Reproductive Ecology of *Caretta caretta* In South Carolina

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STUDY COMPLETION REPORT

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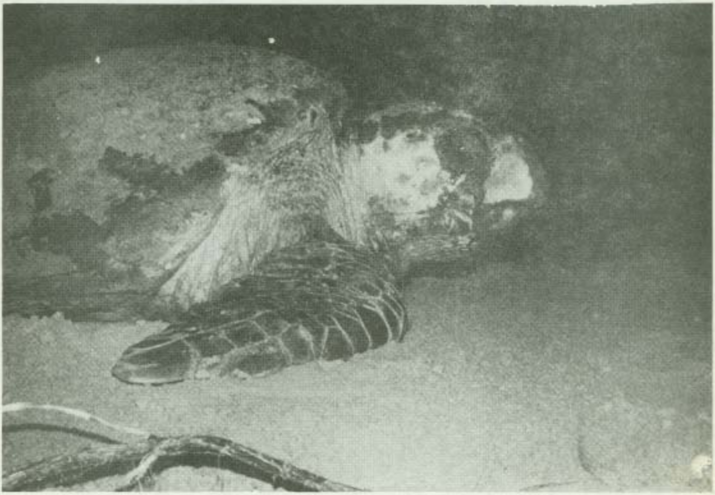
IN SOUTH CAROLINA



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Study Duration: October 1976-September 1979

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Study Objective

To quantify the parameters affecting the reproductive ecology of *Caretta caretta* and evaluate management techniques for that species.

The expanding human population and its increasing resource exploitation are exerting tremendous pressures on natural systems especially in coastal areas. As a result of this, six species of marine turtles are listed as either threatened or endangered. Five factors have been delineated as resulting in their declines. They are: 1) alteration or destruction of habitat; 2) disease or predation; 3) over-utilization for commercial, sport, scientific or educational purposes; 4) inadequacy of regulatory mechanisms; and 5) other natural or man-made factors (Fed. Reg. Vol 43, No. 146, pp. 32800-32811). All five factors affect the loggerhead turtle in South Carolina to some degree.

The loggerhead turtle's life cycle and some of the factors affecting the various stages are shown in Figure 1. Adult and immature turtles arrive in coastal waters in late March or early April. During the spring sturgeon season, some individuals become tangled and drown in the nets (factor #5). From mid-May to mid-August, adult females come ashore to nest on most South Carolina beaches. Sea walls and rip rap often deter or prevent nesting on many developed beaches (factor #1). The nests incubate about 60 days before the hatchlings emerge. Nests may be destroyed by erosion (factor #1), by raccoons, foxes, and ghost crabs (factor #2), or by humans (factors #3 and #4). If a nest successfully hatches, hatchlings may be killed by land predators (factor #2) or die from desiccation when disoriented away from the ocean by artifical lighting near beaches (factor #5). In the ocean, hatchlings are also the prey of sea birds and fishes (factor #2). It is not known where loggerhead turtles spend their early developmental years, or how long it takes them to reach the size of immatures which appear in South Carolina coastal waters. But once they have reached this size (greater than 40 cm carapace length), they are relatively safe from most natural marine predators. However, many immatures die and strand as a result of being caught incidental to commercial fishing activities (factor #5).

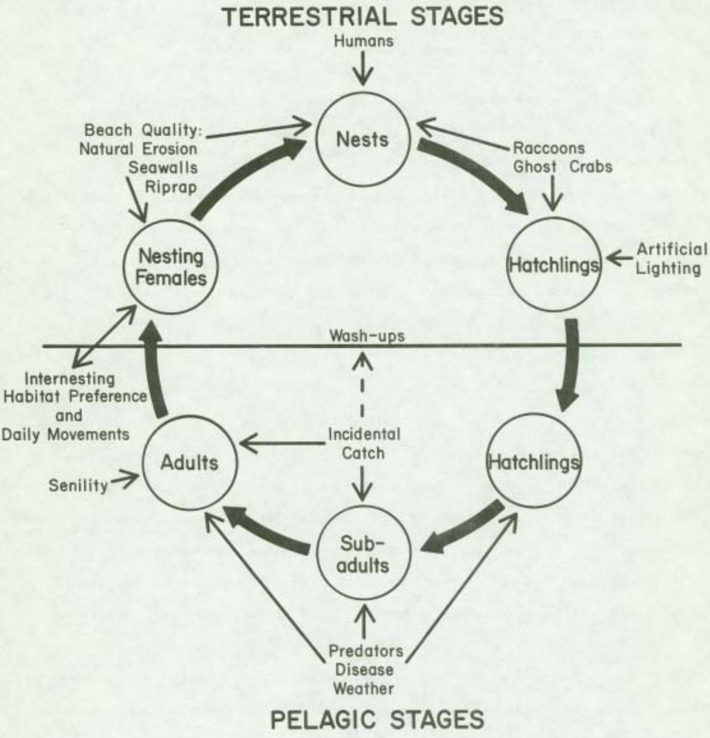

Figure 1. The life cycle of the loggerhead turtle showing factors affecting the various stages in South Carolina.

Adult mortality also occurs from these same sources.

A logical approach in mitigating these impacts is to: 1) quantify the type and extent of the problem, 2) determine suitable management techniques, 3) apply these techniques based upon the needs of the population, and 4) evaluate the management techniques through monitoring. This 3-year study began the first steps in this process.

Job 1, Sonic and Radio Tracking of Nesting Caretta caretta documented daily movements, nesting and internesting habitat use. This baseline data would aid in evaluating such factors as beach quality, disturbances on nesting beaches and the interaction between turtles and commercial fisheries as they may affect the reproductive effort of the species. Job 2, Abiotic and Biotic Factors Affecting Nest Failure of Caretta caretta, quantified the major source of nest mortality and indicated where management techniques needed to be applied. Jobs 3 and 5, Feasibility of Raccoon Aversion Therapy on Caretta caretta Eggs, tested one possible management technique in order to determine its suitability for reducing turtle nest predation. These three investigations provide some of the data necessary for the establishment of an adequate management program for the loggerhead turtle in South Carolina.

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PROJECT TITLE: ENDANGERED SPECIES

State: South Carolina

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SONIC AND RADIO TRACKING OF NESTING *CARETTA CARETTA*

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and

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Job Duration: October 1976 to September 1979

ABSTRACT

This study represents the telemetric monitoring of 37 adult female loggerhead turtles during the 1977-79 nesting seasons. Information on activity, movements, and habitat utilization is presented. The results represent some of the first at-sea information available for loggerhead turtles. At-sea activity associated with terrestrial emergences is characterized as well as activity patterns and types of movements made during within-season internesting periods. Telemetric techniques of tagging and monitoring were evaluated.

INTRODUCTION

The difficulties in studying a pelagic species have focused research of marine turtles on the readily accessible terrestrial activities (Harrisson, 1956; Carr and Caldwell, 1956; Carr and Giovannoli, 1957; Caldwell et al. 1956, 1959a, 1959b; Baldwin and Lofton, 1959; Caldwell, 1962; Hughes and Mentis, 1967; Lebuff and Beatty, 1971; Bell and Richardson, 1976). These activities represent only a limited portion of the total life cycle of the species. In an effort to expand knowledge beyond the nesting beach, various methods of tagging have been used.

Long term flipper tagging studies have provided much of our current knowledge about the species. But flipper tagging is dependent upon recapture of the animal and then return of the information to the tagger, sometimes with considerable time lag. High tag losses noted by many researchers often do not justify the cost expenditure of the project for the information gained.

The use of telemetry equipment as a tag should be cost justified as compared to other methods of tagging. The expected result is generally intensive information on a few individuals as compared to low frequency returns on many individuals by conventional tagging. In addition, by extending the range and area of observation, telemetric monitoring should result in minimal disturbance to the free ranging animal.

Remote sensing is a technique "to extend the range of man's observations" (Craighead and Craighead, 1965). Since tagging studies have provided limited data on non-terrestrial activities, various remote sensing techniques have been employed, such as florescent dyes (Witham et al., 1973) ballon trailers (Carr, 1962) and satellite tracking (Stoneburner, 1979), with limited success.

The success of telemetric monitoring depends on the suitability of the equipment and the resourcefulness and perserverance of the researcher. Recent developments in reliable, long range electronic tracking equipment have now made such techniques possible. This study was designed to utilize remote sensing techniques, to quantify habitat use and ultimately solve resource management problems.

METHODS AND MATERIALS

This study was conducted in three stages during three different nesting seasons. A feasibility study was conducted in 1977 when one loggerhead turtle was equipped with a sonic transmitter. This turtle was monitored to determine whether commercially available sonic telemetry equipment could be used to locate and monitor marine turtle activities in South Carolina waters.

In 1978 seven loggerhead turtles were equipped with sonic transmitters. Four of these turtles were also equipped with radio transmitters. This stage of the study was designed to gain information on the movements of individuals turtles. It also explored the use of radio telemetry to monitor terrestrial emergences.

The final stage of the study, conducted in 1979, was designed to increase the number of turtles monitored and to evaluate habitat use in addition to individual movements. Twenty-nine turtles were instrumented with both sonic and radio transmitters and monitoring of both terrestrial and pelagic activities was conducted. The increased number of individuals monitored extended the information base from individual to population level.

Study Area

The study area is defined as the area which was telemetrically monitored. This area extended from North Inlet, South Carolina to Raccoon Key, South Carolina. This is approximately 67 km straight line distance along the coast and included North, Sand, South, Cedar, Murphy, and Cape Islands as well as Raccoon Key. The oceanic area monitored included this length of coast and extended up to 67 km seaward, thus just under 4,500 km^2 were within the area monitored (Fig. 2).

The barrier islands within the study area are undeveloped or have only limited development. The near shore waters are generally shallow (< 10m) and often this topography resulted in shoals and sand bars near the nesting beaches. The outer limit of the study area was approximately at the Gulf Stream currents.

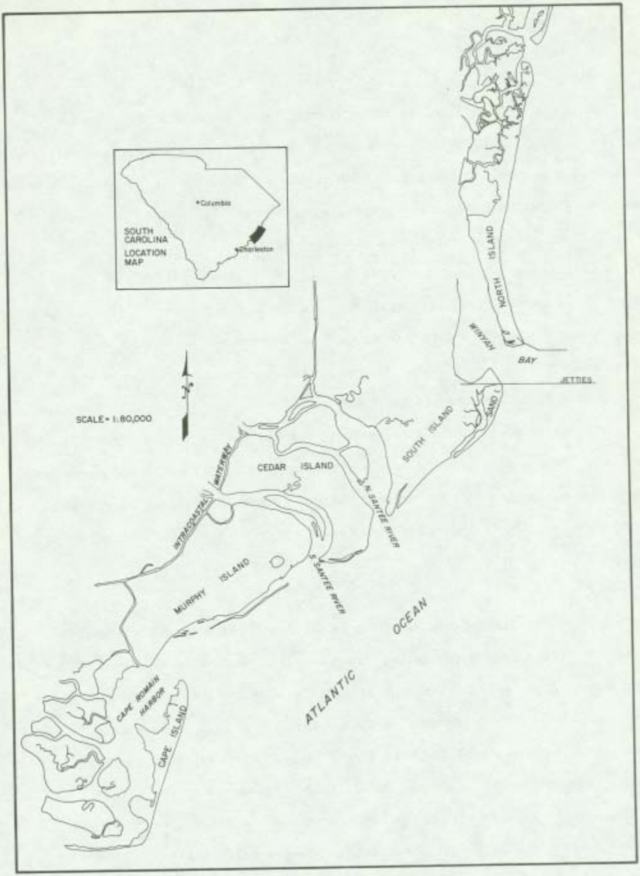


Figure 2. Map of the area of coastal South Carolina used during telemetric monitoring of loggerhead turtles

The intensity of telemetric monitoring within the study area varied considerably. South Island was the principal site where turtles were intercepted on the beach and equipped with radio and sonic transmitters and the radio base station was located there. This radio base was effective in monitoring terrestrial emergences on Sand, South, and Cedar Islands. Physical confirmation of radio monitored terrestrial emergences of instrumented turtles was conducted on South and Sand Islands. The south end of North Island and Cedar Island were radio monitored from the base but were not accessible for interception and confirmation.

The primary sonic telemetry monitoring area was the near shore waters (< 5km from shore) off of Sand and South Islands. The secondary area was from Winyah Bay to Cape Romain Shoals and less than 8 km from shore. The remaining portion of the study area was monitored periodically and primarily at night or during continuous tracking of individual turtles.

Radio Tracking

One Falcon Five Model receiver and two TRX-24 radio receivers (Wildlife Materials, Inc.) were used to monitor terrestrial emergences. In 1978 a monitoring station was maintained on top of a 14 m observation tower on South Island. This tower was 3 km inland and 6 km by road from the front beach. The eight-element yagi antenna used to monitor the beach was rotated by hand during radio checks made at 15 minute intervals and was operated from dusk to dawn.

A radio base station was maintained for monitoring in 1979. This station consisted of a travel trailer set up behind the primary dunes of the South Island beach. Three antennas were mounted 15 m above the ground on wooden poles. These five-element yagi directional antennas were stationary mounted at 90 degree angles from each other. Thus one antenna was directed up the coastline, one toward the open ocean, and one down the coast. Each antenna had a separate coaxial cable which led to a switching box in the base station. This switching box allowed research personnel to monitor all antennas simultaneously or any antenna individually. Monitoring of antennas simultaneously eliminated the need for rotating a single antenna and greatly reduced the time required to conduct a frequency check. Monitoring individual antennas allowed the general direction of the signal source to be determined. Transmitters placed at the north and south ends of South Island were used to test receiving equipment and as standards of signal strength.

The radio base station was operated from dusk to dawn each night from 30 May to 16 August 1979. Base operations included one person (monitor) to operate the receiver and another person (recovery) to intercept an instrumented turtle on the beach. All frequencies were checked at 15 minute intervals throughout the night. Individual turtles were easily identified by the tuned frequency of the signal received. The time and duration of signal contact were recorded. Individual data cards were maintained on each instrumented turtle as well as daily records and summaries of base operations. When a signal was received by the monitoring base, the recovery personnel would confirm the direction, strength, and frequency of the signal using a three-element hand held antenna and receiver. The person assigned to recovery would then move to the instrumented turtle on foot or on a Honda ATC-90 motorcycle. Recovery on Sand Island required transporting the receiving equipment and motorcycle across a tidal creek in an aluminum pram. Once located, using the radio signal and tracks in the sand, the instrumented turtle was not disturbed for identification until just before re-entering the ocean. The condition of the turtle and equipment was checked, and the fate (nesting or non-nesting) and location of the emergence were recorded. The hand-held receiver was also used by recovery personnel to confirm radio signals on North Island and Cedar Island from the north end of Sand Island and the south end of South Island respectively.

Sonic Tracking

Two Smith-Root model TA-25 sonic receivers were used with SR-70-H hydrophones. In 1979 a MT-74 transformer was added to better tune the receivers and thus increase the range of transmitters. A variety of boats was employed during sonic telemetry checks. This was necessitated by varying conditions such as sea state, distance from shore, water depth, length of tracking interval, and mobility required, as well as factors of safety, availibility, and cost. The types of boats used included: a 73-foot St. Augustine Fishing Trawler, a 22-foot Stamas cabin boat with a 120 hp inboard engine, a 17-foot Boston Whaler with a 115 hp outboard engine, and a 14-foot Zodiac inflatable boat with a 10 hp motor.

Locations depicted in Figures 6 through 12 inclusive are based on Loran coordinates or vessel location when in the immediate vicinity of an instrumented turtle. Although numerous additional locations were obtained, the plotted locations represent the most precise locations. Continuous monitoring of instrumented turtles at close quarters was not generally conducted because of the possible influence of such activities on turtle movements and behavior.

Instrumentation

Adult sized loggerhead turtles were intercepted on the return leg of a terrestrial emergence. Turtles were turned on their carapace while radio and sonic transmitters were attached. In 1977 the only turtle which was monitored was instrumented on 12 July. In 1978 turtles were instrumented between 8 June and 9 July. The instrumentation of 29 study animals in 1979 occurred between 30 May and 12 June.

Radio transmitters were of the big game type supplied by Wildlife Materials, Inc. (Model MLP 21100 MD). These transmitters had an eighteen inch stainless steel whip antenna and were hermetically sealed. These lithium battery powered transmitters weighed 300 g. Radio transmitters were attached by a 1.1 cm (7/16") plastic coated stainless steel cable which was laced through holes drilled through the right posterior marginal scutes of the carapace using a portable electric drill. The cable was laced from the ventral surface of the carapace, through the marginal scutes and the transmitter base and then snugly clamped on the dorsal side of the transmitters (Fig. 3). The dorsal placement of the transmitter and clamp eliminated contact between the rear flippers and the instruments.

Figure 3. Instrumentation of a loggerhead turtle with a radio transmitter showing the mounting on the dorsal side of the posterior marginal scutes.

The receiving range of radio transmitters was generally 3 km with a hand-held antenna and a minimum range of 4 km using the radio base station antennas. All checks of range were made with the transmitter placed directly on the beach to simulate the transmitter elevation of an instrumented turtle. The resulting monitoring range of the base station was 8 km of coast and is considered a conservative estimate of effective range.

Sonic transmitters used in 1977 and 1978 were locally constructed. These transmitters were approximately 10 cm x 15 cm x 15 cm and weighed 2.0 kg. Transmitters were attached by clamping the cable which was encased in the transmitter through two holes drilled in the posterior left marginals.

In 1979 the sonic transmitters were specially constructed for use on marine turtles by Smith-Root, Inc. These transmitters were cylinders 33 cm long and 5 cm in diameter and weighed 0.8 kg. The plastic coated stainless steel attachment cable was affixed to the transmitter by two hose clamps. This cable was then used to attach the transmitter to the posterior left marginals of the carapace (Fig. 4).

The range of sonic transmitters was variable. Range was particularily influenced by water turbulence and turbity. Transmitter ranges were tested in Winyah Bay which represented both turbulent and turbid conditions. The effective minimum range was determined to be 1.5 km. Maximum range was attained in the clear waters offshore and approached 2.5 km. Using the effective minimum range, an area of

Figure 4. Instrumentation of a loggerhead turtle with a sonic transmitter showing the adjustable hose clamp and cable used for mounting on the dorsal surface of the posterior marginals.

7.1 km^2 could be monitored at each sonic checkpoint. Interference from prop turbulence, electronic equipment used on boats, porpoise vocalizations, and pistol shrimp (Alpheus sp.) proved to be a frequent nuisance to operation of the hydrophone and sonic receiver. Identification of individual turtles was often difficult because of similar frequency and pulse rates of sonic transmitters.

In 1979, a telemetry research team of 10 individuals was employed full time. Because of the complexity of the study and the need for each person to be involved in all phases of data collection, data forms were adopted to insure uniformity and completeness.

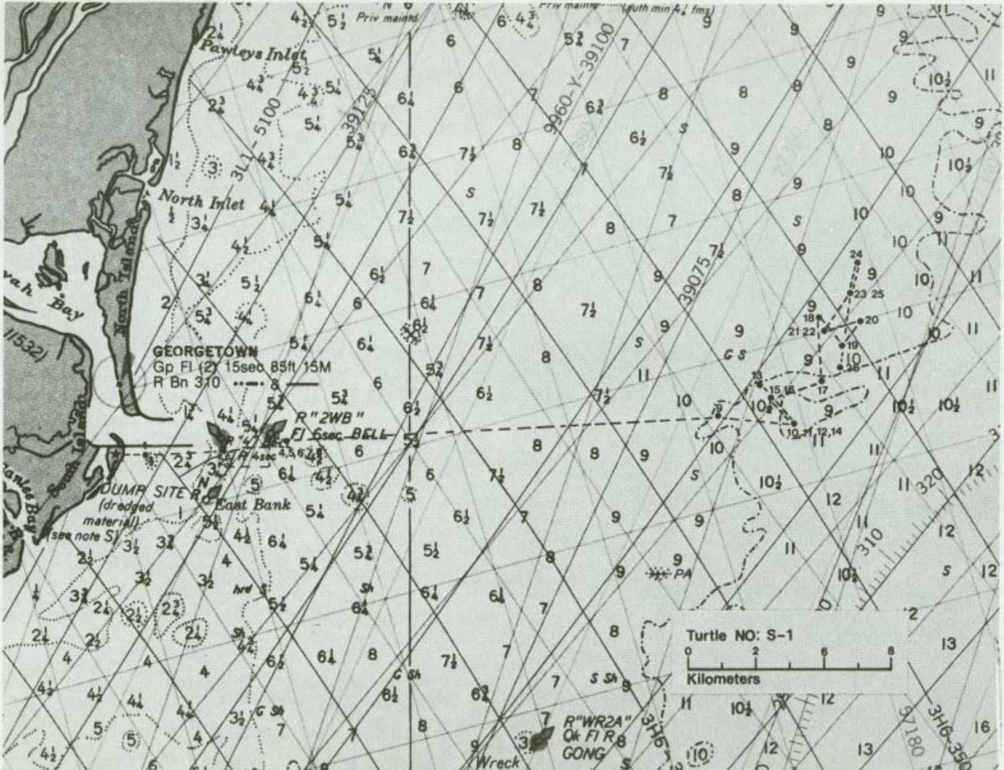
A tagging data card was used to supply information on individual turtles (Fig. 5). Each sonic and radio contact of a turtle was recorded on the back of the individual turtle data card. The operation of sonic receivers was detailed in a standard operating procedure and required the use of two additional forms. The sonic search form catalogued data during sonic receiver use until contact was made with a sonic transmitter. A positive contact resulted in the use of a sonic telemetry hourly form. The sonic operating procedure and data forms are in Appendix 1.

RESULTS

The sonic telemetry feasibility study conducted in 1977 involved 66.5 hours of continuous monitoring of a 109 cm (curved carapace length) adult female loggerhead turtle (S-1). This turtle was instrumented after nesting on the night of 12 July at 2300 hrs. Turtle S-1 moved 8.3 km from the nesting beach after instrumentation and remained stationary until sunrise on the morning of 13 July (Fig. 6). On 13 July, S-1 sustained a movement at a constant heading for 11 hours. This movement averaged 2.35 km/hr and covered a distance of 25.8 km. Thus S-1 was 34 km from the nesting beach the night after nesting. Following this movement away from the nesting beach S-1 established an area of concentrated activity around an offshore live bottom reef. Movement was within 8 km of the

Event	Date (da-mo-yr)	Time (Hrs)	Location (Loran C coor)
*Int Nest Emer	12-VII-77	2230	Sand Island
Sonic Loc 1	13-VII-77	0030	15486-71558
Sonic Loc 2	13-VII-77	0100	15502-71580
Sonic Loc 3	13-VII-77	0220	15502-71580
Sonic Loc 4	13-VII-77	0330	15512-71595
Sonic Loc 5	13-VII-77	0400	15512-71595
Sonic Loc 6	13-VII-77	0500	15512-71595
Sonic Loc 7	13-VII-77	0530	15512-71595
Sonic Loc 8	13-VII-77	0600	15512-71595
Lost Contact - Vessel Failure			
Sonic Loc 9	13-VII-77	1130	15600-71720
Sonic Loc 10	13-VII-77	1730	15610-71740
Sonic Loc 11	13-VII-77	1830	15610-71740
Sonic Loc 12	13-VII-77	2100	15610-71740
Sonic Loc 13	14-VII-77	0900	15614-71737
Sonic Loc 14	14-VII-77	0940	15610-71740
Sonic Loc 15	14-VII-77	1020	15614-71734
Sonic Loc 16	14-VII-77	1100	15614-71736
Sonic Loc 17	14-VII-77	1245	15615-71747
Lost Contact			
Sonic Loc 18	14-VII-77	1800	15649-71747
Sonic Loc 19	14-VII-77	2000	15647-71755
Sonic Loc 20	14-VII-77	2030	15651-71757
Sonic Loc 21	14-VII-77	2245	15643-71752
Sonic Loc 22	14-VII-77	0800	15643-71752
Sonic Loc 23	14-VII-77	0830	15656-71753
Sonic Loc 24	14-VII-77	0930	15661-71755
Sonic Loc 25	14-VII-77	1030	15656-71753
Sonic Loc 26	14-VII-77	1145	15648-71754

Figure 6. Map depicting telemetric locations of turtle S-1 in 1977.



Pawleys Inlet
North Inlet
North Island
South Island
GEORGETOWN
Gp Fl (2) 15sec 85ft 15M
R Bn 310
R "2WB"
Fl 6sec BELL
DUMP SITE
(dredged
material)
(see note S)
East Bank
Priv maintd
3L1-5100
39125
9960-Y-39100
39075
R "WR2A"
Qk Fl R
GONG
Wreck
PA
310
320
Turtle NO: S-1
Kilometers

reef during the remaining tracking interval. Monitoring was discontinued because of an electronic failure in the receiver. Turtle S-1 was found to have a diurnal activity pattern and nocturnal movements were associated with terrestrial emergences only. This turtle sustained directional movements and was capable of maintaining a consistent heading in the open ocean (Fig. 6).

Telemetric monitoring of a single loggerhead turtle in 1977 was conducted in order to gain information on equipment requirements and the feasibility of sonic monitoring of marine turtles based on turtle activity and movement patterns. Two elements were found to be essential for this type of study. First, a larger more seaworthy boat was necessary for comfort and safety on sustained tracking cruises. Second, Loran C and radar equipment was necessary to accurately locate and plot the movements of instrumented turtles.

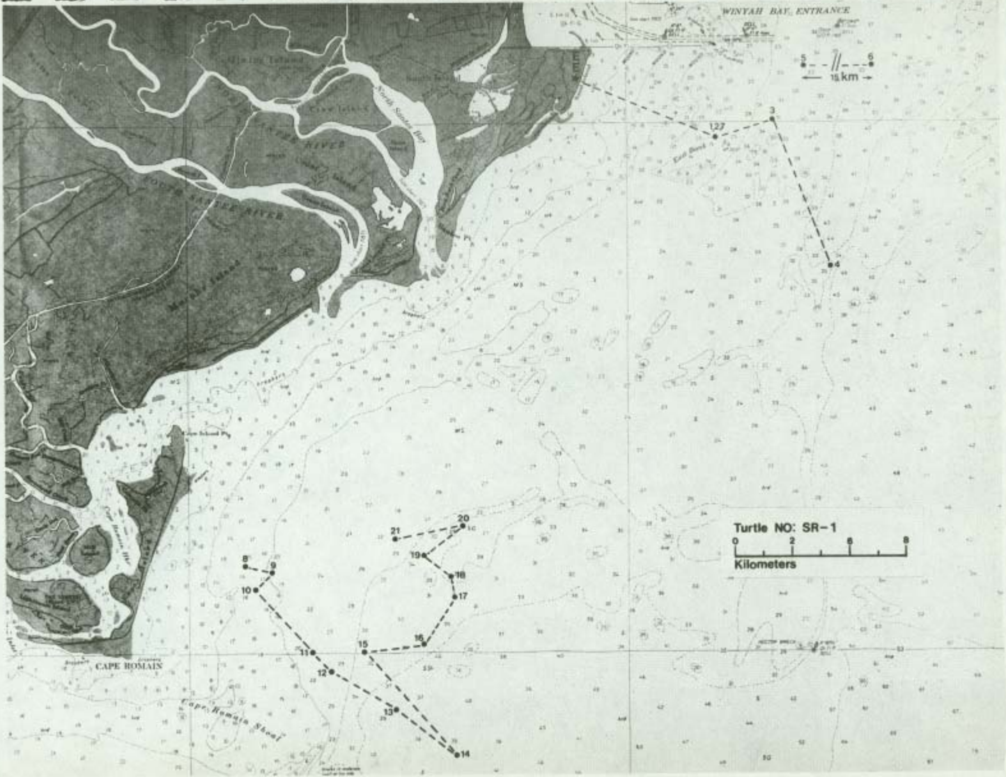
In 1978, telemetric monitoring was conducted on seven adult female loggerhead turtles. Their curved carapace length ranged from 94-107 cm. The first four turtles instrumented (SR-1, SR-2, SR-3, SR-4) received both sonic and radio transmitters while the last three were equipped with sonic transmitters only (S-2, S-3, S-4). Sonic contact was maintained during 206.5 hours and resulted in 826 telemetric locations. There were also six terrestrial emergences monitored by radio telemetry.

Turtle SR-1 was instrumented on Sand Island following nesting at 0300 hrs on 8 June. Sonic telemetric monitoring was initiated two hours after release and immediate contact was made with SR-1. This turtle was located 5 km east of the nesting beach at the East Bank Shoal Buoy (Fig. 7). SR-1 had moved to this position in less than two hours and remained at the edge of this shoal until 0700 hrs when movement to the southeast was initiated. Movement was southeasterly along the general configuration of the depth contours until 1325 hrs when signal was lost in heavy seas. Contact was lost 11 kms southeast of the nesting beach.

Sonic contact was regained 13 days later (22 June) five km east of the north end of Sand Island at 1100 hrs. Contact was terminated 2.5 hrs later due

Event	Date (da-mo-yr)	Time (hrs)	Location (Loran C coor)
*Int Nest Emer	8-VI-78	0300	Sand Island
Sonic Loc 1	8-VI-78	0500	15480-71575
Sonic Loc 2	8-VI-78	0700	15480-71575
Sonic Loc 3	8-VI-78	0900	15490-71585
Sonic Loc 4	8-VI-78	1415	15467-71595
Lost Contact			
Sonic Loc 5	22-VI-78	1115	15505-71590
Sonic Loc 6	22-VI-78	1330	15544-71659
Discontinued Monitoring			
E Non Nest Emer	23-VI-78	2150	Sand Island
E Non Nest Emer	23-VI-78	2350	Sand Island
Sonic Loc 7	24-VI-78	0955	15480-71575
Discontinued Monitoring			
Sonic Loc 8	27-VI-78	1930	15349-71502
Sonic Loc 9	27-VI-78	2000	15350-71504
Sonic Loc 10	27-VI-78	2045	15346-71501
Continued Monitoring from Anchorage			
Sonic Loc 11	28-VI-78	0730	15339-71511
Sonic Loc 12	28-VI-78	0830	15337-71514
Sonic Loc 13	28-VI-78	1015	15338-71527
Sonic Loc 14	28-VI-78	1300	15334-71537
Sonic Loc 15	28-VI-78	1600	15345-71522
Sonic Loc 16	28-VI-78	1700	15352-71531
Sonic Loc 17	28-VI-78	1900	15365-71535
Sonic Loc 18	28-VI-78	2000	15369-71535
Sonic Loc 19	28-VI-78	2100	15370-71531
Continued Monitoring from Anchorage			
Sonic Loc 20	29-VI-78	0900	15378-71537
Sonic Loc 21	29-VI-78	1130	15370-71525

Figure 7. Map depicting telemetric locations of turtle SR-1 in 1978.


WINYAH BAY ENTRANCE
5
6
15 km
3
127
4
NORTH SANTEE RIVER
North Santee Bay
SOUTH SANTEE RIVER
CAPE ROMAIN
Cape Romain Shoal
Turtle NO: SR-1
0
2
4
6
8
Kilometers
8
9
10
11
12
13
14
15
16
17
18
19
20
21

to factors of boating safety with the final location 15 km east of the nesting beach. No terrestrial emergence was monitored by radio that night; however, on the following night (23 June), radio contact was made at 2150 hrs and again at 2350 hrs. These radio contacts documented terrestrial activity but the fate of these emergences (nesting or non-nesting) could not be confirmed because high tides prevented access. SR-1 was subsequently located the following morning off the East Bank Nun Buoy at 0955 hrs. Monitoring was discontinued in order to check on the location of turtle SR-4. A search for SR-1 was made at the East Bank Shoal Buoy again at 1500 hrs the same day (24 June) without success, and SR-1 was not located near the nesting beach on 25 or 26 June.

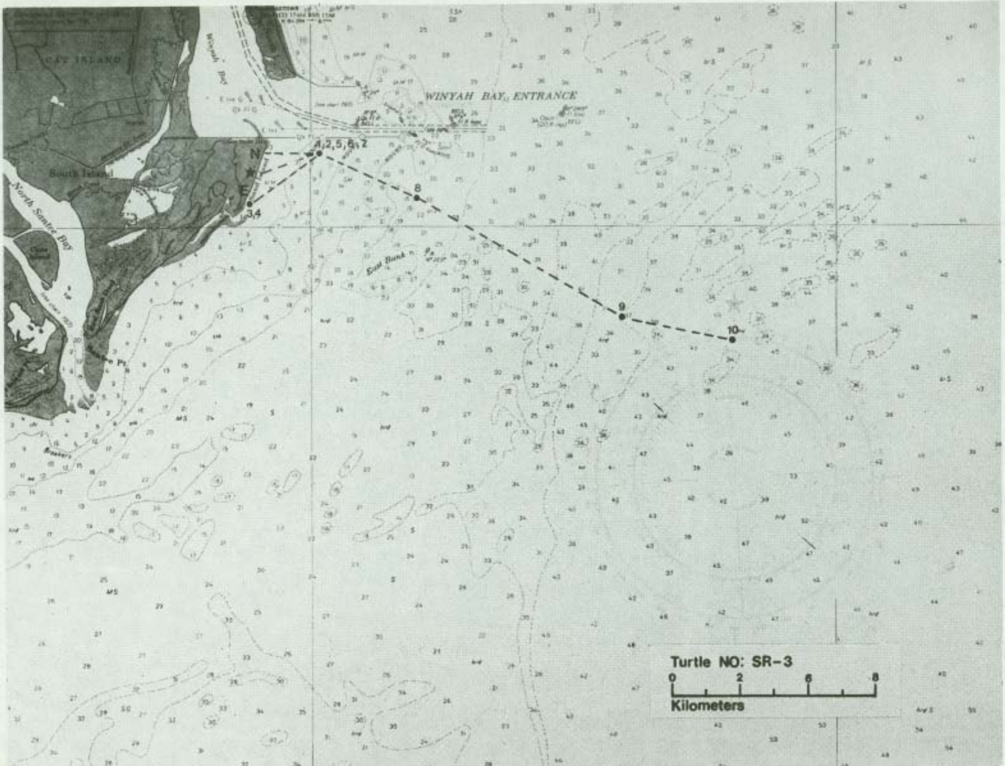
Sonic contact was reestablished at 1900 hrs on 27 June at Cape Romain Shoals incidental to monitoring S-2. Turtle SR-1 was located 3 km east of Cape Island and remained in this area until 0600 hrs on 28 June. At this time SR-1 initiated an easterly movement and by 1300 hrs had moved 9 km on a heading of 130^{o}. After this, rather erratic movements resulted in an 8 km displacement to the north by nightfall on 28 June. Movements were limited to this area until 1130 hrs on 29 June at which time contact was discontinued.

Turtle SR-2 was instrumented with a sonic and radio transmitter after nesting during the night of 8 June. SR-2 was released at 0400 hrs. This was one hour after the release of SR-1. No sonic contact was made with this turtle despite repeated checks. On 24 June, radio signals were received during a non-nesting emergence on the north end of Sand Island. This was the only location known for this turtle after release. Sonic monitoring was conducted in the waters in front of Sand Island the morning after radio location of SR-2 but no signal was received.

Turtle SR-3 was instrumented with sonic and radio transmitters on Sand Island the night of 17 June. Radio contact was lost at 0200 hrs when SR-3 entered the ocean, but no sonic signal was recorded until 12 days after release (29 June) when SR-3 was located less than 1 km from the north end of Sand Island (Fig. 8). This sonic location of SR-3 was just outside of the surf in water

Event	Date (da-mo-yr)	Time (hrs)	Location (Loran C coor)
*Int Nest Emer	17-VI-78	0200	Sand Island
Sonic Loc 1	29-VI-78	1306	15485-71558
Sonic Loc 2	29-VI-78	1600	15485-71558
Sonic Loc 3	29-VI-78	2030	15474-71551
E Non Nest Emer	29-VI-78	2335	Sand Island
Sonic Loc 4	30-VI-78	0530	15474-71551
Sonic Loc 5	30-VI-78	0630	15485-71558
Sonic Loc 6	30-VI-78	1245	15485-71558
	Discontinued Monitoring		
Sonic Loc 7	30-VI-78	1850	15485-71558
N Nest Emer	30-VI-78	2130	Sand Island
Sonic Loc 8	1-VII-78	0135	15488-71575
Sonic Loc 9	1-VII-78	0615	15487-71604
Sonic Loc 10	1-VII-78	0800	15495-71621

Figure 8. Map depicting telemetric locations of turtle SR-3 in 1978.


CAT ISLAND
Winyah Bay
WINYAH BAY ENTRANCE
South Island
North Santee Bay
East Bank
N
E
4,2,5,6,7
3,4
8
9
10
Turtle NO: SR-3
0
2
6
8
Kilometers

approximately 1 m deep. SR-3 remained at this location from 1300 hrs (initial contact) until 2130 hrs when the turtle moved into the surf zone at Sand Island. Signal was disrupted here because of high water turbulence and by turbidity. Radio contact was established at 2222 hrs when the turtle began a non-nesting emergence which lasted until 0105 hrs. The long duration of this emergence resulted from a movement over a washover terrace to the marsh on the landward side of the island. Although apparently disoriented, SR-3 ultimately returned to the front beach and the ocean.

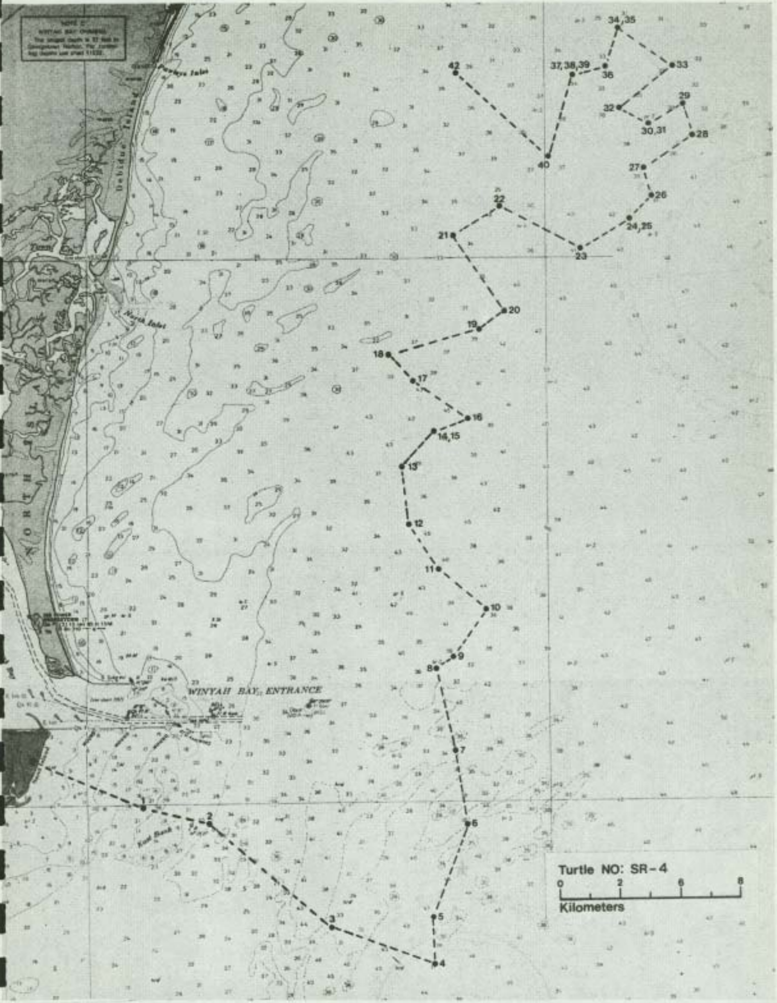
Sonic signal was not regained until 4 hours and 25 minutes after SR-3 entered the ocean. When sonic signal was established, the turtle was 1 km offshore near the location of the previous day. SR-3 remained at this location the entire day. That night (30 June), a nesting emergence was radio monitored and visually confirmed from 2115 hrs until 2315 hrs. Sonic contact was regained at 2345 hrs. SR-3 moved from the nesting beach to the northern edge of East Bank Shoals by 0135 hrs. By 0615 hrs, SR-3 was 11 km southeast of the nest site. At 0830 hrs this turtle was 15 km from Sand Island where contact was terminated and no further contact was made with this turtle.

Turtle SR-4 was equipped with sonic and radio transmitters on the night of 17 June and released at 0200 hrs. Initial sonic contact was made at 0320 hrs and SR-4 reached the East Bank Shoals at 0500 hrs (Fig. 9). This 120° heading from the nesting beach was maintained until 1025 hrs, resulting in a 15 km movement over a period of 8.5 hrs (1.8 km/hr). From 1025 hrs until dark (2100 hrs) a bearing almost due north was maintained. The turtle, while on this northerly heading, covered 12 km in 10.5 hrs (1.1 km/hr). The change in the bearing by SR-4 at 1025 hrs was a clear and precise shift in direction.

After nightfall on 17 June, monitoring of sonic signal was continued while at anchor. The only movement monitored was a 1 km movement toward land and then back again. This unusual event occurred between 0240 hrs and 0400 hrs and was preceeded and followed by no movement for the remainder of the night.

Event	Date (da-mo-yr)	Time (hrs)	Location (Loran C coor)
*Int Nest Emer	17-VI-78	0200	Sand Island
Sonic Loc 1	17-VI-78	0320	15484-71569
Sonic Loc 2	17-VI-78	0500	15483-71580
Sonic Loc 3	17-VI-78	0800	15476-71600
Sonic Loc 4	17-VI-78	1025	15478-71616
Sonic Loc 5	17-VI-78	1210	15489-71617
Sonic Loc 6	17-VI-78	1400	15508-71622
Sonic Loc 7	17-VI-78	1500	15522-71620
Sonic Loc 8	17-VI-78	1730	15536-71616
Sonic Loc 9	17-VI-78	1905	15538-71618
Sonic Loc 10	17-VI-78	2105	15549-71621
Sonic Loc 11	17-VI-78	2330	15550-71616
Sonic Loc 12	18-VI-78	0200	15560-71612
Sonic Loc 13	18-VI-78	0400	15571-71612
Sonic Loc 14	18-VI-78	0715	15580-71619
Sonic Loc 15	18-VI-78	0900	15580-71619
Sonic Loc 16	18-VI-78	1115	15583-71623
Sonic Loc 17	18-VI-78	1400	15586-71618
Sonic Loc 18	18-VI-78	1630	15597-71614
Sonic Loc 19	18-VI-78	1815	15614-71631
Sonic Loc 20	18-VI-78	2000	15618-71627
	Discontinued Monitoring		
Sonic Loc 21	19-VI-78	0630	15635-71623
Sonic Loc 22	19-VI-78	0800	15645-71629
Sonic Loc 23	19-VI-78	1000	15644-71642
Sonic Loc 24	19-VI-78	1240	15651-71651
Sonic Loc 25	19-VI-78	1400	15651-71651
Sonic Loc 26	19-VI-78	1500	15660-71657
Sonic Loc 27	19-VI-78	1600	15666-71654
Sonic Loc 28	19-VI-78	1730	15673-71661
Sonic Loc 29	19-VI-78	1800	15677-71660
Sonic Loc 30	19-VI-78	1900	15674-71659
Sonic Loc 31	19-VI-78	2000	15674-71659
Sonic Loc 32	19-VI-78	2100	15675-71658
Sonic Loc 33	19-VI-78	2200	15682-71660
Sonic Loc 34	20-VI-78	0000	15665-71648
Sonic Loc 35	20-VI-78	0100	15665-71648
Sonic Loc 36	20-VI-78	0200	15665-71646
Sonic Loc 37	20-VI-78	0900	15666-71643
Sonic Loc 38	20-VI-78	1100	15666-71643
Sonic Loc 39	20-VI-78	1200	15666-71643
Sonic Loc 40	20-VI-78	1215	15655-71640
Sonic Loc 41	20-VI-78	1745	15655-71640
Sonic Loc 42	20-VI-78	2000	15658-71623

Figure 9. Map depicting telemetric locations of turtle SR-4 in 1978.


WINYAH BAY ENTRANCE
North Inlet
NORTH ISLAND
Debidue Island
Turtle NO: SR-4
0 2 6 8
Kilometers

Activity was again initiated at 0450 hrs of 18 June. A slow meandering movement during daylight hours on 18 June resulted in an 8 km displacement to the NNE by nightfall. Monitoring was discontinued at 2100 hrs. A marker buoy was placed at this location when a search for other instrumented turtles was begun. Contact with SR-4 was reestablished at 0600 hrs the following morning (19 June) just north of the marker buoy. The slow, meandering northerly drift of the turtle continued all day. A visual sighting of SR-4 was made at 2100 hrs and these erratic movements continued until 0200 hrs on 20 June. A marker buoy was dropped and contact discontinued to search for other sonic signals. Contact was reestablished seven hrs later (0900 hrs) at the marker buoy location. No significant movement was monitored during the morning and at 1215 hrs a marker buoy was again dropped and a search of other areas initiated. SR-4 was at the same location when the boat returned to the marker buoy at 1745 hrs that evening. This sonic monitoring cruise was terminated at 2000 hrs on 20 June after a marker buoy was placed at the last location.

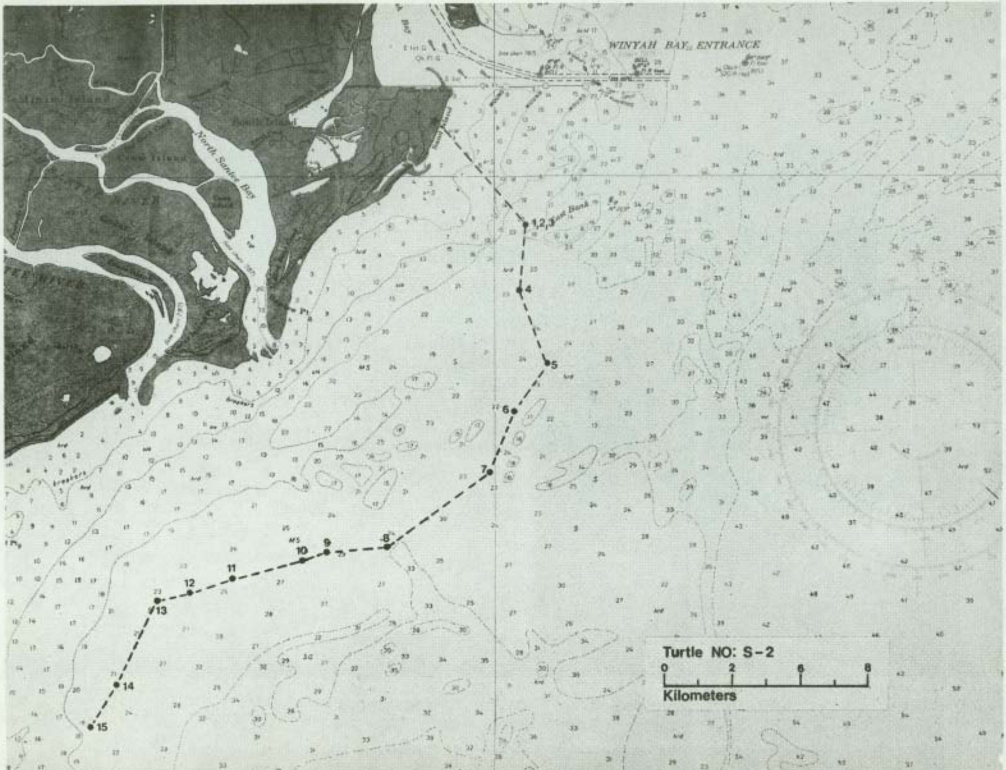
On 24 June and again on 29 June, extensive monitoring was conducted in the area of the buoy from small boats without gaining contact. Thus the last location of SR-4 was at 2000 hrs on 20 June.

Turtle S-2 was instrumented with a sonic transmitter after nesting on Sand Island the night of 26 June. This 94 cm (curved carapace length) turtle was first located at the SW edge of the East Bank Shoals at 0315 hrs on 27 June (Fig. 10). A southerly movement was initiated at first light (0500 hrs) and by 0900 hrs S-2 was 8 km south of the East Bank Shoal. Monitoring became more difficult as the day progressed because of strong SE winds, rough seas, and the limited range of this particular transmitter. A great deal of effort was required to maintain contact with this turtle because the research boat was rapidly blown away from the instrumented turtle. S-2 was, however, monitored from the East Bank Shoals to the Cape Romain Shoals over a period of 14 hours. At 1900 hrs signals were obtained from SR-1 and S-2 simultaneously. Monitoring of SR-2 was discontinued

Event	Date (da-mo-yr)	Time (hrs)	Location (Loran C coor)
*Int Nest Emer	27-VI-78		Sand Island
Sonic Loc 1	27-VI-78	0315	15470-71566
Sonic Loc 2	27-VI-78	0400	15470-71566
Sonic Loc 3	27-VI-78	0500	15470-71566
Sonic Loc 4	27-VI-78	0600	15455-71566
Sonic Loc 5	27-VI-78	0700	15445-71567
Sonic Loc 6	27-VI-78	0745	15437-71565
Sonic Loc 7	27-VI-78	0900	15426-71562
Sonic Loc 8	27-VI-78	1150	15405-71548
Sonic Loc 9	27-VI-78	1330	15397-71538
Sonic Loc 10	27-VI-78	1430	15396-71535
Sonic Loc 11	27-VI-78	1530	15386-71526
Sonic Loc 12	27-VI-78	1600	15381-71524
Sonic Loc 13	27-VI-78	1700	15374-71517
Sonic Loc 14	27-VI-78	1830	15357-71510
Sonic Loc 15	27-VI-78	1900	15351-71508

Discontinued Monitoring

Figure 10. Map depicting telemetric locations of turtle S-2 in 1978.



WINYAH BAY ENTRANCE
North Santee Bay
South Island
Cedar Island
1,2,3
4
5
6
7
8
9
10
11
12
13
14
15
Turtle NO: S-2
0
2
6
8
Kilometers

at 2000 hrs in favor of S-1 because of the greater range of this transmitter. Thus contact with S-2 was terminated and no further contact was obtained.

Turtle S-3 was equipped with a sonic transmitter on the night of 9 July. This 94 cm (curved carapace length) turtle moved into the water at 2315 hrs after nesting on Sand Island. No telemetric contact was made with this turtle subsequent to release.

Turtle S-4 was equipped with a sonic transmitter after a non-nesting terrestrial emergence on Sand Island. This 97 cm (curved carapace length) turtle entered the ocean at 0015 hrs on 10 July (Fig. 11). Sonic contact was not made until 0345 hrs. From this time until 0430 hrs S-4 was moving from the beach to the East Bank Shoal. Turtle S-4 was stationary from 0430 hrs until 0630 hrs despite heavy shrimp trawling activity in the area. By 0700 hrs S-4 had moved just NE of East Bank and by 0800 hrs was just SE of the Winyah Bay south jetty. S-4 moved to the Winyah Bay ship channel in the morning and occupied an area just seaward of the ship channel entrance for the remainder of the day. A rapid movement to the west, up the ship channel, was initiated at 2000 hrs. The turtle's movements were restricted to the north side of the South Winyah Jetty until contact was lost at 2345 hrs (10 July). Monitoring directly in the channel was discontinued because of ship traffic. However, the Winyah Bay entrance was monitored for the remainder of the night. Extensive sonic searches were initiated at first light on the morning of 11 July but no further contact was made with S-4.

Radio Telemetry 1979

During 1979, a total of 143 terrestrial emergences were monitored (Table 1). Of these, 29 occurred during initial tagging, 113 were radio monitored, and one was a visual observation of an instrumented turtle nesting on Cape Island. Thirty-six of the 113 radio monitored emergences involved more than 60 minutes of continuous signal. These were judged to be nesting emergences based on the minimum time required for a loggerhead turtle to nest. This was further substantiated by visual confirmation of 19 of 36 nesting emergences. Monitoring

Event	Date (da-mo-yr)	Time (hrs)	Location (Loran C coor)
*Int Non Nest Emer	10-VII-78	0015	Sand Island
Sonic Loc 1	10-VII-78	0430	15480-71570
Sonic Loc 2	10-VII-78	0530	15480-71570
Sonic Loc 3	10-VII-78	0630	15480-71570
Sonic Loc 4	10-VII-78	0700	15484-71572
Sonic Loc 5	10-VII-78	0800	15497-71576
Sonic Loc 6	10-VII-78	0900	15499-71578
Sonic Loc 7	10-VII-78	1000	15499-71578
Sonic Loc 8	10-VII-78	1100	15504-71580
Sonic Loc 9	10-VII-78	1200	15504-71580
Sonic Loc 10	10-VII-78	1230	15505-71586
Sonic Loc 11	10-VII-78	1400	15508-71588
Sonic Loc 12	10-VII-78	1500	15508-71588
Sonic Loc 13	10-VII-78	1600	15508-71588
Sonic Loc 14	10-VII-78	1630	15509-71587
Sonic Loc 15	10-VII-78	1730	15509-71587
Sonic Loc 16	10-VII-78	1830	15509-71587
Sonic Loc 17	10-VII-78	1930	15509-71587
Sonic Loc 18	10-VII-78	2030	15509-71587
Sonic Loc 19	10-VII-78	2100	15500-71576
Sonic Loc 20	10-VII-78	2300	15496-71570

Figure 11. Map depicting telemetric locations of turtle S-4 in 1978.

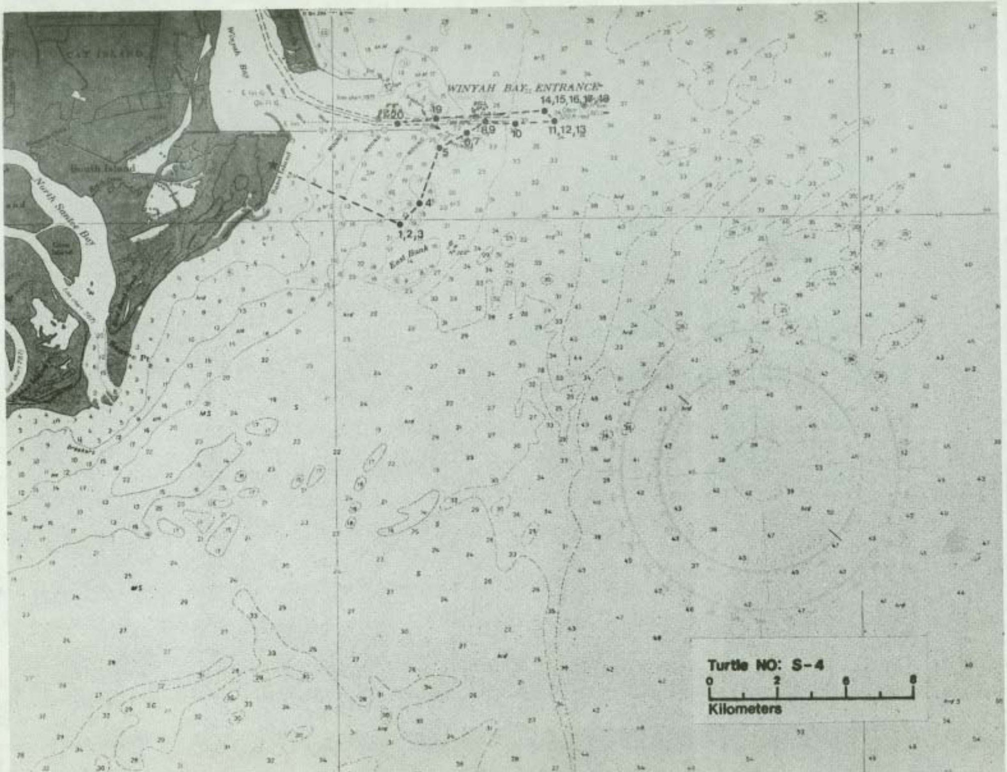

WINYAH BAY ENTRANCE
14,15,16,17,18
19
20
8,9
10
11,12,13
6,7
5
4
1,2,3
East Bank
North Santee Bay
South Island
CAT ISLAND
Winyah Bay
Turtle NO: S-4
0
2
6
8
Kilometers

Table 1. Radio monitored terrestrial emergences of loggerhead turtles in 1979.

1979

RADIO MONITORED
TERRESTRIAL EMERGENCES

	CEDAR ISLAND	SOUTH ISLAND	SAND ISLAND	UNKNOWN	INITIAL TAGGING
Nesting Emergences	5	8	20	1	13
Non-nesting Emergences	5	14	34	12	16
TOTAL	10	22	54	13	29

of emergences lasting from 5 to 59 minutes were considered to be non-nesting and there were 64 such emergences telemetrically monitored. There were an additional 15 short duration contact (< 5 min). These brief signals were generally intermittant and represented contact while the instrumented turtle was in the wash of breakers or in the near shore waters adjacent to the radio base station. These signals served only to document the presence of the instrumented turtle in the vicinity of the base, but they have no documented activity associated with them.

Based on terrestrial monitoring of the 29 instrumented loggerhead turtles it was found that an average of 1.69 nests were laid per female, and an average of 2.69 non-nesting emergences were made per female. Thus an average of 4.38 emergences were made by radio instrumented females for a ratio of 1 to 1.6 nesting to non-nesting emergences. Monitoring of Sand and South Islands for all terrestrial turtle activity (Job Number 2) in 1979 resulted in a 1 to 1.4 nesting to non-nesting ratio (N=831 emergences). Nesting activity of the 29 instrumented turtles represented 43 of 350 nests deposited on Sand or South Islands in 1979 or 12.29%. Non-nesting emergences by these turtles represented 12.68% of the total (61 of 481) for the season.

All 29 turtles were instrumented on the 3 kms of beach of South Island and 22% of the subsequent terrestrial activity was monitored on that island. Fifty-four percent of subsequent activity was monitored on the 3 km beach of Sand Island which is immediately to the north of the tagging beach. Cedar Island, which is the next island south of the tagging beach, received 10% of the monitored activity. In addition, one instrumented turtle was observed nesting on Cape Island which is 15 kms south of South Island.

Eight of the 29 turtles were not monitored during any terrestrial emergence after tagging. Five of these turtles were instrumented following a nesting emergence and three after a non-nesting emergence. Three of these eight turtles had confirmed soni locations. Two turtles were located near Cape Island and the other was adjacent to North Island.

Mortality of instrumented turtles was confirmed in two cases. Turtle #7902 was monitoréd during repeated, prolonged periods in early July. These contacts resulted from a radio transmitter which was aboard a trawler working nearby. The transmitter had been removed after the turtle was recovered dead from the trawler's nets. These instruments were later returned to research personnel. Turtle #7905 was found dead on Cedar Island on 17 July. This turtle was located after it had stranded on the side beach of the island. Radio location telemetry techniques were required to find the carcass which was hidden from view by marsh grass. Turtle #7904 was captured in a trawler's net on 2 July and released alive off of Murphy Island. The same observer reported recovering several pieces of sonic transmitter from the same area a week later. This sonic unit was unidentified. Rumors of additional captures of instrumented turtles were known but verification was not possible.

Sonic Telemetry 1979

Sonic telemetric monitoring was conducted between 7 June 1979 and 21 August 1979. The 72-foot R/V Atlantic Sun was used during four cruises for a total of 19 days. During these 19 days, search patterns were conducted or sonic contact was maintained 24 hrs a day. Additional sonic monitoring was conducted during 21 days from small boats. The waters within two miles of the nesting beaches of Sand and South Islands were monitored on 20 occasions, while the nearshore waters from Sand Island to Cape Island were monitored an additional 12 times.

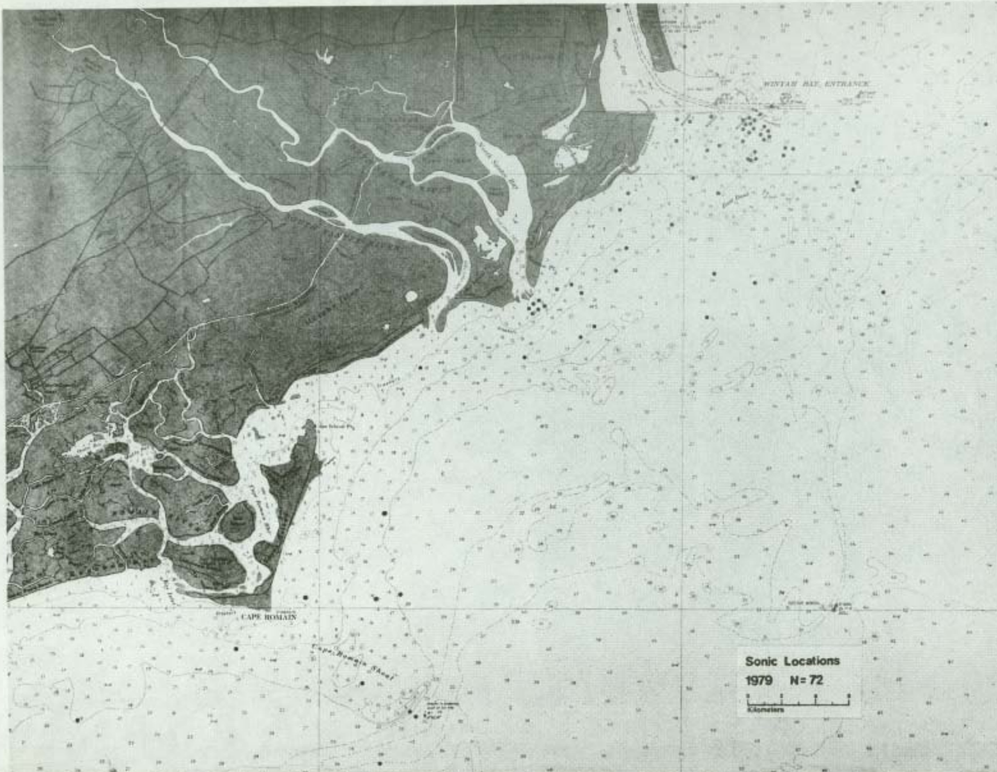
A total of 72 individual locations of instrumented turtles were documented (Fig. 12). This includes no more than two locations per day for any individual turtle and thus does not include the 15 minute locations taken during continuous tracking of individual turtles. The distribution of sonic locations for turtles showed a high use in areas of high relief topography. The area around the end of the south Winyah jetty received the greatest use by instrumented turtles. On one occasion, five of the 29 turtles were in the vicinity of the end of this jetty. The East Bank Shoals and the shoal waters off of the north end of Cedar Island also received high use. The Cape Romain Shoals had frequent use by turtles, considering the distance from the tagging beach. The movements of turtles were also found to parallel high relief contour lines, but no patterns were recognized for depth or bottom type during the nesting season.

Sonic locations were obtained on turtles the day prior to emergence on 10 occasions. Post-emergence sonic locations were obtained following eight non-nesting emergences and eight nesting emergences. These 26 locations involved 11 different turtles.

Sonic telemetric locations were determined for 22 of the 29 turtles at some time following instrumentation. Of the remaining seven turtles, five were never monitored by radio telemetry. The remaining two turtles returned to nest with transmitters intact but were not located at sea.

Turtles were regularly located more than 10 kms from the tagging beach. These locations were, however, within 10 kms of shore. While turtles moved considerable distances from the tagging beach these movements were along the coast and not directly out to sea.

Figure 12. Locations of loggerhead turtles at sea as determined by sonic telemetry during 1979.


WINYAH BAY ENTRANCE
CAPE ROMAIN
Cape Romain Shoal
Sonic Locations
1979 N=72
Kilometers

Finally, the frequency of sonic locations for turtles generally paralleled emergence activity. Thus as terrestrial activity diminished in August, so did the frequency of sonic contacts. By 15 August no sonic contact could be made with any instrumented turtle despite thorough checks from Winyah Bay to Cape Island within 10 kms of shore.

DISCUSSION

Tracking Feasibility

The telemetric monitoring of adult female loggerhead turtles during the nesting season in South Carolina was found to be possible using commercially available equipment. The use of radio transmitters to monitor terrestrial activities in conjunction with sonic telemetric monitoring was found to enhance the interpretation of sonic location data by relating marine activities to terrestrial emergences.

Monitoring of terrestrial activities also allowed inspections to be made of the transmitters and instrumented turtles throughout the season. Additionally, turtles were examined on Sand Island during other research activities to determine if any turtles were returning with defective radio transmitters. In no case was an instrumented turtle observed on the beach without concurrent monitoring from the base station. Thus, reliability of sonic and radio transmitters appeared to be very high as no failures were recorded.

The type and attachment of equipment was found to be satisfactory. Normal nesting activities were recorded for instrumented turtles including multiple nests with fertile eggs. No equipment loss or damage was observed for any individual during the study. Neither carapace damage nor enlargement of the holes used for transmitter attachment occurred during the study. There was no injury to the rear flippers or fleshy parts resulting from the method of attachment. There was also no evidence of attraction of predators to the sound or sight of instruments. Transmitters were undamaged by the activities of the turtles which suggests that no active rubbing or scraping of the transmitters against fixed objects occurred. Interference with copulation was considered possible; however, viable nests were produced throughout the season without damage to even the radio antennas. While copulation would have been possible without damage to equipment, it seems more likely that copulation did not occur following instrumentation.

The use of floating transmitters, attached to the turtle by a line, increases the probability of entanglement and interference from curious boaters. The use of direct attachment was felt to be safer. No mortality which appeared to be in any way related to instrumentation, was observed or recorded.

The ease with which sonic tracking can be conducted is directly related to the range of the transmitters. A minimum effective range of 1 km was required in order to monitor an individual turtle for an extended time. A range of 1.5 to 2.0 km was found to be more manageable. The greater range enabled the use of a larger tracking vessel without entering the shallow shoal waters frequently used by turtles. Greater range also facilitated the efficiency of sonic search patterns. For example a sonic check conducted for a transmitter with a 1 km range encompasses an area of 3.14 km^2, while a transmitter with a 2 km range results in four times as much area monitored per sonic check.

The larger research vessel increased the time interval of continuous monitoring and thus reduced the travel time required to move from a land base to an instrumented turtle. The larger vessel also increased the climatic conditions under which monitoring could be conducted.

The use of Loran C and radar location equipment was found to be essential to accurately plot the locations of instrumented turtles. This is particularly true of night monitoring or monitoring when out of sight of land. Radar-verified Loran C coordinates were found to be a consistent and accurate method of plotting boat positions. There was, however, an additional problem in determining the relative position of the turtle from the boat. Boat movements were much more influenced by wind, current, and sea state than were turtle movements and discerning boat movements from turtle movements proved difficult. This difficulty was compounded by the inability to determine a precise distance from the hydrophone to the instrumented turtle. Boat speed and manuverability often prohibitated the use of triangulation, thus compass bearing and signal strength were used to estimate the direction and distance from the boat to instrumented turtles. Precise turtle locations could only be obtained by approaching the instrumented turtle until the sonic signal was strong enough to be omnidirectional. Signal reception from all directions was found to occur only when in the immediate vicinity of the transmitters.

Internesting Activities

Pelagic activities were basically of two types. The first type involved long distance directional movements while the second was unpatterned activity in a limited area. The directional movements are typified by speeds of 1 to 3 km/hr and involved remarkably straight paths. This type of movement seemed deliberate, in that, movement was steady and was initiated and terminated abruptly. Changes in direction sometimes occurred and were also abrupt about a point as opposed to gradual alterations of the coarse.

The second movement type involved concentrated activity in limited areas referred to as core areas. Core area movements were unpatterned movements during daylight hours which resulted in less than a 5 km displacement between night areas. Core area activity often was interspersed with periods of no discernable movement. The duration of this type of activity was generally one to three days for any one area.

Internesting activities were almost exclusively diurnal. Whether a long distance movement or movement in a core area, activity was initiated at sunrise each morning. No correlation between activity and time during the day was observed, but by late evening activity became greatly reduced.

Nocturnal activities of turtles were limited except for those associated with nesting. Turtles could be monitored at night and no change in signal strength or direction were usually recorded. Turtles were not displaced by wind or currents at night and could be left after dark and relocated in the same area before daylight the following morning. The reason for the infrequent movements recorded at night are unknown, but the magnitude of such movements was limited.

Nocturnal periods of inactivity away from the nesting beach and frequent periods of inactivity in core areas during the first few days following nesting depict resting inactivity. While verification of function of an activity associated with emergence was possible by visually observing the turtle on the beach, activity at sea is difficult to categorize due to infrequent or even rare visual encounters which occurred with instrumented turtles. Visual contacts could only be made by remaining in the vicinity of a turtle in a small boat until the turtle surfaced for air. This often involved waiting for one hour or more and would generally result in observation of the turtle and the radio transmitter.

In general, movement patterns between nestings involved diurnal movements about several core areas with directional sustained movements between core areas or to and from the nesting beach.

Nesting Activities

Activities associated with nesting developed characteristic patterns and were classified as pre-emergence, post non-nesting emergence, and post-nesting emergence. Pre-emergence activity involved a movement to within 3 km of the nesting beach, prior to the night of emergence. The length of time between arrival in the area and emergence was variable, and may relate to the inability of a turtle to accurately predict the time of egg maturation. This lack of accuracy seemed more pronounced early and late in the nesting season. The rock jetty on the south side of Winyah Bay which extends more than 3 kms seaward of the beach appeared to concentrate pre-emergence turtles. This concentration was particularly evident at the end of the jetty. It appeared that this conspicuous physical feature was used for orientation prior to emergence. In late afternoon and early evening turtles would move into the turbulent surf zone immediately off the beach and maintain themselves in this zone during movements paralleling the beach until emerging.

Frequently a terrestrial emergence would not result in a successful nesting and would initiate a post non-nesting emergence pattern of activity. This pattern involved movement paralleling the beach while in the surf zone until another emergence was made or until sunrise. Turtles which made one or more unsuccessful emergences would maintain themselves in the waters near the nesting beach the following day. Little or no movement was recorded until late afternoon or evening when pre-emergence behavior was repeated that night.

Following a successful nesting, turtles would move away from the nesting beach at night to a nearshore topographic feature such as the East Bank Shoals or the Winyah Bay ship channel. Turtles would then remain in this area until first light when a directional movement would typically be initiated to a core area.

SUMMARY

Radio and sonic telemetric monitoring is a feasible technique for determining activity and movements of loggerhead turtles. The transmitters used and the attachment methods provided information without injury to the turtles.

South Carolina's nesting loggerhead turtles remained in the nearshore waters adjacent to the coast during the entire nesting season. Internesting movements tended to be parallel to the coast and were primarily to the south of the nesting beach. Shoals and areas of high relief were found to receive concentrated use by turtles during the internesting period, while the areas immediately adjacent to the nesting beaches supported high use associated with nesting activity. Turtles were inactive at night and daylight activity involved either long, straight line movements or unpatterned activities in core areas.

This study represents some of the first information on the movements and habitat use by nesting loggerhead turtles while at sea. Since all but a small fraction of the turtle's life is spent at sea it is obviously important to have this information in developing management plans. Information gained on the type and pattern of turtle activities should aid in understanding and mitigating the various factors affecting the nesting population in South Carolina.

Monitoring of pre-emergence activity demonstrated a potential for disturbance from the beach. This potential is a result of the extended periods of time a turtle remains in the surf zone prior to emergence. During this entire time a turtle could be affected by beach activities and be deterred from nesting. This disturbance to the turtle would not be apparent to those on the beach causing the activity and it would go unmeasured by researchers conducting beach surveys.

The high use of near shore waters by nesting loggerheads throughout the nesting season clearly demonstrates the potential for conflict with nearshore commercial fishing activities. This potential may be reduced somewhat by the high utilization by turtles of areas around shoals and in areas where boat operation is not possible.

There would also seem to be an increased susceptability of turtles to night trawling activity since they are inactive at this time.

Finally, concentration areas do occur around obvious physical features along the coast and alteration of these features may result in alteration of nesting distribution or essential habitat.

<u>Authors Note</u>

This manuscript will receive additional analysis and editing prior to journal publication.

PROJECT TITLE: ENDANGERED SPECIES

State: South Carolina

Project No.: E-1
Study No.: I

Job Number 2 Title:

ABIOTIC AND BIOTIC FACTORS AFFECTING NEST FAILURE OF *CARETTA CARETTA*

Sally R. Hopkins

and

Thomas M. Murphy

Job Duration: October 1976 to September 1979

ABSTRACT

Fates were determined for 1,579 nests of the Atlantic loggerhead (Caretta caretta) on four South Carolina barrier islands from 1977-1979. Raccoons (Procyon lotor) destroyed 59.4% of the nests overall and from 16.1 to 95.9% on individual islands. Poachers took 47.5% from one island and abiotic factors accounted for [illegible]%. Ghost crabs (Ocypode quadrata) were not important predators, destroying only 2.5%. The red fox (Vulpes fulva) destroyed 12.8% on one island, but was not a nest predator on the other islands. Hurricane David was not a significant factor in nest mortality compared to natural predation. The overall hatch was 7.4%. The spatial and temporal aspects of nesting and predation, age of nests when depredated, density of nesting, and feeding efficiency of raccoons are discussed as they relate to the number of nests affected by each factor and to management techniques.

INTRODUCTION

The reproductive strategy of marine turtles to lay large clutches of eggs several times a season is believed to be an adaptation to offset high mortality of nests and epipelagic young. This strategy has proved successful for millions of years (Carr, 1967), but in recent times increased nest losses and increased mortality of subadults and adults have reduced populations of all marine turtle species (IUCN Red Data Book, 1970).

Since the survival rates of the pelagic stages of the life cycle are unknown, and may remain so for some time, it is important to document the survival rates of the accessible terrestrial stages to obtain data on population recruitment for this species.

Several studies documented nest destruction for C. caretta (Klukas, 1967; Routa, 1968; Gallagher et al., 1972; Davis and Whiting, 1977; and Mann, 1978). One such study conducted in South Carolina by Baldwin and Lofton (1959), provides a data base on the Cape Romain rookery for comparative purposes.

The purpose of this study was to quantify the types and extent of the biotic and abiotic factors associated with nest failure in the South Carolina loggerhead rookery. Published data from the first year of the study (Hopkins, et al., 1978) is combined with the remaining two years in this report.

METHODS

Study Area

The study area comprised four islands on the South Carolina coast from North Inlet estuary in Georgetown County, south to Bulls Bay in Charleston County (Fig. 13). These barrier islands were selected because of their relative concentrations of nesting turtles, their physical and biotic attributes and their accessibility for research.

North Island, which lies between North Inlet and Winyah Bay, is one of the more stable beaches on the South Carolina Coast (Brown, 1977). Its moderate

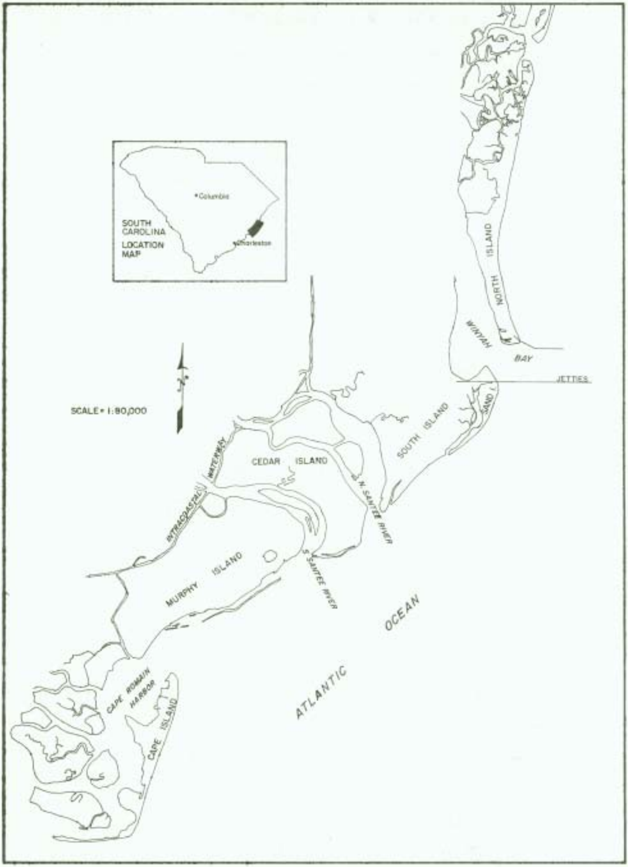


Figure 13. Location map showing the four study islands in South Carolina.

to high dunes, some reaching more than 6 m, are covered predominantly with sea oats (Uniola paniculata). There is a wide, high berm, and erosion occurs only in the crescentic central portion of the 14-km beach. The island's interior supports a mature maritime forest and is undeveloped except for a small Coast Guard light station on the southwest side.

Sand Island, on the southern side of Winyah Bay, has accrued since the south jetty was constructed in the 1890's. It has no trees and only two small thickets of wax myrtle (Myrica cerifera). The beach on the seaward side of the jetty is short and steep and is backed by low dunes covered with sea oats, sea beach panic grass (Panicum amarum) and beach elder (Iva imbricata). Many of the dunes were scarped by erosion in 1977, and the intermittent washover terraces along the front beach enlarged and became almost continuous during the three year period as erosion progressed. However, the 3-km beach in 1977 accrued almost 300 m each year at the south end of the island.

South Island lies to the southwest of Sand Island, and the two are separated by a small tidal inlet. Sections of South Island beach are eroding, and dunes are absent along the central portion of the 3-km beach where spring tides wash under dead wax myrtles. Low to moderate scarped dunes backed the flat beach in 1977, but both the southern and northern dunes were unscarped in 1978 and 1979 as sand from offshore bars was deposited upon the berm.

Cape Island, in the Cape Romain National Wildlife Refuge, is located north of Bulls Bay and is part of the Santee River delta complex. The 8-km island is a cuspate foreland and has undergone such severe erosion that the north flank has shifted from a north to a north-northeast orientation (Brown, 1977). The portion of the beach surveyed (3 kms) is steep and narrow with a mixture of low to moderate scarped dunes and washover terraces.

Cape Island underwent the same type of erosion as Sand Island during the course of the study in that some dunes were replaced by expanding washover terraces. This process was greatly accelerated by Hurricane David in 1979 on both islands.

Study Procedures

Prior to the nesting season each island's study area was divided into numbered segments with permanent marker poles. Each nest was located by segment and also by its approximate location within that segment, estimated to the nearest tenth.

South Island was surveyed daily by ORV for the following dates: 18 May to 30 August, 1977; 19 May to 26 September, 1978; and 15 May to 10 September, 1979. Cape and Sand Islands were surveyed twice weekly in 1977 and every third day in 1978 and 1979. The survey dates for Cape Island were: 10 June to 1 September, 1977; 18 May to 31 August, 1978; 21 May to 6 September, 1979. The survey dates for Sand Island were: 18 May to 22 September, 1977; 22 May to 5 October, 1978; and 17 May to 5 September, 1979. North Island was surveyed twice weekly from 26 May to 26 September in 1977 only. Cape, Sand and North Island, accessible only by boat, were surveyed by Honda ATC motorcycles. A stratified regular sample of nests was obtained for these three islands.

Initially each beach study area was approximately 3 kms long, since two of the islands were this length. However, because of low density nesting on North Island, the survey area was extended to the midpoint of the beach (approximately 8 kms) to provide a larger sample size. The particular 3-km section of Cape Island was chosen for its high nesting density for comparison with moderate and low density nesting areas. The survey areas increased slightly on South and Sand Islands during 1978 and 1979 from the deposition of sand.

The following precedure was used for each nest. The body pit of terrestrial emergences was probed with a pointed dowel to locate the nest cavity. A small hole was dug by hand to verify the presence of eggs since other factors, such as decayed driftwood, or a ghost crab burrow, could be mistaken for a nest cavity. Nests were marked with numbered flags which were offset 1 m on a specified compass direction from the nest. The sand was replaced and all probe marks were erased. In this way the location of the nest could be known and monitored throughout the incubation period without indicating its exact location. For a sample of South Island nests in 1979, the turtle's tracks and body pit were raked and swept to remove all visible signs associated with the nest.

The date laid, nest location relative to the dunes, a description of the nest site and other pertinent information were noted. On each beach survey new nests were marked and previously marked nests were checked for disturbance. When the fate of a nest was determined, the date and cause were recorded. Any undisturbed nest which had not hatched after 70 days was excavated to determine the cause of its failure. Successful nests were also excavated to determine viability and the number of eggs per nest. Wind direction and speed, tide stage, precipitation and temperature were recorded daily for South Island.

RESULTS AND DISCUSSION

Abiotic Factors

Abiotic factors are generally considered to be: freshwater flooding from rainfall, windblown sand covering the nests, saltwater inundation by high tides, and severe beach erosion.

Nests destroyed by freshwater inundation were reported by Klukas (1967) and by Ragotskie (1959). South Carolina experienced a drought during the summer of 1977, and on South Island there was no precipitation from 26 June to 22 July, so freshwater flooding was not a factor that year. There were normal summer weather patterns in 1978 and 1979 with no unusual amounts of rainfall except for Hurricane David in 1979. Any effects of the heavy rains associated with Hurricane David were masked by the storm surge tides which covered all nests. Salt and freshwater inundation appears to affect nests in a like manner, i.e. causing low oxygen conditions surrounding the eggs, depending on the severity of the flooding (Ragotskie, 1959). Nests destroyed in this way were either partially successful (less than 10% hatch), contained embryos arrested at various developmental stages, or eggs and sand below the water table had blackened from anaerobic conditions. Nests lost to severe beach erosion were completely washed away. Windblown sand accumulation was not a factor on the beaches studied.

Beach erosion is common along the southeast Atlantic coast and results from a slight but persistent rise in sea level and a reduction in riverborne sand over the past 50 years from damming (Hillestad et al., 1975). The period of greatest erosion, except for hurricanes, occurs whenever the highest monthly tides coincide with strong onshore winds.

The number of nests destroyed by salt water inundation or erosion on each island was dependent on the island's beach profile, the location of the nest, and the availability of nests relative to the biotic factors. Of the 1,579 nests sampled, 220 (13.9%) were lost to these two abiotic factors on all four islands (Table 2). On North Island the four nests affected were located in the central, eroding portion of the island. The low number of nests lost to erosion on South Island (14 of 364) was due, not to the beach profile, but to most nests being already depredated by raccoons (P. lotor); therefore, few were available for the tides to affect. The potential for nests to be destroyed by tides on South Island was higher; 13.6%, 16.0% and 14.9% of the nests were located in the eroding section of the beach in 1977, 1978 and 1979, respectively. The fact that only 3.8% were destroyed by abiotic factors reflects the high predation rate by raccoons.

On Sand Island 156 of 602 nests were destroyed by abiotic factors. The percentage lost to these factors each year was highly variable as this was influenced by biotic factors which affected the availibility of nests and by changes in the beach profile. The number of nests laid on washover terraces was 19.4%, 30.4% and 17.2% for 1977, 1978 and 1979, respectively. The increase to 30.4% in 1978 probably reflects the deterioration of the dune system and the enlargement of the areas covered by washover terraces. The number of nests lost to abiotic factors in 1978 was also high, 48.8%. This was probably influenced by increased availibility of nests since human poaching

Table 2. Fates of 1,579 C. *caretta* nests on four barrier islands in South Carolina, 1977-1979.

	SAND ISLAND %				SOUTH ISLAND %				CAPE ISLAND %				North ISLAND %	ALL ISLANDS %
	1977	1978	1979	TOTAL	1977	1978	1979	TOTAL	1977	1978	1979	TOTAL	1977	TOTAL
	N=158	N=217	N=227	N=602	N=87	N=156	N=121	N=364	N=134	N=193	N=207	N-534	N=79	N=1579
Abiotic Factors	19.6	48.8	8.4	25.9	3.5	3.9	4.1	3.8	20.1	3.1	6.3	8.6	5.2	13.9
(Erosion & Inundation)														
Biotic Factors														
Humans	47.5	10.1	0.9	16.4	0.0	0.6	0.8	0.6	0.0	0.0	0.0	0.0	2.5	6.5
Ghost Crabs	3.2	0.5	7.5	3.8	4.6	0.6	3.3	2.5	0.0	0.0	2.9	1.1	2.5	2.5
Multiple Predators (Crab/Raccoon/Fox)	6.3	0.5	7.0	4.5	1.1	3.2	1.7	2.2	1.5	1.0	0.0	0.8	8.9	2.9
Raccoons	16.4	16.1	39.2	24.9	86.2	87.2	86.8	86.8	75.4	95.9	63.3	78.1	69.5	59.4
Fox	--	--	12.8	4.8	--	--	--	--	--	--	--	--	--	1.9
Hatched	7.0	24.0	7.9	13.5	4.6	4.5	0.0	3.0	3.0	0.0	5.8	3.0	11.4	7.4
Hurricane David	--	--	16.3	6.2	--	--	3.3	1.1	--	--	21.7	8.4	--	5.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

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Table 2. Fates of 1,579 C. caretta nests on four barrier islands in South Carolina, 1977-1979.

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Fox	--	--	12.8	4.8	--	--	--	--	--	--	--	--	--	1.9
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Hurricane David	--	--	16.3	6.2	--	--	3.3	1.1	--	--	21.7	8.4	--	5.5
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

had been curtailed significantly from the previous year. The decrease in nesting on washover terraces to 17.2% in 1979 might indicate the affects of a new dune system on the prograding southern end of the island. The low percentage of nests lost to abiotic factors in 1979 reflects increased predator activity plus the influence of Hurricane David.

Although the percentage of nests destroyed by abiotic factors on Cape Island was similar to that on Sand Island in 1977, the number decreased because of high raccoon predation in 1978 and the combined factors of raccoons and Hurricane David in 1979. The effects of the tides on the Cape Island beach appeared to be more severe than on the other islands. In 1977, the front face of the foredune retreated landward about 10 m. In addition six of the segment markers, which were initially driven almost two meters into the sand, were washed away as wave action created a steeper beach profile. It is a conservative estimate that from 1/4 to 1/3 of the nesting substrate was removed from the 3-km study area and nests on or at the base of the dunes were lost (Fig. 14). As this erosional process continued throughout the study, the percentage of nests which were laid on washover terraces remained fairly constant (39.6% in 1977, 34.2% in 1978, and 33.8% in 1979). Rather than the areas of washover terraces increasing, as on Sand Island, the scarped face of the foredune retreated landward each year and the dunes were smaller in height as the rear dunes became the foredunes.

Prior to the 1930's the Santee Delta was in a stable or constructional phase. Diversion of a major portion of the river's flow in 1942 has had a dramatic effect on the islands of the delta complex. Since then they have been in a continuing destructive phase. Since 1941, Cape Island has eroded over 215 m (Stephen et al., 1975). Baldwin and Lofton (1959) reported almost 1/3 of the nests monitored in 1939 were on the wide, sloping beach type and the least nesting at the base of scarped dunes and on washover areas.

During the course of this study and in previous seasons according to Cape Romain personnel, the highest nesting density was on the southeastern part

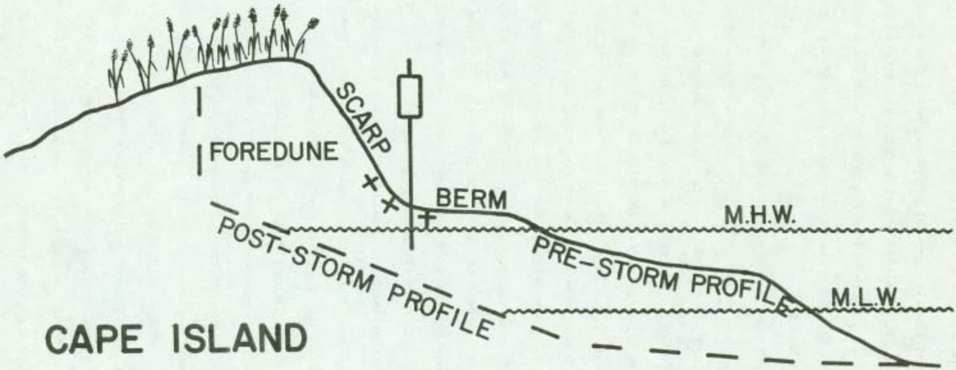

Figure 14. Diagram of erosional processes on Cape Island, South Carolina, 1977.

of the island. This section (also our study area) was comprised almost entirely of scarped dunes and recent or re-vegetated washover terraces. The wide beach type described by Baldwin and Lofton (1959) is found today on the northeast end of the island where nesting is relatively sparse. The beach type currently used for nesting is less suitable than the types used in 1939 which leads to increased losses to abiotic factors. This apparent inappropriate site selection may be related to factors of offshore topography and to marginal but still acceptable beach conditions.

Hurricane David occurred at the peak of the hatching season and all remaining nests on the study area were destroyed. The hurricane's landfall near Savannah, coincided with the evening high tide. Thus the storm surge was combined with bi-monthly spring tide. It was felt at the time that this would have a major influence on recruitment, especially on Cape Island where trapping had reduced raccoon predation. When compared with all the other factors over the three-year period for all islands, its effect, just over 5%, was not significant. Major storms occur about once every twenty years in South Carolina and although they may affect one year class, hurricanes should not be considered an important factor in low recruitment of loggerhead turtles.

Biotic Factors

Biotic factors were those factors involving other living organisms. These factors may be plant roots overgrowing the eggs, invertebrate predators entering a nest, vertebrate predators and poachers. The four biotic factors affecting nests on the islands studied were: the ghost crab, the raccoon, the red fox, and man (Table 2).

Clearly the major predator of turtle nests was raccoons. On any given nesting beach, the number of nests destroyed by any predator, not just raccoons, may be determined by the inter-relationship of any or all of eight factors (Table 3).

Table 3. Factors affecting raccoon predation of loggerhead turtle nests on barrier islands.

POSSIBLE FACTORS AFFECTING RACCOON DEPREDATION

1. The spatial distribution of nests.
2. The spatial distribution of predators.
3. The temporal distribution of nests.
4. The temporal distribution of predators.
5. The age of nests.
6. The predator feeding efficiency.
7. Predator density relative to habitat.
8. Relative density of nests.

Spatial Distribution of Nests

Generally, the spatial distribution of nests on Cape and South Islands was about even in all segments with slight differences in frequency depending on beach quality in 1977. There were shifts in nesting distribution as the erosional forces deteriorated the quality of the beach. Figure 15 illustrates this for Cape Island over the three year study.

Nesting on North and Sand Islands was not as evenly distributed. Several segments on the Winyah Bay side of the north jetty had no nesting. In 1977, one 300 m segment on Sand Island (11% of the study area) contained 30% of the nesting for that island. In 1978, four 150 m segments (20% of the study area) contained 45% of the nests. Although the dunes in two of these segments washed away, the remaining two segments (10% of the study area) had 25% of the nesting in 1979.

Spatial Distribution of Predators

The percentage of raccoon predation, by segment, for each island was similar to the overall percentage of raccoon predation for each island. Even

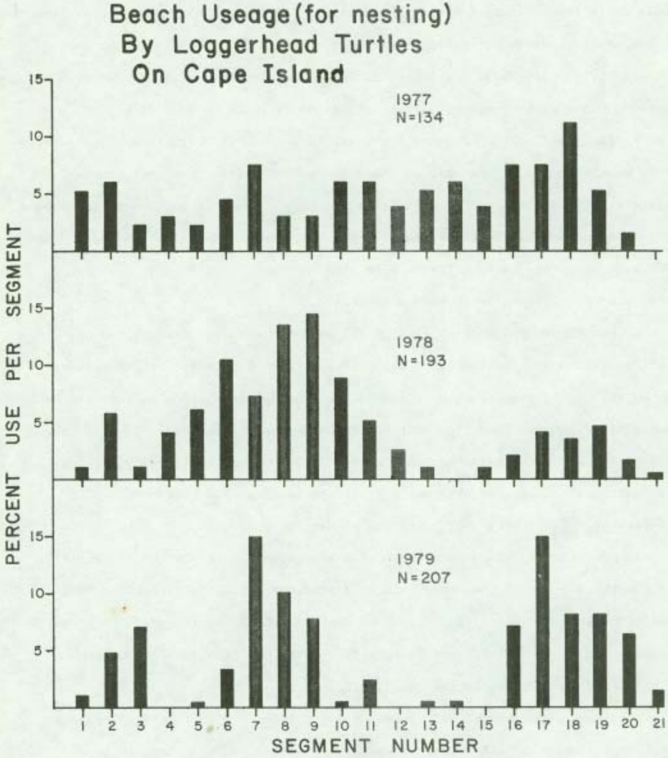

Figure 15. Shifts in nesting distribution on Cape Island, South Carolina for 1977-79.

segments with a high degree of nesting had a proportionate number of nests destroyed in that segment relative to the entire island.

The predation of nests on Sand Island by red foxes was not evenly distributed. Their den site was located behind the dunes in segment #1. Seventy-nine percent of the nests destroyed by foxes occurred in segments #1, 2, and 3. Thus the location of a nest, while not important in determining if a nest was eaten by a raccoon, was important with regard to predation by foxes on Sand Island.

Klukas (1967) noted areas of the beach at Cape Sable where raccoon concentrations were high and it was also on these areas that nesting was most intense. This beach type was backed by tall trees and shrubs. He did not report the amount of predation in these beach segments versus the other segments but indicated that even with trapping, raccoon tracks were always present, and he reasoned that these were core areas for raccoon dispersal.

In our study, depredation closely followed the spatial distribution of nesting. Raccoons appeared to be ubiquitous on all of our beaches and because of the relatively short length of the islands' study areas, they appeared to be evenly distributed. Thus, any nest had about the same likelihood of being taken by a raccoon as any other nest. All areas of the beaches utilized by turtles for nesting were likewise utilized by raccoons to prey upon those nests.

Temporal Distribution of Nests and Predators

In general, the temporal distribution of nesting and predation was parallel for the three years of the study. In 1977 predator activity intensified toward the latter part of the nesting season on three of the study islands. This relationship is shown in Figure 16 for 1977. This was also noted by Gallagher et al. (1972) on Hutchinson Island, Florida.

There was about a week's lag time on South Island in 1977 before raccoons began to find nests. After several weeks the depredation equalled, or in some cases exceeded, the nesting effort as raccoons preyed upon older nests to compensate for the decrease in nesting. The temporal distribution of nesting

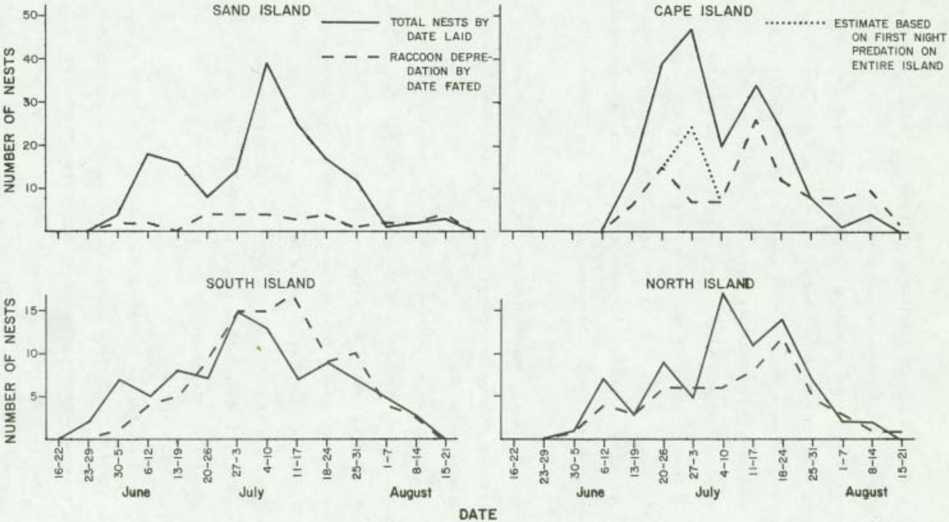

Figure 16. The relationship between the temporal distribution of nesting and the temporal distribution of raccoon predation for C. caretta nests, 1977.

and predation was even more closely parallel in 1978 and 1979 as the number of nests destroyed the same night they were laid increased.

Predation paralleled nesting on Cape Island also. The dotted line (Fig. 16) is an estimate based on first night predation for the entire island. Cape Romain personnel were screening nests for a transfer project during this time and it was felt that marking the nests not screened would bias the data on abiotic factors toward poorer nest sites. Therefore, raccoon depredation was estimated for this period. The graph also shows predation exceeded laying toward the end of the season. In 1978, so many nests were destroyed the same night they were laid (153 of 184) that the temporal relationship between nesting and predation was almost identical. This same relationship was also closely parallel in 1979.

North Island's predation likewise paralleled the nesting effort except for a lag at the peak of the season. However, predation decreased along with nesting at the close of the season.

Sand Island did not follow the pattern of the other islands and showed a low but sustained predation rate throughout the season. This same pattern held true for 1978 and although predation by raccoons was higher on Sand Island in 1979, it still showed a sustained rate throughout the season. There was a two-week lag time before the red foxes began to depredate nests on Sand Island.

Most nests were taken by raccoons during the first two or three nights. First-night predation was highest on Cape Island in 1978 (83%), and even though predation was lower in 1979, the number of nests taken the same night they were laid was still high, 72% (Fig. 17).

In 1977, South Island had the same percentage (36%) taken both the first and second night. In 1978, the first-night predation rate was 60% and in 1979 it was 62%. While second night predation was about the same, first night predation almost doubled. This is more than twice the rate of depredation for the second night in both years (Fig. 13).

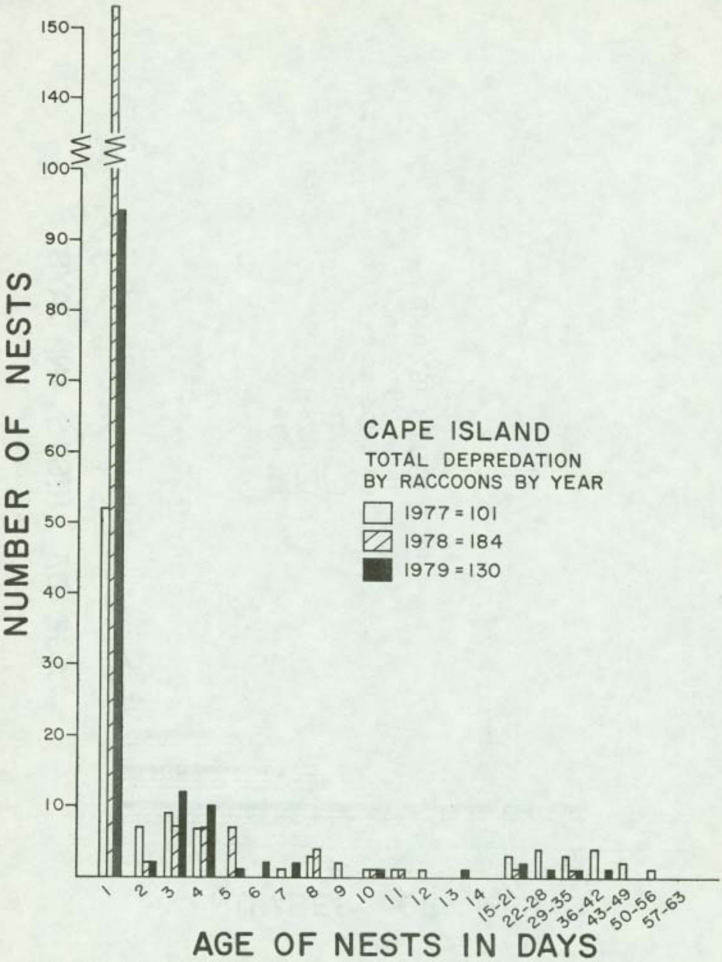

Figure 17. Age specific nest losses for raccoon depredated nests only of *C. caretta* on Cape Island for 1977-79.

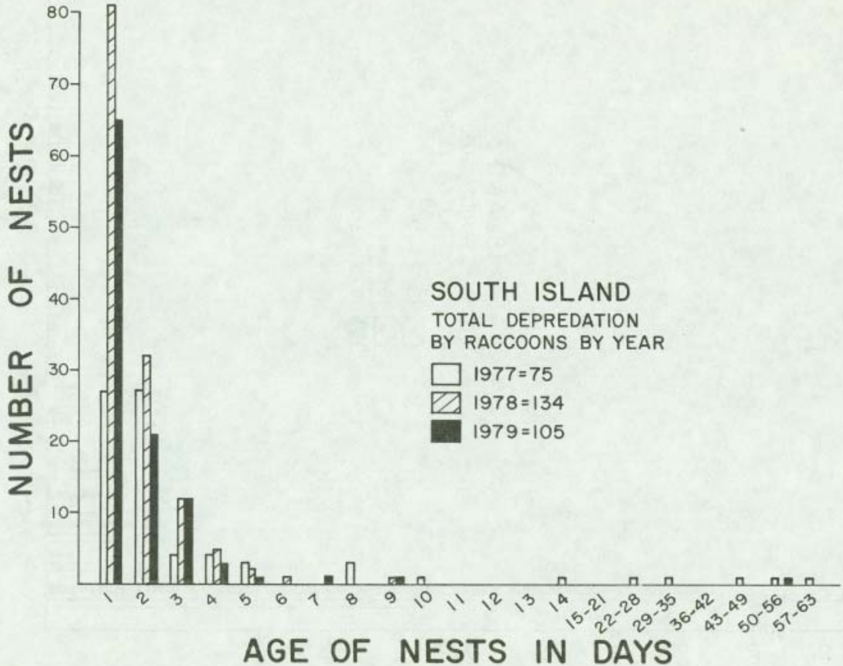

Figure 18. Age specific nest losses for raccoon depredated nests only of *C. caretta* on South Island for 1977-79.

Sand Island showed no high first-night predation in any year of the study (Fig. 19). Even in 1979 when the predation rate was the highest, the age of nests wehn destroyed was distributed throughout the incubation period. Davis and Whiting (1977) reported 87% first-night predation at Cape Sable and Gallagher et al. (1972) had 34% of the nests destroyed the first 48 hours after laying.

Age of Nests

Nest age appears to be an important factor in determining if a predator can locate and destroy a nest. Rainfall and more often wind should affect the duration of the turtles' scent and visual cues associated with the crawl and body pit. To test this, a sample of 10 nests were raked and then swept smooth on South Island in 1979. This procedure was done in early morning to allow the wind the maximum time to erase all signs before dark. Nine nests were eaten by raccoons almost immediately and one was inundated by tides showing that raccoons were still able to find nests even when the visible signs were erased.

These data for age specific nest losses to raccoons are consistent with those of Holden (1964) and Klukas (1967) for Cape Sable. They reported few nests taken after they were 2-3 days old. They also noted a slight rise in predation when nests were within a few weeks of hatching. Bustard (1972) observed this same phenomenon for foxes in Australia and it likewise occurred on the islands in this study, especially Sand Island (Fig. 19).

Predator Feeding Efficiency

The feeding efficiency[1] of predators is a factor affecting nest loss, but

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[1] $$F.E. = \frac{\text{\# Nests eaten}}{\text{Total \# nests available}} \times 100$$

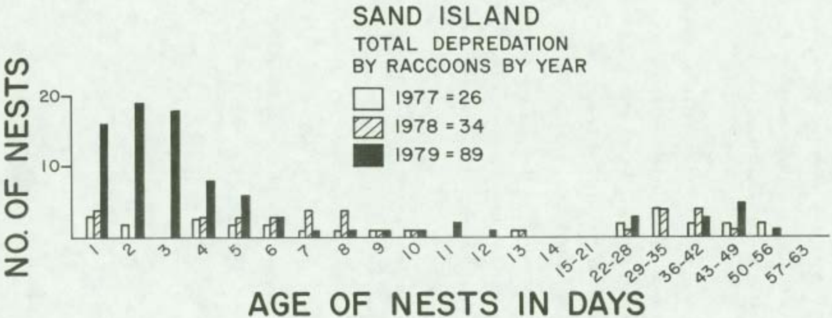

Figure 19. Age specific nest losses for raccoon depredated nests only of _C. caretta_ on Sand Island for 1977-79.

it is difficult to quantify because it is an indication of learned behavior in the animal. An attempt to quantify this concept was made by Hopkins et al. (1978) and similar calculations were made for the 1978 nesting season for comparative purposes on South Island.

When nest availability represented the entire time a nest was in the sand, the feeding efficiency of raccoons appeared to be different for 1977 versus 1978. The highest calculated value in 1977 was 15% for the eleventh week of the season (Hopkins et al., 1978). Calculated values in 1978 were greater than 30% for 6 of the 14 weeks of the season. Of 314 nests destroyed by raccoons in three years on South Island, all but 13 nests were taken within 7 days of laying. Based on this, nest availability approaches zero after a nest is over one week old. When feeding efficiencies for 1977 and 1978 were re-calculated for nests being available a maximum of seven days, the values were much higher and more similar between years. When converted to a seven night availability, the values in 1977 ranged from 16% to 50%, and those in 1978 ranged from 15.5% - 66.7%. There was an inverse relationship between efficiency and availability; efficiency was lower when nest availability was high.

While feeding efficiency is an interesting concept, nest age and predator density appear to be more important from a management standpoint. For example, while there was an increase in the number of nests laid in 1978 (+69) and in 1979 (+34) over the 1977 nesting effort, the percentage of nests destroyed each year remained about the same (see Table 2). Also, first-night predation increased from 36% in 1977 to 60% in 1978 and 62% in 1979. Therefore, the usefulness of this concept is diminished by high rates of predation and is over-shadowed by nest age.

Predator Density and Relative Density of Nests

The relative density of nests and the density of predators relative to habitat are obviously the two important factors which would affect the number of nests destroyed. There are no data for the raccoon populations on the islands studied, so the designations of high and low to describe them are estimates based on tracks along the beaches and subjective evaluation of habitat.

Sand Island has moderately high nesting density, about 75 nest per km, but poor raccoon habitat. The presence of only a few raccoons in 1977 and 1978 resulted in low predation even with fairly high nesting. Heavier raccoon use and the addition of red foxes increased predator density in 1979 with resultant higher predation rates. North Island had low density nesting, about 10 nest per km. Although it has good raccoon habitat, it had the lowest over-all predation of the three large islands (except for the trapping effort on Cape Island in 1979) and no older nests were taken. This indicated that nest density may fall below a level to support beach use by raccoons. This was shown by depredation dropping from 84% for the first half of the season to 60% for the second half.

Cape Island has probably the highest nesting density for the species in the United States. There were an estimated 166 nests per km for the three years of this study (G. Garris pers. comm.) and nesting estimates by refuge personnel were even higher in past years. The high first-night predation all three years, mentioned earlier, results from many fresh nests being laid each night most of the season. The predation on Cape Island during this study far exceeds that of 1939 when Baldwin and Lofton reported only 5.6% loss after a winter of extensive raccoon control. Trapping was begun again in 1979 and a drop of 32.6% was noted in the predation rate over the previous year.

South Island had the highest average predation of 86.8%. The nesting density (42 nests per km) was high enough to support beach use by raccoons, and more raccoons may have been drawn to the beach since the predation rate kept pace with the increased nesting effort.

Of the 8 factors affecting predation, those acting on the four islands studied in order of importance were; density of predators, nest age as it relates to feeding efficiency, relative density of nests, and to a lesser extent, the temporal distribution of nest and predators. Spatial distribution of raccoons did not appear to be a factor since they were everywhere, but spatial distribution of red foxes was related to nest loss for this predator. Spatial distribution of nests was important also with regard to abiotic causes of nest failure.

The data indicate that ghost crabs were not an important source of depredation in this study area, taking only 2.5% of the nests (Table 2). In some cases it was impossible to discern whether raccoons and/or foxes dug into a nest first, followed by a crab, or whether egg shells on the surface brought there by a crab, lured raccoons or foxes to the nest. Therefore, for these nests, multiple predators were listed together (Table 2).

The percentage of nests taken by poachers on Sand Island in 1977 was 47.5%. Increased law enforcement patrols in 1978 reduced this to 10.1% and other turtle research requiring night time use of the island further reduced this to 0.9% in 1979.

One hundred seventeen nests hatched during the three year study (7.4%). Of these, 29 were disturbed by predators after the nest hatched making an accurate count of the eggs impossible. The mean number of eggs per clutch for the 88 remaining nests was 114.4 with a range of 46-171.

The mean clutch sizes were 105.6 for 1977, 112.2 for 1978, 124.9 for 1979. The mean clutch size was obtained from all four islands in 1977, from Sand and South Islands in 1978 and from Sand and Cape Islands in 1979. The mean clutch size on Sand Island in 1978 was 115 (N=43) and in 1979 it was 117.9 (N-14). The mean clutch size for South Island was 113.3 (N=3) in 1977, and it was 81.5 (N=4, with one nest containing only 46 eggs). Numbers of eggs could not be determined from the four nests hatched on Cape Island in 1977, but the mean clutch size was 134.7 (N=10) in 1979. The difference in mean clutch size by year and by island are unexplained.

The overall nest viability[2] for the three years was 68.8%. For the individual years, it was 75.5% in 1977, 62.7% in 1978, and 75.5% in 1979. The lower nest viability in 1978 was caused by inundation (see Table 2) resulting in only partial hatches for about 1/3 of the nests.

CONCLUSIONS

Prior to this study, information on nesting effort and nest mortality for these islands was scanty or non-existent. Aerial survey data from Stancyk and Talbert (pers. comm.) indicated that these four islands were important nesting beaches in that they comprised about 70% of the total nesting effort in the state. These islands were also important for studies of nest mortality because of their high potential for management.

Several important results have been gained from this study. The nesting effort and the causes and extent of nest mortality have been quantified for a major portion of the South Carolina loggerhead rookery. The compensatory nature of the factors affecting turtle nests for each island, and the year to year variations among islands, has been documented. Without this comprehensive type study, the compensatory nature of these mortality factors would not have been apparent, and the applied management may not have produced the desired results. This careful, multi-year study was necessary in order to make management recommendations which would be cost effective and would have the greatest benefit to the South Carolina turtle population.

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2 $\frac{\text{\# hatchlings emerged}}{\text{\# eggs in nest}} \times 100$

Prior to this research, it was generally believed that the only management necessary for nest protection was to reduce raccoon populations. We now know that several management actions may be necessary, depending upon the particular attributes of the island. Studying a single island, or several islands for a single year would not have produced the understanding needed to make these management recommendations.

Also, without this comprehensive data base, the results of any applied management could not have been accurately evaluated. Thus by following the approach outlined in the study introduction, we have quantified the type and extent of the problem. From this understanding, we can determine suitable management techniques and apply them in the most cost effective way. At the same time, we will be able to evaluate these techniques through monitoring by comparing results with the data obtained from this baseline study.

Cape Island

Cape Island has a high nesting density (166 nests/km) but severe erosion and high nest predation by raccoons result in poor recruitment of hatchlings from this island. It can be assumed that many of the 21.7% of the nests destroyed by Hurricane David would have hatched in 1979 (Table 2), showing that raccoon removal that year had afforded some nest protection. However, because the erosional processes are likely to continue, suitable nesting sites may become more scarce.

Management recommendation for Cape Island would be to continue raccoon removal and to move the majority of "doomed" nests to several hatcheries. The high intensity effort of several beach patrols at night can be cost justified because of high nesting density, high first-night predation, and the importance of this island to the South Carolina turtle population.

The nesting effort on Cape Island has been declining over the last six years from an estimated 2600 + nests in 1975 to under 900 nests in 1980 (G. Garris, pers. comm.), without concurrent increases on nearby islands.

Documentation of nesting should be continued to further monitor this decline to determine possible causes. If the nesting effort on Cape Island continues to decrease, the other islands in this study may increase in relative importance and management priorities may change.

Sand Island

Sand Island has a moderately high nesting density (75 nests/km) and reasonable access for implementation of management. The three-fold problems of poaching, erosion and predation on this island will require several management actions, but these are justified because of the high recruitment of hatchlings which can be achieved and sustained with moderate efforts.

Law enforcement patrols proved to be effective in 1978 and research activity in 1979 almost eliminated human poaching (Table 2). However, without this surveillance, poaching rose to 11.5% again in 1980 (Hopkins, unpub. data). Therefore, law enforcement is needed each season to prevent poaching on Sand Island; otherwise it could return to former levels (47%) or higher if not prevented.

The recent increases in predation by red foxes and by raccoons shows that remedial action is also needed here for predators. Because of the relative isolation of the island, if these predators were removed, it may be some time before they would recolonize the island. This would afford considerable nest protection with a minimum of trapping effort.

Erosion must also be considered in management action here. As nest losses to predators and poachers are curtailed, there will be more nests available over a longer period of time for the tides to affect. Because of the compensatory nature of these three factors, nests which are laid on washover terraces or on other vulnerable sites should be moved to safer locations. This would be possible during daylight hours since first-night predation is not high. Although the losses to erosion are difficult to predict on a yearly basis, moving "doomed" nests should reduce this mortality factor to a fairly low level. Without this management, many nests would still be destroyed, (even though they were safe from predators and poachers) due to the low beach profile of this island.

South Island

This island has a lower nesting density (42 nests/km) compared to Sand and Cape Islands which would not justify the labor intensive efforts of a hatchery. Poaching has not been a major mortality factor in the past, so that law enforcement surveillence would probably not be necessary. The suitability of the beach for nesting has improved, but the central portion is still eroding. About 15% of the nests are laid in this section each year. These "doomed" nests could be moved to safer sites by daylight patrol with a minimum of effort.

The major emphasis must be on raccoon removal to effectively increase hatchling recruitment. Removal of 203 raccoons in 1980 from the interior of the island had no effect on predation on the beach (Hopkins, unpub. data). However, when 20 raccoons were trapped from the beach midway through the season, predation dropped from 91.6% to 62.1%. Because of the proximity of the maritime forest to the beach, periodic removal of raccoons will probably be necessary to protect nests throughout the season from new raccons moving into territories voided by those previously trapped. The trapping interval and the duration of trapping should be documented as it relates to the most cost effective way to protect nests.

North Island

North Island has a low nesting density (10 nests/km), a longer beach to survey, and is difficult to access. Erosion is not a major mortality factor on this beach and raccoon predation was not as high as on the other barrier islands with maritime forest. For all of these reasons, any type of management would be difficult to justify at this time. North Island should be surveyed on a limited basis to document any changes which may indicate management is necessary.

Marine turtles have a very long generation interval. Recent information indicates it may require as long as 20 to 25 years for a hatchling to reach adult size. Management techniques applied to increase hatchling recruitment may not be apparent for many years. Female loggerhead turtles nest on a 2-year or a 3-year cycle. Because of this, there is high variability in the nesting effort each season. Thus, there are high, low, or moderate nesting years which are natural fluctuations. It may take many years of sustained management to bring about a noticeable increase in the population. It is only when nesting is monitored over many years that trends can be determined, such as on Cape Island. Therefore, the final step in the approach to recovering loggerhead turtle populations must be to develop a cost-effective means of accurately monitoring the population over an extended period of time.

It is difficult to believe that loggerhead turtles could withstand the severe losses to reproduction reported in this study over a sustained period. Its current status may indicate that it can no longer withstand them, especially when these losses represent only one stage of the life cycle. Therefore the management techniques and recommendations in this report should be implemented as soon as possible and maintained as long as necessary.

Authors Note

This manuscript will receive additional analysis and editing prior to journal publication.

PROJECT TITLE: ENDANGERED SPECIES

State: South Carolina

Project No.: E-1

Job Number 3 and 5 Title:

FEASIBILITY OF RACCOON AVERSION THERAPY ON CARETTA CARETTA EGGS

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and

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Job Duration: October 1976 to September 1979

ABSTRACT

Lithium chloride aversive conditioning to reduce raccoon predation of loggerhead turtle nests was tested under laboratory and field conditions. A total of 1.0 g was determined to produce side effects (diarrhea and emesis) soon after ingestion, and when administered at a level of 0.25 g/egg, eliminated a negative taste reaction to the drug. In two separate series of laboratory tests on 37 raccoons, an aversive conditioned response was observed in only a few individuals. During field testing, there was no significant difference ($t = 1.11$; $p > .05$) in the depredation rate of turtle nests before and after a 3-week test period of lithium chloride treatment. Characteristics peculiar to this predatory-prey relationship facilitated the quantification of the field tests. Despite the undetectable administration of the drug with resultant physiological side effects, an effective psychological association of food with illness was not made by raccoons. The use of lithium chloride as a management technique appears to have no merit.

INTRODUCTION

Predator control has long been a controversial issue. Recognition of the importance of predators in the balance of natural ecosystems and concern for non-target species being killed led to public pressure against the use of lethal toxicants (Leopold, 1964; Cain et al., 1972). As a result, the use of lethal toxicants on federal lands by federal agents was banned in 1972 and funding became available for research on non-lethal methods of controlling predation (Beasom, 1974; Wagner, 1975).

Aversive conditioning with lithium chloride (LiCl) was first applied to coyote (Canis latrans) predation on sheep (Gustavson et al., 1974; Gustavson and Garcia, 1974; Gustavson et al., 1976). In theory, the predator (coyote) ingests the target prey item (sheep carcass) impregnated with a chemical emetic (lithium chloride), which causes an acute physiological reaction that creates an aversive response whereby the predator avoids eating that particular prey species in the future. If successful, this method would prevent coyotes from preying on sheep while still maintaining their role in the ecosystem.

Laboratory experiments with lithium chloride aversive conditioning on coyotes (Conover et al., 1977; Olsen and Lehner, 1978) did not produce the clear-cut results reported previously, and there has been considerable debate over whether lithium chloride aversive conditioning is an effective method for reducing predation on sheep by coyotes (Gustavson, 1979; Conover et al., 1979). Lithium chloride has been tested on other species: black bears (Ursus americanus) (Colvin, 1975), wolves (Canis lupus) and cougars (Felis concolor) (Gustavson et al., 1976), and hunting dogs (Weisman, J. A., 1976 Aversive conditioning: A method of breaking hunting dogs from running deer Unpub. report. Univ. of Georgia at Athens) with varying results.

The Atlantic loggerhead turtle (Caretta caretta) was listed as threatened by the U.S. Department of Interior in 1978 pursuant to the 1973 Endangered

Species Act and there have been increased efforts to mitigate mortality factors affecting this species. The raccoon (Procyon lotor) is the major predator on the nests of the loggerhead (Holden, 1964; Klukas, 1967; Gallagher et al., 1972; Davis and Whiting, 1977; Hopkins et al., 1978).

The purpose of this study was to determine if lithium chloride aversive conditioning would be an effective means of reducing raccoon predation on loggerhead turtle nests. Laboratory tests were conducted to determine: dosage level for raccoons, reaction time, whether or not an aversion was produced, how many treatments were needed to produce an aversive response, and the duration of this response. Field testing was conducted to determine the utility of this method as a management technique under field conditions.

Thanks are expressed to personnel at Cape Romain National Wildlife Refuge, Santee Coastal Reserve and the Yawkey Wildlife Center for their assistance in obtaining raccoons for the laboratory tests. Thanks are also expressed to John W. Coker for his valuable technical assistance. This research was partially financed with grant-in-aid funds under Section 6 of the Endangered Species Act of 1973 (PL93-205).

MATHODS AND MATERIALS

Laboratory Tests

Raccoons were live-trapped from federal and state lands in the lower coastal plain of South Carolina and held in 2 x 4 x 2 m pens for the duration of testing. These pens were converted dog runs which were wire enclosures with concrete floors. Each pen contained a wooden hutch for cover. All raccoons were acclimated to the facilities and to a feeding schedule for at least one week prior to testing. Unless otherwise noted, aversion tests were conducted in the late afternoon and at night to coincide with typical nest predation activity patterns. A maintenance ration of commercial dry dog food was provided each morning and fresh water was given *ad libitum*.

Two separate series of laboratory tests were conducted. The first series was conducted from November, 1976 to May, 1977 and was designed to determine dosage level, reaction time, if an aversive response was produced and the duration of this response. These tests were administered in the morning so that behavior and reaction time could be observed.

Based on the amount of lithium chloride per Kg body weight reported effective for coyotes (Gustavson et al., 1974), approximately 0.84 g should be necessary to cause illness in a 3.2 Kg raccoon, the average weight for raccoons in coastal South Carolina (K. B. Stansell, pers. comm.). To determine the dosage necessary to cause illiness, between 0.5 and 2.0 g of lithium chloride solution (1.0 g LiCl/2.0 ml H_2O) was mixed with opened chicken eggs in bowls and given to raccoons. Other methods of administration with different food items proved less satisfactory because the exact amount of lithium chloride consumed could not be determined. During these experiments, reaction time and any aversive behavior were recorded.

The second series of tests was conducted from January, 1978 to April, 1978. This series was designed to test the dosage level determined from the previous tests on a larger number of individuals, to determine the affects of multiple exposure, and to determine a dosage level per egg which would not produce a negative reaction to the drug's taste.

For this series of tests, the lithium chloride solution was injected uniformly into intact chicken eggs which were then burited in 40 liter galvanized tubs filled with sand (Fig. 20). Although the dosage level per egg varied (0.5 g and 0.25 g), the total amount of lithium chloride given to each raccoon (1.0 g) was held constant by adjusting the number of eggs a raccoon received. All animals were given untreated eggs during the acclimation period to insure that eggs were a recognized food item for the raccoons to be tested.

Figure 20. Raccoon excavating eggs from a galvanized tub filled with sand.

In the first test, seven raccoons were given two treated eggs per day (0.5 g LiCl/egg) for 20 consecutive days. In the second test, six raccoons received four treated eggs (0.25 g LiCl/egg) and two untreated eggs per day for 20 consecutive days. In the final test, five raccoons received four eggs (0.25 g LiCl/egg) every fourth day for five trials per raccoon. The maintenance diet was fed on intervening days. Each time a raccoon was exposed to treated eggs was counted as one trial. If eggs were eaten or partially eaten, that trial was recorded as no aversion. If eggs were dug up but no opened, that trial was recorded as an aversive response. The initial exposure to the treated eggs was not included in the total number of trials because raccoons were naive for the first treatment.

Different raccoons were used for each test and two raccoons were maintained as controls during each test. These controls were fed on the same schedule and given the same number of eggs as the experimental animals, but were not exposed to lithium chloride.

Field Tests

Testing was conducted in 1978 during the summer turtle nesting season on the beach at South Island in Georgetown County, South Carolina. Fresh loggerhead turtle eggs were obtained from nests that were partially depredated by raccoons. Each egg was uniformly injected with 0.25 g of lithium chloride solution. Twelve injected and approximately the same number of untreated eggs were placed in a false nest which was dug by hand at the apex of a turtle track. Only tracks which did not result in a nest were used (non-nesting emergence). It was hoped that the olfactory and visual cues of the turtle track would be associated with the induced illness. False nests were spaced at approximately 0.4 km intervals, depending upon the location of a recent, non-nesting emergence.

Twice weekly, four to six false nests were buried during late afternoon, located with small stake-wire flags, and checked at dawn the following morning to determine if they had been eaten. During the three-week test period, (26 June - 16 July), a total of 30 treated false nests were buried on the nesting beach. The rate of predation prior to June and the previous year's predation rate were used to evaluate the effects of the lithium chloride treatment.

RESULTS

Laboratory Tests

In the first series of laboratory tests, a dosage of approximately 0.5 g LiCl produced emesis at two hours in one animal and no visible signs in another. Eight raccoons that consumed 1.0 g LiCl had the onset of diarrhea from eight to 60 min post-treatment. Some individuals continued to have diarrhea for several hours. A dosage of 2.0 g LiCl produced severe emesis in 30 min and severe diarrhea in 40 min in one raccoon, but only thirstiness and lethargy in another. Although the onset of visual signs of illness varied widely amoung individuals, 1.0 g appeared to cause the desired effects in an acceptable time.

There was an obvious negative reaction to the taste of the chemical, therefore a small amount of white corn syrup was added to each bowl to mask the taste of lithium chloride when seven new raccoons were given 1.0 g/egg. Every raccoon consumed the entire amount of the mixture and all exhibited diarrhea and emesis. Subsequent to this treatment, eggs were offered to these individuals on an intermittent schedule and some aversive behavior was noted. The duration of the aversive behavior was related to the frequency at which eggs were offered since they were not offered on a regular schedule. However, two individuals refused eggs all four times they were offered during an 18-day period after one treatment.

During the second series of laboratory tests, 1.0 g LiCl was used, but it was not feasible to inject the drug into intact chicken eggs if the corn syrup was also added. Therefore the dosage level/egg was adjusted downward to eliminate the negative taste reaction.

The results of the first test are presented in Table 4. Of 133 trials, 10 resulted in an aversive response. In 44 of the trials the eggs were partially eaten, indicating that the dosage level per egg was still detectable. In the second test, the dosage was reduced to 0.25 g LiCl/egg and untreated eggs were also included. At least two eggs per trial were eaten in all 114 trials. Only 28 of 448 treated eggs were not eaten, and 27 of 228 untreated eggs were not eaten. The majority of the eggs were eaten in all trials and there was no appearant discrimination due to the taste of the drug.

The final test, administered every fourth day for a total of 25 trials, resulted in no aversive response despite the induced illness. For these three tests on 18 raccoons, a total of 272 trials resulted in aversive behavior on only 10 occassions.

Field Testing

The predation rate prior to field testing was 93.4% (N = 61). During the three week test period, the predation rate was 89.8% (N = 49, not including the false nests). All false nests had been consumed by raccoons when checked

Table 4. Results of test using 0.5 g lithium chloride per egg with two eggs given to seven experimental and two control raccoons for 20 consecutive days. N = not eaten; P = partially eaten; E = eaten. *not counted in total number of trials.

TRIALS	CONTROL	CONTROL	EXP. 1	EXP. 2	EXP. 3	EXP. 4	EXP. 5	EXP. 6	EXP. 7
*1	E	E	E	E	E	E	E	E	E
2	E	E	E	E	E	E	E	E	E
3	E	E	E	E	P	E	E	N	E
4	E	E	E	N	N	E	E	E	P
5	E	E	E	P	N	N	E	P	E
6	E	E	E	E	E	E	E	E	E
7	E	E	E	P	E	E	E	P	E
8	E	E	E	P	E	E	E	E	E
9	E	E	E	N	P	E	E	P	P
10	E	E	P	P	P	E	E	E	E
11	E	E	E	E	P	P	E	P	P
12	E	E	E	P	N	P	N	P	N
13	E	E	E	P	E	P	P	P	P
14	E	E	P	N	E	E	E	P	P
15	E	E	E	E	E	E	E	E	E
16	E	E	P	E	P	P	P	P	P
17	E	E	E	E	E	E	E	P	E
18	E	E	P	E	E	P	E	P	P
19	E	E	P	E	E	E	E	P	E
20	E	E	P	P	P	E	E	E	E

the morning following their burial on the beach. The post-treatment predation level was 87.0% (N = 46). The test period predation rate was not included in the test for significance in order to compare the two most dissimilar values. There was no significant difference ($t = 1.11$; $p > .05$) in the predation rate before and after the lithium chloride treatment according to the test of equality for two percentages (Sokal and Rohlf, 1969). The overall percentage of raccoon predation for the test year was 87.2% compared to 86.2% in 1977 and 86.8% in 1979.

Discussion

An aversive conditioned response is the avoidance of certain prey or food items by an animal through learned behavior. In order to initiate an aversive conditioned response with a chemical emetic, three sequential events should occur: the administration of the drug, the physiological reaction producing unpleasant symptoms, and the psychological response by the animal resulting from associating the induced illness with the food or prey item. During the course of this research, numerous factors influenced the successful execution of these three events.

One factor that complicated the first event, administration of the emetic agent, was the detection of the agent. Taste was the major limiting factor in successfully administering lithium chloride. Either the taste was so unacceptable that raccoons did not ingest enough to develop symptoms or they ingested the dosed food but associated the illness with the drug's taste and not the food item. Raccoons shook their heads and dropped treated eggs but consumed untreated eggs without hesitation. Conover *et al*. (1977) noted that coyotes avoided portions of chicken carcasses which contained lithium chloride. Similar taste rejection behavior was reported by Anderson (1980) and Burns (1980) for raccoons and coyotes, respectively. The goal to obtain an aversion to eggs was not achieved so long as the aversion was to the taste of lithium chloride and not to eggs. A dosage of 0.25 g/egg was determined to be the level at which there was no apparent discrimination between dosed and undosed eggs.

When non-detection is important in establishing the correct association between induced illness and the target food item, then other forms of administration (e.g. coyote "getters", injections and encapsulated crystalline LiCl) may interfere with the establishment of the correct association.

The rapidness with which lithium is absorbed from the intestine brings about the second event, the physiological side effects. Lithium ions separate from anions in the stomach and gut where lithium enters the bloodstream. Although the reaction time was variable among individuals, 1.0 g of lithium chloride produced an induced illness. The observed diarrhea, thirstiness and emesis may have been accompanied by stomach pain, nausea, muscular weakness, vertigo and a dazed feeling reported for humans (Gattozzi, 1970). Gattozzi described the symptoms as a cross between seasickness and a hangover.

The emesis and diarrhea appeared to lessen in severity with repeated exposures in the two tests which were given for 20 consecutive days. Gattozzi (1970) in discussing the use of lithium chloride in the treatment of human mood disorders, said that the side effects occurred when lithium levels in the blood climbed above 1.3 - 1.5 meq/L, but abated within a few days or weeks, even though the absorptive peaks were the same, early and late in treatment. The lessening of side effects might have had some bearing on the non-aversive responses of raccoons during repeated daily exposure. However, subsequent testing at four day intervals, while producing side effects, also failed to elicit an aversive response.

The psychological association (third event) between the illness and the food item must be made. Johnson (1970) reported that the food habits of raccoons seem to depend on availability, preference and learning, and that learning appears to be an important factor, especially where predation is concerned. Because of their ability to learn and their powers of memory (Kitzmiller, 1934), raccoons would seem to be ideal subjects for aversive conditioning.

During the second laboratory series, 938 of 1,015 eggs were consumed by 18 experimental raccoons (92.4%) compared to 330 of 344 eggs (96.0%) for six control raccoons. These data show that although successful administration of the emetic with the resultant physiological side effects was accomplished, the psychological association between the food item and the illness was not strong enough in most individuals to produce an aversive conditioned response.

Despite the predominately negative results in the laboratory, a field test was conducted because the laboratory trials had provided a means of administering the drug at an undetectable dosage which resulted in the desired phsysiological responses. The ineffective psychological association of illness to food item was questioned because it may have been an artifact of captivity. Field testing eliminated possible boredom and aberrant behavior due to confinement as well as the forced proximity to the test food. In addition it provided alternate food sources and a test on a population rather than on individuals.

The evaluation of the field test was facilitated by the characteristics peculiar to this predator-prey relationship. Turtles leave distinct one m wide tracts in the sand, and nests are easily located at the apex of these tracks (Fig. 21). Thus the prey density and distribution is readily quantified. Prior research documented the predation level for the previous year (Hopkins et al., 1978) and also prior to testing. Also the prey item (turtle nest) is non-mobile, which preserves its spatial attributes and eliminates behavior associated with attack and escape (Lehner, 1976).

Despite the suitability of this predator-prey relationship and the elimination of factors of captivity, no mitigation of predation could be documented. Since no useful aversive behavior was observed under laboratory or field conditions, other factors which could affect the

Figure 21. Aerial photograph of a loggerhead turtle track leading to and from a raccoon depredated nest.

proper physiological association may have been involved. The non-aversive behavior of raccoons could be explained by the "learned safety" mechanism described by Kalat and Rozin (1973) for rats. By this mechanism, preconditioning raccoons to eggs would interfere with an aversive conditioned response. Because both laboratory and wild raccoons had previous experience with undosed eggs, "learned safety" may have influenced aversive conditioning. While short-term aversion may be produced in certain individuals, the use of lithium chloride on a wild population of raccoons appears to have no merit.

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APPENDIX 1

Sheet No. ____________

SONIC SEARCH

Date ____________________ Vessel ____________________

Observer ______________________________

Weather ______________________________

Sea Conditions ______________________________

Receiver No. ______________

Time	Loran		Remarks	Contact Time	Sonic No.	Sheet No.

SONIC TELEMETRY

HOURLY

SHEET NO. ____________

DATE ______________________ VESSEL ______________________

OBSERVER ______________________

WEATHER ______________________

SEA CONDITIONS ______________________

SONIC NO. __________ FREG. __________ PULSE RATE __________

RECEIVER NO. __________

GEN. LOCATION (BEARING AND DISTANCE TO LAND-MARK)

____

DEPTH __________ WIND SPEED __________ DIRECTION __________

TIME	LORAN		SIGNAL STRENGTH	BEARING	REMARKS

SUMMARY

TURTLE MOVEMENT

BOAT MOVEMENT

OTHER (LORAN)

S.O.P.

(Standard Operating Procedure) for Sonic Telemetry Hourly Data Sheets

These data sheets are designed to standardize type and form of sonic location data. This will facilitate computer analysis and minimize confusion. The sheets are numbered and all sheets must be accounted for. All data blanks must be filled for each sheet. Do not trust your memory with the intention of completing the form later!

One form is used for each different turtle for which contact was made in any given hour. A new sheet is also used each hour for each turtle. This is a separate sheet for each turtle contacted and for each hour. These sheets are designed for positive contact with each turtle and are not to be used for recording locations during a search pattern until contact with a sonic transmitter is made.

The date should be recorded as day/month/year. The month is recorded as a roman numeral and the year will be 79 and must be included as more than one year of data has been recorded. The vessel blank should be completed with the boats' initials, e.g. Atlantic Sun (A.S.); Two Angels (T.A.); Stamas (S); Boston Whaler (B.W.) or Zodiac (Z). The observer's initials should be legibly printed. Weather should be recorded in general terms; Clear, Calm, and Hot; Rainy and Windy etc. (Cloud Cover). Sea conditions should include wave height and general type of sea condition, e.g. rolling sea; choppy, etc. The sonic number is the unit number assigned to a particular unit and will correspond to the radio channel number of the radio unit on the same turtle. A unit number chart is included in this SOP to convert pulse rate and frequency to unit number. The frequency is read directly from the receiver dial but may vary slightly between different receiving units (see enclosed Table). The pulse rate is recorded in the enclosed table in pulses per minute. When checking pulse rate record the rate as pulses, per the amount of time you counted (e.g. 40/½ min., 80/min./ 160 / 2 minutes). Use the stop watch! The time element is used to evaluate the reliability of the count. A count should be at least one minute, but this is not always possible.

The receiver number is written on the top of the receiving unit. This number is needed in order to know the frequency and to evaluate the relative strength of signal as it relates to battery strength of the receiver.

General location should be recorded in order for different workers to gain their bearings when coming on duty and to help evaluate the accuracy of Loran C equipment. It also helps in data analysis and in locating a turtle with a vessel not equipped with Loran C. Landmarks should be specific and on the charts (e.g. buoys, rivers, islands, etc.). Record at least two landmarks and the compass bearings to each. Record bearing based on 360^{o} of the compass. Also estimate distance to the landmark.

Record the depth of the water in feet. This reading should come from a depth meter and not estimated.

Estimate wind speed and use a compass to determine wind direction unless on the Atlantic Sun which is equipped to monitor wind speed and direction. If any data is estimated, note it with (est.).

The time of a location will be recorded on a 24 hour day and not as AM and PM. Make sure you record correctly. It is hoped that you can add 12 to a number for PM equivalents.

The Loran locations are to be recorded directly from the Loran C unit. Note if the Loran C unit is displaying a green or orange light. Record the complete five digit reading for each of two stations each time. Mistakes here will not be tolerated.

Signal strength should be recorded in relative terms (e.g. very strong, strong, good, fair, poor, very weak, and the compass bearing to the transmitter (360^{o}). This information is used to differentiate boat drift from actual turtle movements.

The remarks section should include any general comments. Write down everything. Your memory will not help me much in September. Things such as boat drifting from turtle, signal irregular, simultaneous signals, interference from porpoise, equipment troubles, visual sightings of turtles, etc.

Summary is just that, describe in detail the movements of turtles or lack thereof. Was the movement straight or meandering? Was it fast or slow? Was the turtle sunning? Was the turtle following a contour line (use chart)? Also record the boat movement. Was the boat being blown or drifting away from the turtle or was the movement in pursuit of a moving turtle? Was the boat at anchor? The summary of "other" is for notes on the equipment such as the Loran C unit or receivers or transmitter. It is also for recording the presence of bird species seen, the presence of porpoise (species), whales, sharks, squid, shrimp, jellyfish, flying fish, man of wars, other vessels, trawling activities, etc. Write it down, it may be important!!!

In general

(1) No data is better than bad data.

(2) Be accurate, neat, and complete.

(3) Check your work.

(4) Record all times using a 24 hr. clock.

(5) Record all bearings to the object and express as a degree reading not a compass point.

(6) If a data point is estimated record that it is estimated.

(7) If a data point is not available record that it was not available (N.A.) and why.

(8) Ask questions if you don't know.

Finally

Record on the data sheet a note when you start a shift and a note when you complete a shift. Also note on the sheet any time when a new transmitter is first encountered, and last encountered. Note when a turtle is left to initiate a search pattern for other turtles and if a buoy was dropped. If a search pattern is initiated, reference the Sonic search sheet number. Note the time and location of the first movement of a turtle in the morning and the last movement at night.

Take time at shift changes to brief the next work. STAY AWAKE!!!!!! The first bad data point you record may be the last data point you collect on this project.

STANDARD OPERATING PROCEDURES FOR BASE STATION MONITORING OF MARINE TURTLES

Equipment Required

1 Receiver, Falcon Five or TRX-24
1 Headphones
1 12 volt battery
1 connecting cable for 12 v battery
1 lantern or candle, (spare batteries)
paper and pencils
note cards
watch or clock
list of radio frequencies and turtles to be monitored
mobile radio

Base Station Set-Up Procedures

1) Observe antennae on tower for damage
2) Connect antennae cables to switch box in order
3) Connect RCVR cable to receiver
4) Test receiver (check battery level)
5) Test mobile radio
6) Test lantern, etc.
7) Wind and reset clock to correct time

Monitoring Procedures

1) Start at dusk and monitor every 15 minutes until dawn
2) Turn on Falcon 5 receiver (use int power if available)
3) Select test transmitter and set gain with switch box set on ALL ANT.
4) Make battery test (BT), (battery level should be above .6) reset to signal (*).
5) Set delta F (ΔF) to 0.
6) Select Falcon Five (number for transmitter #1 on list).
7) Allow ~ 15 seconds to listen for signal
8) Set dial for trans, #2 and proceed as above
9) Continue through F5 numbers for all transmitters.

BASE MONITORING (TRX-24)

1) Begin monitoring Ch. 1.
2) Select low band
3) Select monitor mode S-M (speaker monitor, this will also supply sound to headphones)
4) Set fine tune to 0 begin rotating fine tune very slowly toward → 15 → 30
5) Listen for signal
6) Select Ch. 2 and proceed as above (variations of amount of time, fine tuning is encouraged)
7) Continue through channels as above

Confirmation of terrestrial turtle activity

1) Record time signal first heard
2) Switch antenna to obtain best signal from proper antenna for direction
3) Instruct recovery person to monitor with hand held antenna for verification of direction (recovery person goes to turtle)
4) Continue monitoring for duration and relative signal strength
5) Continue to monitor other channels every 15 minutes
6) Record time turtle reenters water
7) Complete data form with recovery person's notes as to turtle's activities, etc.

Recovery personnel equipment required

Hand held antennae
Receiver TRX-24 only
Walkie talkie
Headphone
ATC - Honda
Flags, prob stilk
Marker
Note cards, pencils
Watch

Procedure for confirming terrestrial turtle activity on Sand Island

1) Confirm signal from island at boat site. Note time.
2) Advise base that turtle is on Sand Island and you are crossing (if possible).
3) Hook boat to ATC and proceed to inlet (don't forget your paddles).
4) Load ATC in boat.
5) Make your crossing (note your location in relation to something on the other side for direction, listen to surf in relation to your location, proceed with caution).
6) Check signal on Sand Island (note signal strength for possible distance). Note time.
7) Unload ATC.
8) Pull boat from water (if tide is rising pull boat well above water line).
9) Proceed down beach checking each crawl for signal.
10) When turtle is located observe as required.
11) Check equipment on turtle before she reenters the surf. Note the time she enters the surf.
12) Flag nest or crawl as required (date, radio number and sonic number are to be written on flag). Note location.
13) Return to boat.
14) Advise base of your status.
15) Reload ATC in boat
16) Return to South Island (again be aware of your location).
17) Return boat to original location (turn boat in direction for hooking, flip it).
18) Return to base.