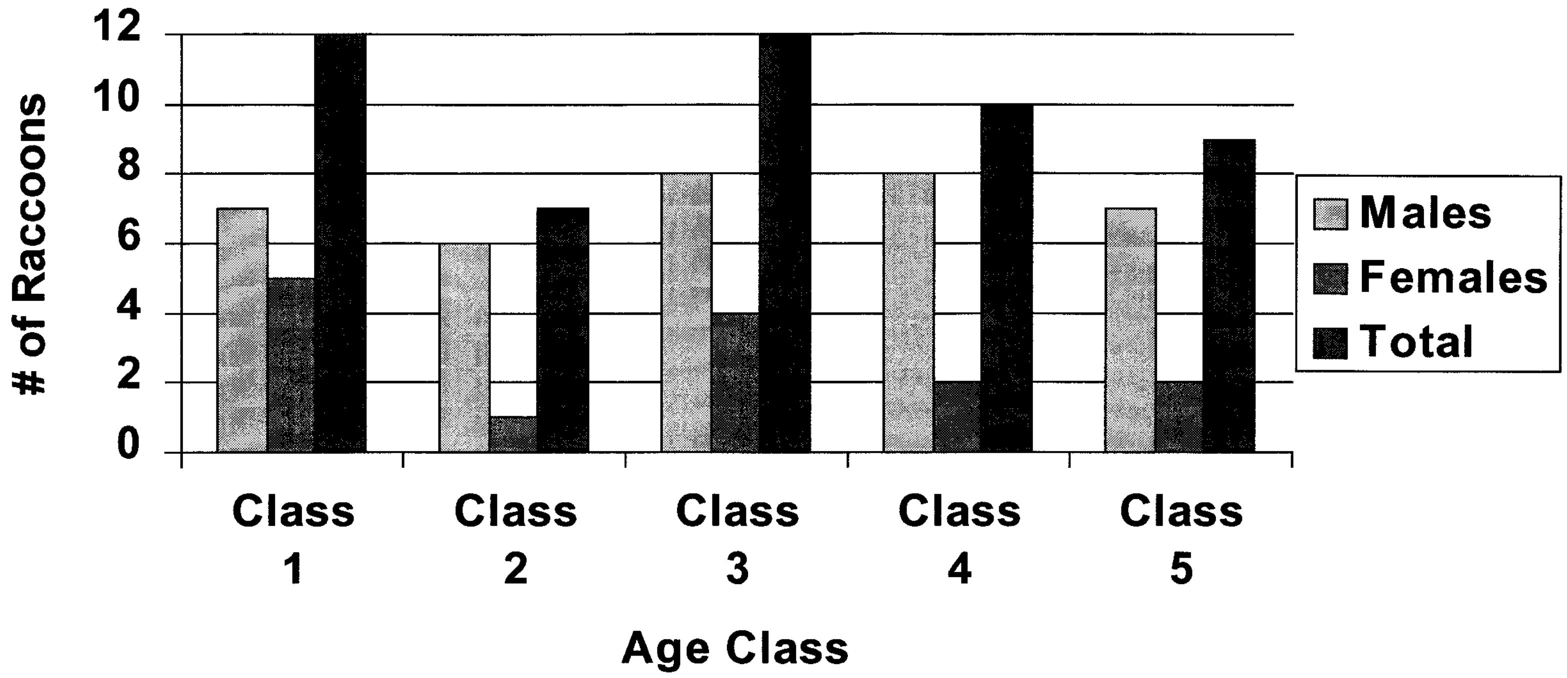


Figure 4-1. Distribution of raccoons by age class (1995)

Table 4-5. Raccoon densities during trapping periods for 1995

Island	# of raccoons captured	Density during capture period (per ha.)
Panther	14	0.26
White Horse	18	0.46
Gullivan	8	0.37
Hog	10	0.41
TOTAL	**50**	**0.36**

1996 Field Season

Raccoon removal was conducted again in 1996 on Panther Key. There were a total of 2 captures in 168 trap nights. No depredation was observed in 1996, and I assume that this is attributable to the removal of raccoons on Panther Key (Table 4-6).

Table 4-6. Number of depredated nests for Panther Key (1996)

Year	# of nests	# depredated	% depredated
1996	61	0	0

The hatch success for sea turtles on Panther Key drastically improved for the 1996 field season when compared to hatch rates for the 1995 field season (Table 4-7). I attribute this drastic increase to the effectiveness of raccoon removal and the lower incidence of devastating storms (i.e. hurricanes and tropical storms) in 1996.

Table 4-7. Hatch success for Panther Key (1996)

# of nests	# hatched	# of eggs evaluated	# of emerged hatchlings	# unhatched
61	58 (95%)	5809	4875 (84%)	934 (16%)

In addition to the animals trapped on Panther Key, raccoons were removed on Gullivan Key (n=1), and mark-recapture was conducted on White Horse (n=15) and Hog (n=5) Keys.

There were 15 initial captures and 1 recapture for a total of 16 captures on White Horse for 1996. Of these 15 captures, 6 were captured on White Horse in 1995 and 1 was tagged on Gullivan in 1995. This male raccoon is the only record of movement between islands based on my mark-recapture data. Therefore, 8 "new" raccoons were trapped and tagged on White Horse Key in 1996. All raccoons were tagged and released.

There was 1 capture on Gullivan for 1996. This individual was not one of the 8 raccoons tagged on Gullivan in 1995. The individual was eliminated and buried on-site. The raccoon removal method was completely ineffective for Gullivan in 1996. Raccoons depredated nests at a similar rate in 1995, when no removal was attempted (Table 4-8).

Table 4-8. Number of depredated nests for Gullivan Key
(1995-1996)

Year	# of nests	# depredated	% depredated
1995	36	34	94
1996*	33	32	97

* post-removal

Five nights of trapping were run on Hog Key, from April 18-22, 1996. There were a total of 6 captures on Hog, including 1 recapture. Of these 5 initial captures, 2 were captured in 1995, and 3 were "new" raccoons. All raccoons were marked and released.

Of these 23 captures, 13 were males, ranging in size from 2.1 kg to 4.7 kg, with mean weight and standard error of 3.45 +/- 0.182 kg, and 10 were females ranging in size from 1.6 kg to 3.6 kg, with mean weight and standard error of 2.64 +/- 0.208 kg. Age class distribution for females (n=10) captured in 1996 was fairly even (Figure 4-2), but age class distribution was slightly skewed towards young (Class 1) and middle-aged (Class 3) males (n=13) (Figure 4-2). Trapping data are summarized in Table 4-9.

Figure 4-2. Distribution of raccoons by age class (1996)

Table 4-9. Raccoon activity in TTINWR (1996)

Island	# of trap nights	Initial captures	Total recaptures	# of captures per night	% of successful traps
Panther	168	2	0	0.25	1.2
White Horse	97	15	1	3.00	16.5
Gullivan	114	1	0	0.17	0.8
Hog	108	5	1	1.2	5.6
TOTAL	**487**	**23**	**2**	**1.04**	**5.1**

Although a population estimate could not be created for 1996, raccoon densities during trapping periods are summed in Table 4-10.

Table 4-10. Raccoon densities during trapping periods for 1996

Island	# of raccoons captured	Density during capture period (per ha.)
Panther	2	0.04
White Horse	15	0.38
Gullivan	1	0.05
Hog	5	0.04
TOTAL	**23**	**0.16**

Discussion

The data I collected provide a closer look at the Ten Thousand Islands raccoon (*Procyon lotor marinus*), which has been studied by several other researchers (Nelson, 1930; Bigler et al., 1977; Bigler et al., 1977). Although I was able to capture quite a few raccoons (1995= 50; 1996= 23), I was unable to get enough recaptures to run any sort of population model, such as the examples suggested in Hallett et al. (1991). Therefore, I was unable to create a population estimate for the 4 islands I surveyed.

However, I was able to collect information pertaining to the natural history of *P. l. marinus*. For instance, in 1995, I caught more males (n= 36) than females (n= 14). It is possible that this male to female ratio is due to a sex-biased response to live traps as has been suggested by Gehrt and Fritzell (1996), who found that males were captured more frequently during all of their trapping periods. Yet, in 1996, although I have a small sample size, I caught raccoons at nearly a 1:1 ratio (males n= 13, females n= 10). This ratio (1:1) is what is to be expected in nature, although the exploration of this sex-bias theory merits a closer look.

Depredation of sea turtle nests on Panther Key was reduced to zero for the two-year study period. I assume this drastic decrease in depredation on Panther Key was due to raccoon control. This finding is inconclusive, but unconnected research conducted on St. Catherine's Island in Georgia found that there was no shift in raccoon home ranges or centers of activity with regard to sea turtle nesting (Anderson, 1981). Wilkinson (pers. comm.) observed in South Carolina that raccoons not familiar with sea turtle nests may forage on beaches without taking eggs obviously available for exploitation.

Finally, when considering the poor trap success for the 1996 field season, the intangible factor of trap-smart raccoons must be taken into account. Short of conducting a radio-telemetry study, it would be difficult to quantify what percentage of the TTI raccoons are trap-smart, although there is evidence to prove their persistence in the population. For example, low-capture rates on Hog Key and to a lesser degree White Horse Key were experienced in 1996 after those islands were subjected to trapping in 1995. But the greatest evidence is provided by the abysmal trap success on Gullivan Key coupled with extremely high nest depredation for the island (see Table 4-8 and Figure 4-3). From the limited mark-recapture data, only 1 raccoon moved from 1 island to another. This evidence and the fact that low numbers of raccoons re-populated Panther Key, suggest that raccoon removal could be an effective sea turtle management policy for the Ten Thousand Islands (Figure 4-4).

Conclusion

The Ten Thousand Islands raccoon has proven to be the single greatest threat to sea turtle hatch success in the mangrove forests of southwest Florida. Therefore, any sea turtle management strategy should include live trapping on islands that have not previously been exposed to trapping, and explore the possibility of utilizing leg-hold

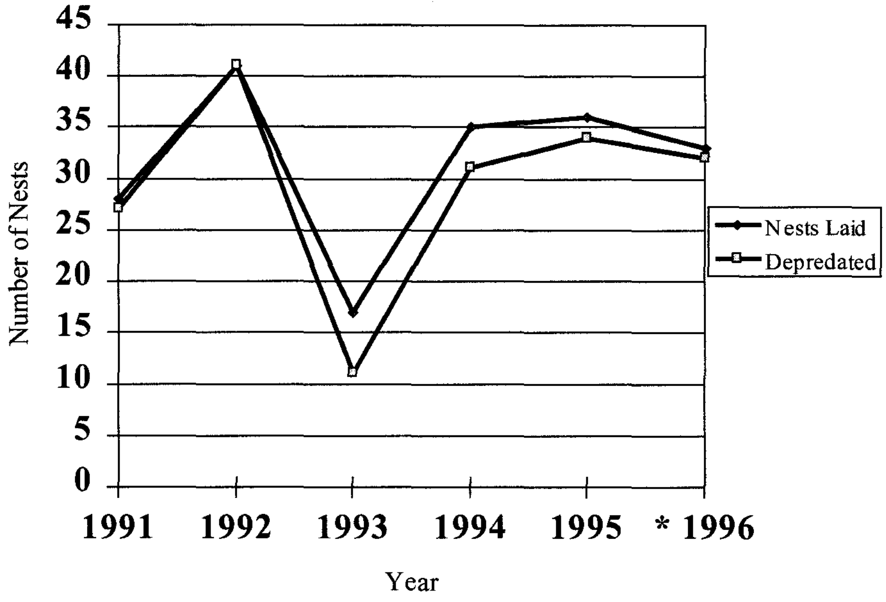


Figure 4-3. Raccoon depredation rates on Gullivan Key, 1991-1996.
* Raccoon control program in effect this year

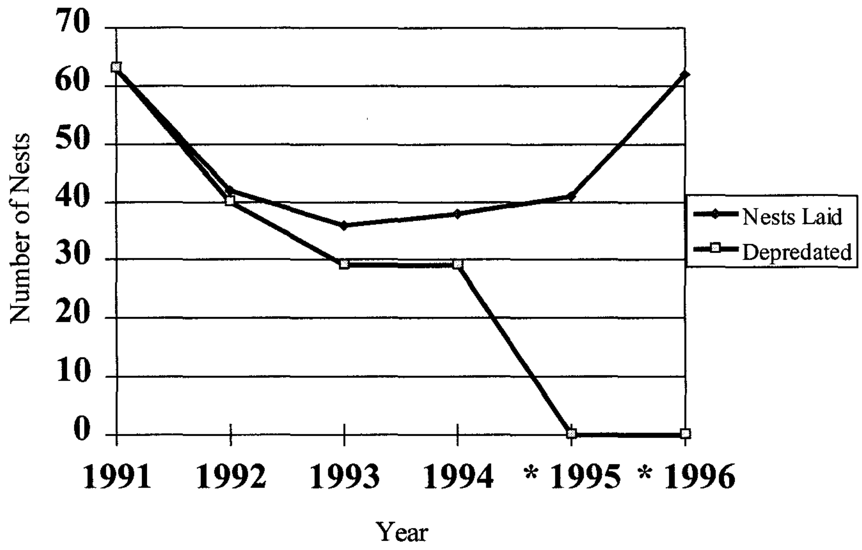


Figure 4-4. Raccoon depredation rates on Panther Key, 1991-1996.
* Raccoon control program in effect these years

traps and shooting as methods of removal for islands that have been exposed to live trapping. In addition, removal efforts should be concentrated on islands with high numbers (>10) of sea turtle nests and/or with the highest probability of hatch success, due to slope, sediment type, etc. These islands include: B, Gullivan, White Horse and Hog Keys. Finally, hatch success will be dramatically affected by weather patterns for the area. High hatch success cannot be expected if numerous storms have direct and indirect effects on the islands as in 1995, a year of heavy storm activity, and 1996, a year of minimal storm activity (see Table 4-3 and 4-7).

It would be beneficial to know about the movement patterns and re-population trends for the TTI raccoons. Conducting radio-telemetry on *P.l. marinus* may provide answers that allow for a long-term raccoon management strategy to be employed. By conducting this study, information could be gathered that may indicate how often raccoon control measures would need to be implemented. It would also be necessary to evaluate the population genetics of each islands' raccoon population. Understanding the relatedness of raccoons on each of the islands, coupled with radio-telemetry, would provide a more complete understanding of the raccoon populations and their movement patterns in the TTI, and allow for a more comprehensive raccoon management strategy.

CHAPTER 5

RECOMMENDATIONS

It appears that loggerhead sea turtles select nesting beaches according to certain criteria of beaches in the TTI. The conclusions reached about loggerheads in the TTI may not be true of *C. caretta* in other parts of the world. Other factors may play a larger part in the decision-making process in sea turtles. For instance, beach lighting, the presence of humans, sea walls and re-nourished beaches could potentially have a greater effect on nesting beach and nest-site selection, particularly in inhabited areas, than the factors I analyzed for the TTI. However, the most important element of my study is that the nesting habitat in the TTI is relatively unspoiled. This means that the nesting preferences exhibited by loggerheads can be assumed to be based on cues inherent to the islands.

1) Aerial surveys can be effective in assessing sea turtle activity in the TTI, reducing expenditures of time, personnel and expenses. Obviously aerial surveys need to be conducted in a helicopter due to the configuration of the islands, but with continued cooperation of the U.S. Coast Guard, an effective, low-cost survey plan could be implemented for the region. The use of aerial survey also provided the first comprehensive evaluation of sea turtle nesting activity for the TTI. This season-long estimate may fluctuate with sea turtle nesting cycles, and changes to the survey technique, but this indicator of sea turtle nesting activity in the TTI should be considered a minimum nesting estimate for the region when you take

into account the five islands that were not included in this study, including one island (Cape Romano) that is known to support from 50 to 100 nests per season (Kraus, pers. comm.).

2) The removal of raccoons is a potential management strategy for improvement of sea turtle hatch success. Even if depredation is reduced significantly, hatch success will not necessarily improve in years of heavy storm activity in the area. Therefore, raccoon removal is simply a method for decreasing depredation of sea turtle nests and indirectly increasing hatch success. In addition, the raccoon research provided some basic data on the status of *Procyon lotor marinus* in the TTI.

3) Other research addressing the effects of exotic invasive species (i.e. Australian pine and the red imported fire ant) into the TTI needs to be undertaken to understand their impacts on sea turtles, as well as other native flora and fauna in the archipelago. In addition, personal observations of Kemp's Ridley (*Lepidochelys kempii*) sea turtles and juvenile green turtles in the area warrants investigation of this area as a potential feeding ground for these two species.

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