DISTRIBUTION OF LOGGERHEAD TURTLE NESTING ACTIVITY IN SOUTH CAROLINA BY AERIAL BEACH SURVEY

Sally Hopkins-Murphy & Thomas M. Murphy

STUDY COMPLETION REPORT

October 1, 1979 through September 30, 1982

E-1, Study No. VI-A-2

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IN SOUTH CAROLINA BY AERIAL BEACH SURVEY

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Study Duration: October 1, 1979-September 30, 1982

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PART I

AERIAL SURVEY METHODOLOGY FOR LOGGERHEAD TURTLE NESTING ACTIVITY IN SOUTH CAROLINA

By

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Study Completion Report

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INTRODUCTION

The most effecient means of gathering data on marine turtle nesting activity over a large area appears to be aerial survey. But aerial survey is only useful if it is reliable and provides reproducible results. Aerial survey was used by Carr and Carr (1977) on the east coast of Florida and in the Caribbean and by Stancyk, (unpub.) in South Carolina. LeBuff and Hagan (1979) flew aerial surveys on the southwest coast of Florida to determine important beaches, nesting peaks and changes in nesting over a seven year period. Richardson et al. (1980) conducted surveys in Georgia as a preliminary population estimation tool. However, a quantification of the variability in this method has not been documented adequately. The puropse of this study was to first quantify the major factors affecting the precision and accuracy of track counts and then to standardize the most reliable method for conducting aerial survey.

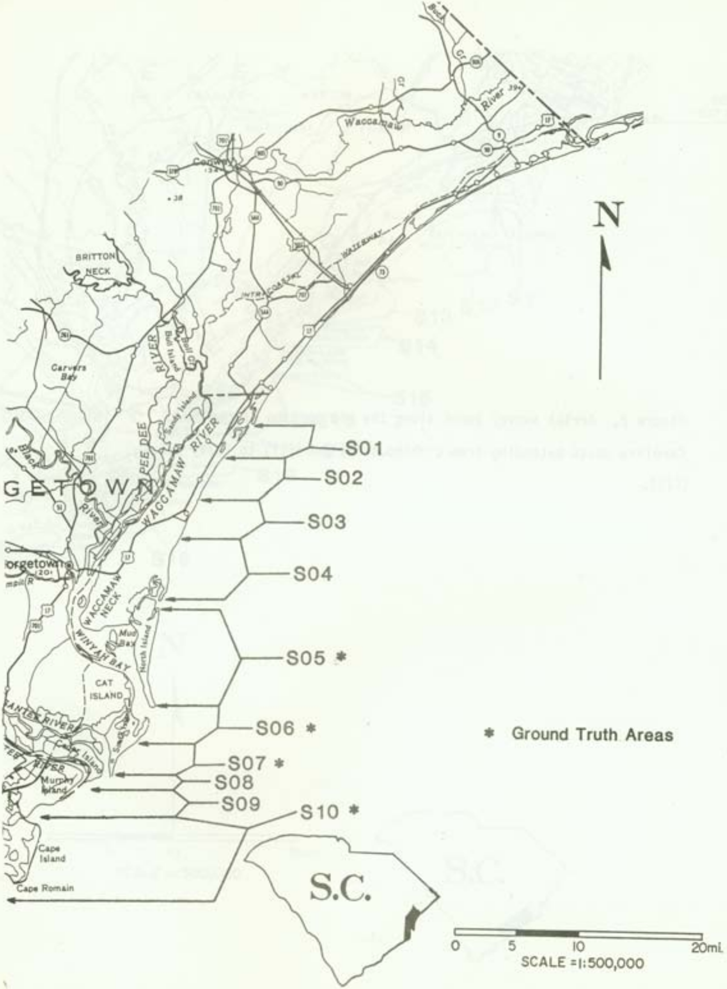
ACKNOWLEDGEMENTS

Thanks are expressed to J. Coker, R. Dunn and W. Oldland for their able technical assistance, to K. Kriet and G. Garris for providing ground truth information and to D. Scott, our pilot for his skillful flying. We would also like to acknowledge and thank the Yawkey Foundation Trustees, S. C. Nongame Check-off and Section 6 Federal Aid Endangered Species funding for financial support.

STUDY AREA AND SURVEY METHOD

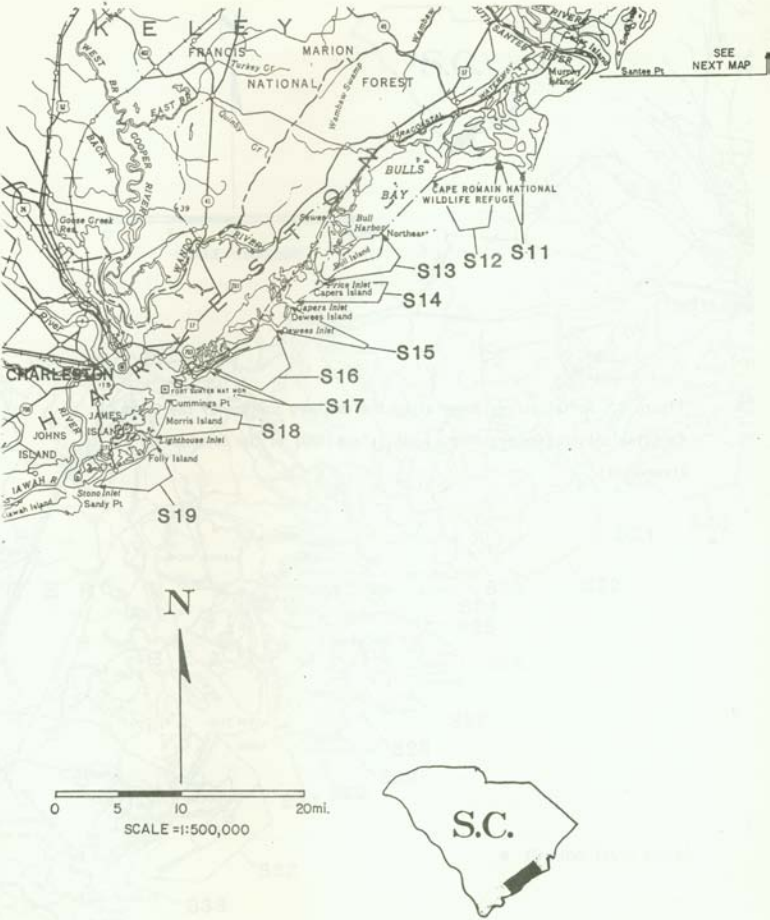
Survey flights were made each summer from 1980-1982 over the South Carolina coast from Murrells Inlet to the Savannah River (Figures 1, 2, & 3). The aircraft was a Hughes 500 D helicopter with front and rear doors

Figure 1. Aerial survey zones along the northern portion of the South Carolina coast extending from Murrells Inlet (S01) to Cape Island (S10).



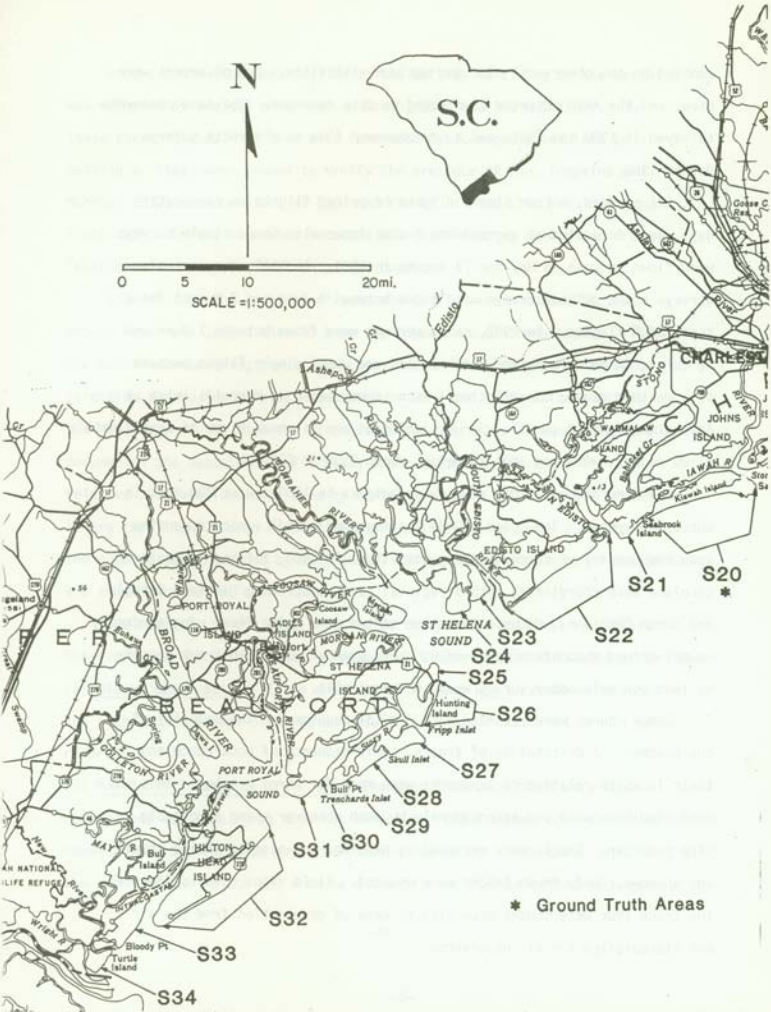
N
S01
S02
S03
S04
S05 *
S06 *
S07 *
S08
S09
S10 *
* Ground Truth Areas
S.C.
0 5 10 20mi.
SCALE =1:500,000
Conway
BRITTON NECK
Carvers Bay
PEE DEE RIVER
WACCAMAW RIVER
WACCAMAW NECK
WINYAH BAY
CAT ISLAND
North Island
Mud Bay
Cape Island
Cape Romain
INTRACOASTAL WATERWAY
Waccamaw River

Figure 2. Aerial survey zones along the mid portion of the South Carolina coast extending from Lighthouse Island (S11) to Folly Beach (S19).



SEE NEXT MAP
FRANCIS MARION
NATIONAL FOREST
Turkey Cr
Wambaw Swamp
WEST BR
EAST BR
BACK R
COOPER RIVER
Goose Creek Res.
WANDO RIVER
SANTEE RIVER
Cape Island
Murphy Island
Santee Pt
BULLS BAY
CAPE ROMAIN NATIONAL WILDLIFE REFUGE
Sewee
Bull Harbor
Bull Island
S11
S12
S13
Price Inlet
Capers Island
S14
Capers Inlet
Dewees Island
Dewees Inlet
S15
CHARLESTON
S16
FORT SUMTER NAT MON
S17
Cummings Pt
Morris Island
S18
JAMES ISLAND
JOHNS ISLAND
Lighthouse Inlet
Folly Island
Stono Inlet
Sandy Pt
S19
N
0 5 10 20mi.
SCALE =1:500,000
S.C.

Figure 3. Aerial survey zones along the southern portion of the South Carolina coast extending from Kiawah Island (S20) to the Savannah River (S34).


N
S.C.
0 5 10 20mi.
SCALE =1:500,000
CHARLESTON
JOHNS ISLAND
WADMALAW ISLAND
Kiawah Island
Seabrook Island
EDISTO ISLAND
ST HELENA SOUND
PORT ROYAL ISLAND
LADIES ISLAND
Coosaw Island
Morgan Island
ST HELENA ISLAND
Hunting Island
Fripp Inlet
Skull Inlet
Bull Pt
Trenchards Inlet
PORT ROYAL SOUND
HILTON HEAD ISLAND
Bull Island
Bloody Pt
Turtle Island
BEAUFORT
COMBAHEE RIVER
COOSAW RIVER
MORGAN RIVER
BROAD RIVER
COLLETON RIVER
BEAUFORT RIVER
SOUTH EDISTO RIVER
NORTH EDISTO
STONO RIVER
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29
S30
S31
S32
S33
S34
* Ground Truth Areas

removed on the oberrvers' side for maximum visibility. Two observers were used, and the rear observer also acted as data recorder. The same observers surveyed in 1980 and 1981, and a new observer flew on alternate surveys during 1982.

All surveys, either single flights or paired flights on consecutive days, were scheduled at approximate 2-week intervals. Seven single surveys were flown between 16 May and 13 August in 1980. In 1981, three single surveys and 2 paired surveys were flown between 4 June and 2 August for a total of 7 flights. In 1982, seven surveys were flown between 7 June and 22 July. Three were paired flights, and one was a single flight because of a weather caused cancellation. Each survey began at Murrells Inlet at Approximately 6:30 am EDT. Surveys ended at the Savannah River at approximately 11:00 am EDT, with one stop to refuel about 8:30 am EDT.

The aircraft was flown at varying heights in 1980 and at 200 feet in subsequent years. The speed (50-80 knots ground speed) varied depending upon the density of turtle nesting activity. In 1980, flights in South Carolina were coordinated with a regional survey including Florida, Georgia and North Carolina. Because the other states were using fixed wing aircraft, we maintained a constant speed of 80 knots without regard to track density so that our helicopter survey would be comparable.

Track counts were recorded with digital counters on the majority of the beaches. A description of tracks, their sequence of occurrence and their location relative to landmarks were made for three beaches. This was done simultaneously and independently by each observer using a portable tape recorder. Tracks were recorded as nesting, non-nesting (false crawls) and unknown. Only fresh tracks were counted. Field signs used to identify the track type were chosen according to ease of observation from the air and standardized for all observers.

Ground truth (the verification of the turtles' activity on the beach) was recorded by project personnel on North, Sand and South Islands. On these three islands, all body pits (characteristic depressions left by nesting turtles) were probed to verify the presence of eggs (Hopkins and Murphy, 1980). Cooperators at Cape and Kiawah Islands also provided ground truth data. Ground observers recorded all fresh nesting crawls and fresh false crawls and their location on the beach.

In addition, the location of some old crawls were recorded if the ground observers judged them to have the appearance of fresh tracks. These old but fresh-appearing tracks were recorded to identify sources of error. Intensive ground truthing was conducted on Sand and South Islands within one-half hour of the time the aircraft passed overhead. Ground observers documented the description of tracks, their sequence, and their location relative the same landmarks seen by aerial observers. To aid this procedure before the flight, large numbers were drawn in the sand every 2,000 feet. The numbers were recorded by both aerial and ground observers to re-establish the track sequence at each number..

The analysis of our data relative to the results obtained by different observers, aerial bias and aerial accuracy is based on the following error types.
(1) Missed observation: There are several reasons why an observer may not see a track. A missed observation results in a lower number of tracks being recorded.
(2) Misidentification of track type: Counting a nesting track as a non-nesting one and vice versa does not affect the total number of tracks recorded. However, an observer bias may occur toward one or the other crawl type, or the error may be random and produce a low bias if they cancelled each other.

(3) Aging error: Improper aging of a track may bias results in two ways. If the observer tended to identify new tracks as old and did not count them, a lower total would result. However, if old tracks were counted as fresh, then the total recorded would be higher. These two situations could also cancel each other and produce a low bias.

More than one type of error may occur on a single track record. For example, a track could be misaged and misidentified. If the error was a missed observation, then the other two types of error would not be possible. It is impossible to distinguish between a missed observation and an aging error (where a track was thought to be old) without mapped ground truth.

Within the context of this paper, the following terms are defined this way. Aerial bias is the magnitude of disagreement between the aerial observer and the ground truth regardless of the error type with the ground truth confirmed as correct. Accuracy is not used in a statistical sense, but rather refers to the ability to see, correctly age and identify individual tracks on the beach. Precision is the ability to maintain consistency from one flight to the next in the aerial bias and accuracy.

RESULTS

The total counts for each observer for all 7 flights in 1980 are shown in Table 1. Differences between observers were higher for nests(14.6%) than false crawls (4.0%) and was slightly over 6% for total tracks counted. Table 2 shows the aerial bias expressed as a percentage for each observer when compared to the ground truth data. Although the difference between observer results was minimal (Table 1), each exhibited bias relative to ground truth data. Both observers over counted nests and under counted false crawls.

Table 1. Statewide counts of total tracks seen in 1980.

Observers	Flight 1		Flight 2		Flight 3		Flight 4		Flight 5		Flight 6		Flight 7		Totals		% difference between obs.
	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	
Nest	0	0	91	81	65	62	57	53	73	73	49	43	7	6	342	318	14.6
FC	0	0	68	80	159	142	62	61	72	72	35	32	3	4	399	391	4.0
Unk.	0	0	1	6	7	8	6	10	40	34	5	9	0	0	59	67	
Total	0	0	160	167	231	212	125	124	185	179	89	84	10	10	800	776	6.2

Table 2. Comparison of aerial counts with ground truth, 1980

	Ground Truth	Obs. 1	% bias	Obs. 2	% bias
Nest	132	180	+36.4	154	+16.7
FC	241	199	-17.4	193	-19.9
Unk.	1	14		21	
Total	374	393	+ 5.1	368	- 1.6

It was apparent from the percent bias that observers were not counting tracks in the same way. To test this, the sequencing of tracks relative to beach landmarks was attempted in 1981. This would also help determine the causes of errors and distinguish between bias and accuracy.

Little or no turtle activity was noted on the May and August flights in 1980. Flights were not scheduled in these months in 1981 and 1982 because they were not considered cost effective in South Carolina.

The results of the 1981 flights are shown in Tables 3 and 4. The difference between observers was approximately one-third of what it was the previous year for total tracks (Table 3). The aerial bias for nests compared to ground truth also improved by approximately two-thirds for each observer in 1981 (Table 4). The speed of the aircraft was slowed for beaches with a higher track density and probably contributed to the reduced biases along with both observers being more experienced. When aerial observations were compared to the ground truth for 1981 there was an increase in the bias for total tracks (Table 4). This increased bias occurred for the most part on the second day for each of the two paired flights. The results of the sequencing the tracks with ground truth (Table 5) explained the bias. These data show the higher percentage of errors in the missed observation category on the second day of paired flights. It was caused by difficulty in correctly aging tracks.

Table 3. Statewide counts of total tracks seen in 1981

Observers	Flight 1		Flight 2		Flight 3		Flight 4		Flight 5		Flight 6		Flight 7		Totals		% difference between obs.
	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	
Nest	107	112	164	138	111	111	88	85	68	67	80	79	30	30	648	622	8.2
FC	98	107	84	69	80	80	107	99	62	61	45	53	46	45	522	514	3.0
Unk.	2	4	7	13	9	14	8	12	3	8	16	14	2	3	47	68	
Total	207	223	255	220	200	205	203	196	133	136	141	146	78	78	1217	1204	2.2

Although the error rate is recorded under missed observations it was actually an aging error. The error was caused by seeing tracks and thinking they were old because they did not extend below the high water mark. If this aging problem had not occurred on these 2 flights, the aerial bias would have been similar to the 1980 bias. To reduce aging errors, timing the flights with the correct tidal stage was found to be essential. The aerial bias for false crawls remained about the same for both observers between years. Both observers still under counted false crawls and over counted nests, but the nest count bias was reduced from the previous year. In addition, closer spaced landmarks were needed to better document the sequence of crawls.

Table 4. Comparisón of aerial counts with ground truth, 1981

	Ground Truth	Obs. 1	% bias	Obs. 2	% bias
Nest	202	233	+15.3	213	+5.4
FC	337	250	-25.8	266	-21.1
Unk.	1	3		12	
Total	540	486	-10.0	491	-9.1

Table 5. Types of errors recorded for aerial observers when compared to mapped tracks, 1981

Flight Date	Tracks by Grd.Tru.	Observer #1			Observer #2		
		Mis. Ob.	Mis. ID	Aging	Mis. Obs.	Mis. ID	Aging
6/4	19	4	2	0	2	3	0
6/19	32	2	10	3	4	6	1
6/20	60	18	11	0	7	9	1
7/5	21	1	7	0	1	8	0
7/19	16	1	1	0	0	2	0
7/20	33	9	1	0	6	3	0
8/2	35	6	5	0	5	4	2
Total	216	41	37	3	25	35	4
Percent error by type		19.0%	17.1%	1.4%	11.6%	16.2%	1.8%
Total percent by error			37.5%			29.6%	

Table 6. Statewide counts of total tracks seen in 1982

Observers	Flight 1		Flight 2		Flight 3		Flight 4		Flight 5		Flight 6		Flight 7		Total			% difference between obs.
	#1	#2	#3	#2	#3	#2	#1	#2	#3	#2	#3	#2	#1	#2	#1&3	#2		
Nest	79	76	92	114	53	60	85	86	89	108	57	56	58	68	513	568		10.2
FC	58	60	82	74	157	143	115	124	125	118	63	64	80	70	680	653		4.0
Unk.	6	3	2	10	3	6	5	4	9	5	0	4	3	0	28	32		
Total	143	139	176	198	213	209	205	214	223	231	120	124	141	138	1221	1253	1237	2.6

In 1982 to avoid aging error, paired flights were scheduled on the day prior to the optimum tide rather than the day after the optimum tide. A major emphasis was placed on teaching this technique to a new and inexperienced observer (observer 3) who replaced observer 1 on some flights. The results of the 1982 flights for total tracks counted are shown in Table 6. When observers 1 and 3 are combined and compared to observer 2, the resulting percent difference between observers is approximately the same as the previous year. When observer 3 is compared to observer 2, there is a 7.2 difference. After his initial flight, however, there was only a 1.8% difference for the 3 remaining flights. This compares to a 1.2% difference between observers 1 and 2 on their 3 flights together.

Also in 1982 a more detailed method was used to sequence tracks on the intensive ground truth beaches. By drawing large numbers in the sand, the correct sequence was reestablished every 2,000 feet. Because the sample size was too small for observer 1, only observers 2 and 3 are compared as to error category in Table 7. There was a marked increase in accuracy for observer 2 from 29.6% error rate in 1981 to 17.9% in 1982 and the error rate for observer 3 was 18.9%. The percentage for each type of error between observers 2 and 3 was in close agreement.

Table 7. Types of errors recorded for aerial observers when compared to mapped tracks, 1982.

Flight Date	Tracks by Grd.Tru.	Observer #1			Observer #2		
		Mis. Ob.	Mis. ID	Aging	Mis. Ob.	Mis. ID	Aging
6/7	13	1	0	5	-	-	-
6/8	6	0	1	1	0	1	1
6/23	22	0	3	0	0	2	3
7/7	17	1	0	0	-	-	-
7/8	26	1	1	1	3	2	0
7/21	62	3	8	1	3	7	0
7/22	5	0	0	0	-	-	-
Total	151	6	13	8	6	12	4
Percent error by type		4.0%	8.6%	5.3%	5.2%	10.3%	3.4%
Total percent error			17.9%			18.9%	

Thus during 1982 the most frequent error was misidentification. Aging errors and missed observations occurred about equally.

An ANOVA was performed to determine if there was a significant difference in the bias between observers 1 and 2 for the 16 surveys they flew together. The bias was found to be non-significant at the .05 level. Because of the low number of surveys flown together for observers 2 and 3, no ANOVA was calculated. However, the percent bias was so low that it would appear that no real difference between observers was likely.

ANOVA Table

Source of Variation	df	SS	MS
Obs.	1	38.28125	38.28125
Flights	15	112794.4688	7519.631253
Remainder	15	1045.2188	69.68125333
Total	31	113877.9688	3673.482865

$F = 4.54$ $F = 0.5494$ NS

$_{.05}\ _{1,15\ d.f.}$ $F = 107.9147^{*}$

*Significant at $P < .001$

The islands that were selected for ground truth are some of the most heavily used by turtles for nesting (see Part II of this report). Because of this, we were able to ground truth 28%, 34% and 38% of the turtle nesting activity in the study area for 1980, 1981 and 1982, respectively. We compared our flight results with those from beaches with daily surveys. In 1980 we sampled approximately 11.3% of the seasonal activity. In 1981 approximately 11.7% was sampled, and in 1982 about 12.5% was sampled. Therefore, if all 8 possible flights can be flown in June and July at least a 13% sample of the nesting activity should be obtained.

DISCUSSION

There are many variables associated with aerial survey. Some factors affecting the condition of tracks on the beach, such as weather, are beyond the control of observers. Other factors pertaining to flight conditions can be manipulated to some degree. The flight schedule and the variables associated with how the aircraft was flown were factors of major importance to the success of this methodology.

Flight scheduling based on the tidal cycle

One purpose of this study was to count only tracks made during the previous night. To do this with a high degree of reliability, surveys were scheduled to maximize both the monthly tidal cycle and the semi-diurnal tidal period. The twice monthly spring tides washed the widest area of the intertidal zone and removed all old tracks. Surveys were flown the morning after this high tide, which occurred just at dark about 9:00 or 9:30 p.m. EDT. Thus tracks in the intertidal zone were made only by turtles emerging that evening. These were counted as "fresh". When surveys began in the morning, the tide was on a rising cycle. The time of high water is later in the southern portion of the state. Counts were started at the northern end of the study area to maximize the amount of flight time before the rising tide erased tracks. Thus, the direction of the survey provided more flight time before the a.m. high tide. Some false crawls, low on the beach, were erased before completion of the survey. Although the morning high tide occurred during the latter part of the survey, the range of this tide was 1 - 1.5 feet lower than the previous night's high tide. Thus, tracks high in the intertidal zone and nesting tracks above the high tide line remained visible. The accuracy of counting only fresh tracks was affected by: the time of the evening high tide relative to the time at which the turtles crawled, and the relative height of this tide on consecutive days. For example in 1981, the difference of one hour in the tidal cycle resulted in track aging errors on the second flight day. The evening high tide was one hour later after dark the second night. Turtles had enough time to come ashore on a rising tide, nest, and leave on the high tide. Therefore, none of their tracks extended below the high water mark, our criterion for a fresh track. Also since the monthly tidal stage was on a dropping cycle, the high water mark on the beach was lower the second flight day, leaving some older tracks still visible. Thus fresh tracks made soon after dark, and one day old tracks appeared similar. Neither type of track extended below the most recent high water mark. Scheduling flights on the day of the optimum tide and the day prior to this tide in 1982 corrected most of the errors in aging tracks.

Aircraft variables

The position, speed and height of the aircraft affected the ability of observers to see tracks. During the course of this research, some flight conditions were decided upon by subjective means; others could be quantified objectively.

A. Speed

The speed of the aircraft was found to be one of the most crucial factors in achieving accurate data, especially where track density was high. Tracks will obviously be missed if the aircraft speed is too fast. During 1981 and 1982, the speed of the aircraft was adjusted to the track density. On low density beaches (< 1 track/km/flight) tracks could be recorded adequately at 80 knots (92 mph). On moderate desity beaches (1 to 5 tracks/km/flight) it was still possible to accurately count tracks at 60 knots (69 mph). On Cape Island, Cape Romain NWR, where track densities are high. (> 5 tracks/km/flight) it was necessary to fly at 50 knots (57 mph). This speed is below that achievable by most fixed wing aircraft.

B. Height

Flying too low caused a similar problem as flying too fast. Objects were in the field of view for a shorter time. They appeared to pass below the aircraft more rapidly, causing increased eye movement and thus fatigue. During our surveys, 200 feet was found to be the best altitude at which to fly. It was low enough to see details of the body pit, but high enough so that there was ample time to view the entire crawl.

C. Position

The position of the aircraft was found to be important, especially on wide beaches. On these beaches, flying above the surf zone gave a good view of false crawls, but was too far from the dunes to see the body pits of nesting tracks well. Nesting can be used to obtain population indices and is also an indication of beach quality. Therefore, we felt it was important to gain a better view of the dune area. The best position for the aircraft was found to be over the lower intertidal zone, not out over the surf zone. False crawls could still be seen directly below the aircraft with the doors removed and the dunes were close enough to note details of the body pits.

D. Strip Width

The height and position of the aircraft also affected the width of the strip of beach which can be viewed. Caughley (1974) reported that increasing the strip width increases the bias. The strip width for beach aerial survey is not wide for most beaches. By being able to concentrate on the high tide line and intertidal zones to determine fresh tracks, the strip width was further reduced and resulted in a very low bias for total tracks seen.

E. Pilot

The importance of the pilot in maintaining the correct speed and position of the aircraft cannot be over-stressed. A good pilot eliminates the distractions to the observers of poor position and changes in speed or altitude. The pilot controls the flight conditions to afford observers the best and longest view of the tracks below while still completing a statewide survey in a reasonable time.

F. Observer Experience

Observer experience is an obvious variable in any aerial survey, not just turtle track counts. Observers 1 and 2 had extensive previous experience with both aerial survey of other species of wildlife and with ground surveys of marine turtle nesting. Observer 3 had only limited aerial survey experience and none with marine turtles. Observations were made independently between observers. The total counts for each island were discussed during the flight and disputed tracks or segments of the beach were re-flown as a learning experience. The helicopter enabled us to hover and examine a track. In this way we knew how each observer made his decisions based on field signs. Observer 3 was shown slides and photographs of tracks prior to his first flight. He was briefed on how various field signs should be interpreted. His observations were made independently from observer 2, but problem crawls were discussed during his first flight.

G. Fatigue

Fatigue caused a loss of concentration by the observers. This was more noticeable after about 3 hours of flight time and where long sections of coastline had few tracks. Although this factor was difficult to quantify, it was probably not an important source of error.

Beach variables

Of equal importance to the success of this methodology was the standardized interpretation of field signs by minimizing the effects of beach variables. The correct scheduling of flights also improved our results.

The major variables associated with the nesting beach in order of importance were: the activities of turtles on the beach, the beach type, the amount of sunlight, human activity on the beach, wind and rainfall.

A. Turtle activity

The emergence of turtles upon a beach and their activity, left in the form of tracks in the sand, was an important variable in correctly counting tracks.

The following field signs were found to be the most reliable in distinguishing nests from false crawls.

Nesting crawl field signs:

Tracks which resulted in a nest being laid exhibited certain features visible from the air (Figures 4 & 5). The first was a distinct shape of the body pits. They were either circular, if at the base or side of a dune, (Figures 4 and 5C) or oblong if out on the flat berm of the beach or washover terrace (Figure 5A). The landward side of the body pit often had a crescent-shaped cliff (Figure 4D). This is formed as the turtle uses her fore-flippers in a sweeping motion to throw sand behind her in covering the nest and in turning back toward the sea. Covering the nest (Figure 4B) also produces an interruption in the incoming track (Figure 4A) made by the flippers, compared to a continuous track in non-nesting emergences. Another field sign indicating a nesting track was thrown sand (Figure 4C), usually on the upper or landward side of the body pit. This sand is brought to the surface by the rear flippers in excavating the nest cavity. The turtle throws this sand forward over each shoulder as she digs the nest. This sand's moisture content is higher than that of the surface sand. It may also be a different color or texture and was clearly visible from the air. The final indication of nesting was where the length of the incoming track was shorter than the outgoing track (Figure 4A & E). When unequal tracks were observed, it was assumed that the turtle spent an extended period of time on the beach and therefore nested. The longer, outgoing crawl was made after the tide had receded. This was valid except when the turtle became disoriented and wandered for long distances.

False crawl field signs:

The two clearly distinguishing field signs of a false crawl were: lack of a body pit and equal lengths of the incoming and outgoing tracks (Figure 6). Many false crawls did not extend above the line of the last high tide (Figure 6B). They were usually a simple arc or they had a loop at the top. Other false crawls extended above the high water line onto the beach berm or even up into the dunes. In some cases the turtle ascended the dunes and attempted to nest. This type of emergence produced disturbed vegetation and the appearance of a body pit. However, it did not have the typical signs of a true body pit and tracks were also of equal length (Figure 6D). A turtle turning in place on a washover terrace (a washover terrace is defined as an area of the beach where dunes have been flattened by wave action and the sand pushed back over into the saltmarsh) produced similar field signs (Figure 6A). A partially dug cavity (Figure 6C) was usually distinguishable from a depredated nest (Figure 5B) which had scattered egg shells in the area. Another type of false crawl is made when the turtle crawls parallel to the base of a scarped dune causing sand to cascade down upon the track making identification very difficult (Figure 6E).

Field signs for unknowns:

The only time a track was categorized as "unknown" was when the body pit had been obliterated or was out of sight and the two tracks were of equal length (Figure 6E). Since the unknown category essentially provided no information on track type, it was used as little as possible.

On beaches with high density turtle use, numerous turtles crawled over each other's tracks or body pits. This situation caused confusion in counts and identification of track type. A particular problem concerned tracks that meandered over washover terraces. In most cases these were false crawls. If a nest was involved, the turtle almost always wandered after she nested. Thus locating the incoming track quickly from the air made for easier identification. It was also difficult to note individual field signs where there was the interaction of many tracks.

B. Beach type

Variations in beach type also affected the reliability of track counts. Beaches along the South Carolina coast have fine sand, coarse sand, coarse sand

Figure 4. Typical nesting track. (A) incoming track, (B) area where the nest cavity and track has been covered with sand, (C) thrown, wet sand, (D) crescent-shaped cliff, (E) out-going track and (F) high tide line.


C
D
B
A
F
E

Figure 5. Types of nesting crawls. (A) fresh track with oblong body pit, (B) day-old track with raccoon depredated nest, (C) fresh track with typical body pit, (D) weathered, older tracks with body pit and (E) high tide line.

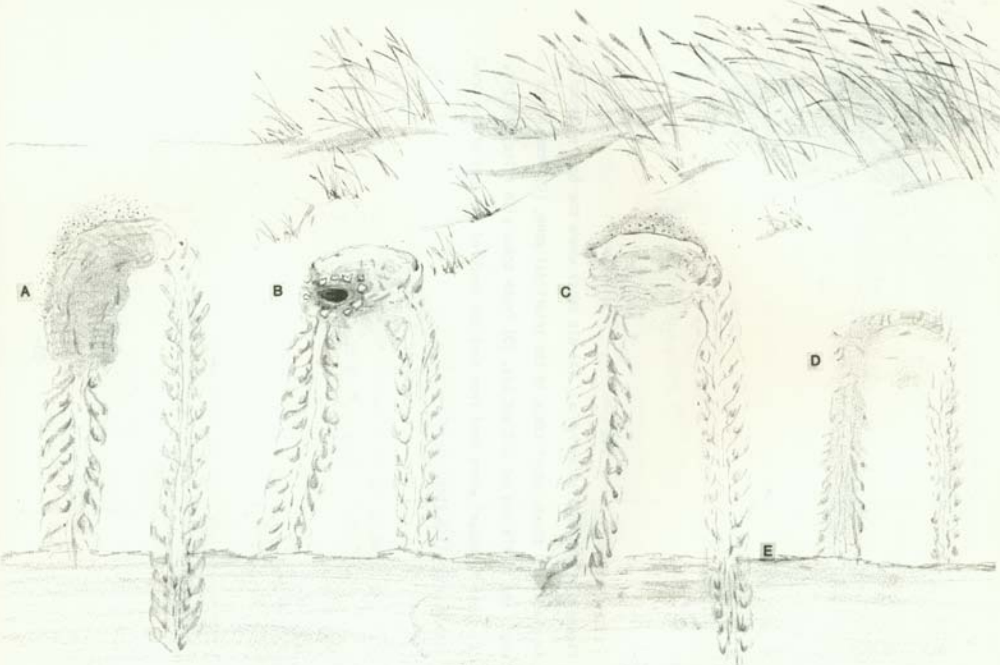
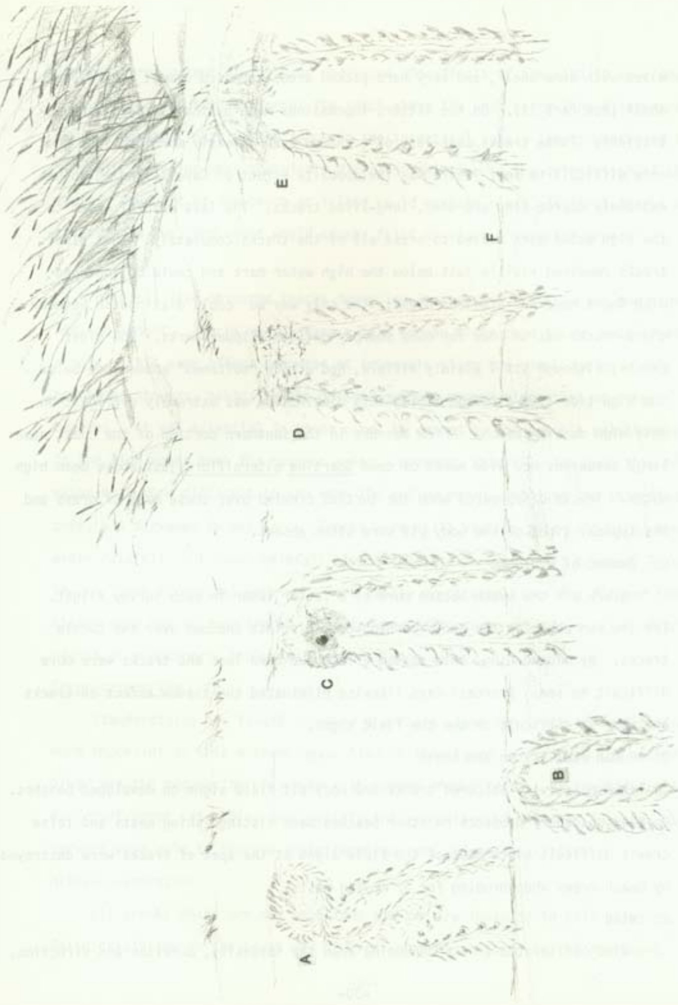

A
B
C
D
E

Figure 6. Types of false crawls. (A) old track where the turtle turned in place, (B) fresh, short track in the intertidal zone, (C) fresh track where the turtle dug but did not lay, (D) fresh track with false body pit, (E) fresh "unknown" where sand from dune has obscured the apex of the crawl and (F) high tide line.


A
B
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F

mixed with some shell, and very hard packed areas composed almost entirely of shell (see Part II). On the latter, impressions made by the flippers were indistinct. These tracks cast less of a shadow even in early morning light and were difficult to see. There was the opposite effect on Cape Island which has extremely coarse sand and deep, long-lived tracks. The last wash of waves to the high water mark failed to erase all of the tracks completely. Thus older tracks remained visible just below the high water mark and could be confused with those made the previous night. The only way we could distinguish between these tracks was to look for more sharply defined flipper marks. The older tracks, although still plainly visible, had a more "softened" appearance below the high tide line although making this distinction was extremely difficult on this high density beach. A few beaches in the southern portion of the coast near large estuaries had wide racks of dead Spartina alterniflora just above mean high water. Tracks disappeared when the turtles crawled over these mats of grass and the typical signs of the body pit were often absent.

C. Amount of sunlight

Glare off the beach became more of a factor later in each survey flight. The low sun angle in the early morning cast distinct shadows over the turtle tracks. By mid-morning, this shadow effect had been lost and tracks were more difficult to see. Overcast days likewise eliminated the shadow affect on tracks and made it difficult to see the field signs.

D. Human activity on the beach

Human activity obscured tracks and body pit field signs on developed beaches. On-going hatchery projects on other beaches made distinguishing nests and false crawls difficult since most of the field signs at the apex of tracks were destroyed by beach crews when probing for or moving nests.

E. Wind

Wind obliterated tracks depending upon the intensity, duration and direction.

The moisture content of the sand moderated the effects of the wind to some degree. The body pit and the portion of the track above the high water line disappeared sooner than that part of the track in the intertidal zone. Tracks weathered differently depending upon the wind's direction relative to the orientation of the beach. One part of the beach or island could contain clear, distinct tracks while tracks made the same night would appear faint or older on another area.

F. Rainfall

Rainfall also obscured tracks depending upon when it fell during the night and the amount. Tracks made before a rain appear older than tracks made after a rain. This same effect occurred at intervals along the coast during widely scattered showers, making tracks on some beaches appear older than on other beaches. It was essential in these cases to depend on the track's relationship to the high water mark for correct aging. However, rainfall also made this high water mark more difficult to see when the entire beach, not just the intertidal zone, was darkened by wet sand. Tracks were still visible after slight or moderate rainfall, but heavy rainfall almost completely removed all tracks. Tracks in the lower intertidal zone were more easily eradicated since the flipper indentations were not as deep there. Flights were found to be of little value after nights of widespread, prolonged rain or strong winds.

<u>Error categories</u>

Standardizing the flight schedule and field signs for track idnetification were important to this methodology. Also of importance in refining the methodology was the sequencing of tracks with mapped ground truth. By identifying the different error categories and quantify the percentage of mistakes in each, observers were able to improve their technique and reduce their bias.

Missed observation

All tracks which are not seen from the air are included in this category. False crawls low on the beach may be overlooked on occasion as the observers vision may be focused high on the beach on another crawl or crawls. The track may be blocked from the view of an observer by the aircraft. This is particularly true for an observer in the rear seat. On some occasions where ground truth is obtained prior to the aerial count, a low false crawl may be obliterated by the incoming tide. Tracks may also be missed if the observer is distracted by a variety of other activities such as checking the altimeter, looking for landmarks, or simply due to a lack of concentration or fatigue.

Misidentification of track type

There are four basic types of tracks seen from the air. The false crawl track with no body pit, the false crawl track with a "false body pit", a nesting track with an obscured body pit and a nesting crawl with a distinct body pit and associated field signs. The first and last of these are rarely misidentified. The second may result in identifying a false crawl as a nest and the third may result in identifying a nest as a false crawl. It is important to understand that the second and third types listed tend to cancel each other when only total nests or total false crawls are recorded.

Misaging of tracks

Tracks which are more than 24 hours old may be mistakenly counted during a survey. This results from improper timing of a survey or the improper use of the high tide line for aging a track. Conversely a fresh track may be omitted as old because of a mistimed survey. These two sources of aging error also tend to negate each other if only total tracks are considered.

Richardson et al. (1980) approached error types with slightly different categories, however, the concepts are the same.

The three types of errors may result in bias, inaccuracy, and /or imprecision.

<u>Sampling errors</u>

When two aerial observers compare their track counts, this shows the difference between observers. When beaches are ground truthed and compared to the aerial observations, this provides the aerial bias. Bias is the error introduced into the samples of track counts by the tendency of observers to identify and select one track type over another. Neither the difference between observers nor the aerial bias is an indication of how accurate an observer is. Accuracy is the ability to see, age and correctly identify individual tracks on the beach. For example, the following is a hypothetical sequence of tracks on a beach with the ground truth and the observations from two aerial observes. N = nest and F = false crawl

													Totals
Ground Truth	N	F	F	N		F	F	F	F	N		N	4N 6F
Obs. X	N	F	F	F		N	F	N	F		F	N	4N 6F
Obs. Z	F	N	F	N	F	F	F	N		F		N	4N 6F

These aerial observers could think that their survey was accurate because there is no bias in their total counts. However, Observer X made 5 errors, 2 aging and 3 misidentification. This is only 50% accurate. Observer Z made 6 errors, 1 missed observation, 1 aging and 4 misidentification errors. This was only 40% accurate. And out of the 10 tracks, the 2 observers agreed on only 4 of them. It is important to understand the difference between bias and accuracy when interpreting aerial survey data and when using it to make population estimates.

Precision is also an important attribute of aerial survey methodology. Precision is the ability to maintain consistency from one flight to the next in the aerial bias and accuracy. The field signs selected for correct track identification and ageing were readily apparent to Observer 3. The ease with which this methodology can be taught to new observers contributes to the precision obtained in our results.

Reliability of ground truth

The aerial survey is only as reliable as the ground survey. Since all calculation are based on the ground truth data, if the ground survey is not reliable, then the results of the flights cannot be accurately interpreted. This is especially true if aerial surveys are flown to obtain population estimates. Our ground truth was highly accurate and recorded a true reflection of turtle activity. It was obtained from beaches where 1) night time projects were underway and each turtle was observed either nesting or false crawling or 2) where every track with a body pit was probed and verified. Also ground truth observers surveyed the beach as near to the fly-over as possible in case tracks made low on the beach were erased by the incoming tide.

CONCLUSIONS

Loggerhead turtles do not usually nest on an annual basis, but are normally on either 2 or 3 year nesting cycles. The amount of nesting activity varies from year to year. Thus surveys conducted every year may not detect changes and this would not be cost effective. The most reliable method for dealing with annual variability of nesting effort appears to be surveys conducted for three years and then averaged. Surveys conducted every five years would probably suffice. On this type of schedule, changes in personnel conducting the survey are likely. The methodology developed in this study would appear to be the most reliable way to monitor the population over a long time interval, and still obtain results that will be comparable to earlier surveys.

The advantages to this methodology are:

1) Counting only fresh crawls enables researchers to sample a known segment of the nesting season.
2) Timing surveys with the correct tidal stage practically eliminates aging errors.
3) A two-day period around each tidal cycle allows for 8 flights per season which should provide a sample of greater than 10% of the nesting season.
4) Standardizing the method by which to identify tracks as nesting or

false crawls: a) provided more consistent data, b) produced a low bias between observers and c) made the method teachable to a new observer.

5) This methodology will provide consistent monitoring of the loggerhead population in future years, even if changes in personnel occur.

RECOMMENDED SURVEY METHODOLOGY

1. Count only fresh tracks.

2. The date of flights should be selected for the morning after a high tide occurring about 9:00 p.m. EDT.

3. Schedule at least 8 flights (2 consecutive flights at the spring tides in June and July) in order to obtain a > 10% sample.

4. Experienced observers should review the standardized criteria for distinguishing field signs of nesting tracks and false crawls prior to the first survey.

5. Inexperienced observers should be shown visual aids when learing how to recognize these field signs.

6. In order to make accurate counts, make efficient use of the time a track is in view and to reduce fatigue, the proper sequence for viewing the beach should be followed. The best methodology was found to be:

A. The observer should scan the high tide line created by the previous night's high tide.

B. Ignore any tracks that do not extend below this line (Figure 5B and D, Figure 6A) regardless of how "fresh" they may appear.

C. If a track extends below this line, the eye should follow this track up to its apex.

D. Examine the apex area for any of the field signs of the body pit described in the text and shown in Figure 4.

E. If identification of the track type cannot be made, based on characteristics of the body pit, examine both legs of the track to determine if they were of equal or unequal lengths.

With a little experience, this sequence of eye movements and identifications of track type can be made in less than one second.

7. Flights should begin slightly before sunrise or when there is enough light to see all the field signs clearly.

8. In South Carolina the flight path should be from north to south to maximize the time between sunrise and the high tide.

9. High density beaches should be flown twice if there is too great a difference between observers' counts.

10. Cancel a flight if there have been strong winds or heavy rains along a major portion of the study area.

11. Ground truth personnel should be experienced and reliable.

12. Beaches to be ground truthed should be selected based on their relative density of crawl activity and be representative of the entire survey area.

13. Ground truth data should strive for 100% accuracy if the aerial surveys are to be used for obtaining nesting indices and estimates.

PART II

DISTRIBUTION OF LOGGERHEAD TURTLE NESTING ACTIVITY IN SOUTH CAROLINA

By

Sally Hopkins Murphy

and

Thomas M. Murphy

Study Completion Report

October 1, 1979 through September 30, 1982

Study E-1, VI-A-2

Submitted: December 16, 1983

INTRODUCTION

In the United States, loggerhead turtle nesting is centered on the eastern coast of south Florida and extends into Georgia, South Carolina and North Carolina (Hopkins and Richardson 1984). South Carolina is second to Florida in both number of nests laid each season and in the density of nesting (Thompson 1983). Prior to the 1970s, information on nesting in South Carolina was scanty. There was one published paper on a study at Cape Romain by Baldwin and Lofton in 1940 (Caldwell 1959), and nesting data for South Island in the late 1960s (Samworth, unpub. data). There was another nesting study conducted on Fripp Island in the late 1960s as part of a head-starting project for loggerhead hatchlings. However, data on the nesting effort were lost.

In the 1970s, Kiawah Island was inventoried prior to development. Monitoring of the nesting effort was begun (Dean and Talbert 1975) and continues to the present (Tolley 1981, Tolley et al. 1982). Systematic beach surveys to monitor relative nesting effort on Cape Romain were also initiated in the early 1970s (Garris, unpub. data). Statewide aerial surveys, conducted by Stancyk (unpub. data) were flown from 1977-1979.

The criteria a loggerhead turtle uses to select a nesting beach are unknown, but are likley related to: offshore topography, beach profile, level of development and natal origin. Alterations, both natural and man-made, are constantly occurring which change the suitability of beaches for nesting. As the South Caroline coastline continues to undergo development and natural erosional cycles, the nesting population of the loggerhead turtle will be affected. The South Carolina Wildlife and Marine Resources Department is charged with implementing management to mitigate these alterations which hopefully will result in recovery of this threatened species. The state is also responsible for longterm monitoring of the loggerhead population statewide. The purpose of this study was to determine the density and distribution of loggerhead turtle nesting in South Carolina to serve as a point-in-time reference for monitoring shifts in distribution and/or changes in nesting density statewide. Documentation of such changes will be necessary to determine the status of the species relative to reclassification or delisting.

METHODS AND MATERIALS

Study Area

The survey area was from Murrells Inlet to Turtle Island, approximately 250 kms, straight line distance. A total of 270 kms of beach area were surveyed. Thirty-four islands or island groups were identified along this survey line (Figures 7, 8 and 9). The length of each island that was surveyed will differ from those shown in a Recovery Plan for Marine Turtles (Hopkins and Richardson, 1984) and in the Proceedings of the Western Atlantic Turtle Symposium (Bacon et al. 1984) because of a difference in the additional survey of beaches on sounds and bays and in subsequent changes in beaches since the referenced data were taken. Brown (1977) proposed a classification of the South Carolina coast divided into four major geomorphological zones: the arcuate strand, the cuspate delta, the transgressive barrier island and the beach-ridge barrier island. The arcuate strand extends approximately 100 km from the North Carolina border to Winyah Bay. Our survey area began at Murrells Inlet, approximately in the center of this zone type. Flights made north of Murrells Inlet were not considered to be cost effective due to low levels of nesting (Talbert, pers. comm.). A brief description of each beach section follows.

The first five beach sections fall within the arcuate strand in Brown's classification. This zone type features a relatively straight coast with few tidal

Figure 7. Aerial survey zones S01 to S05 are included in the arcuate strand area. Zones S06 to S10 are part of the cuspate delta area.

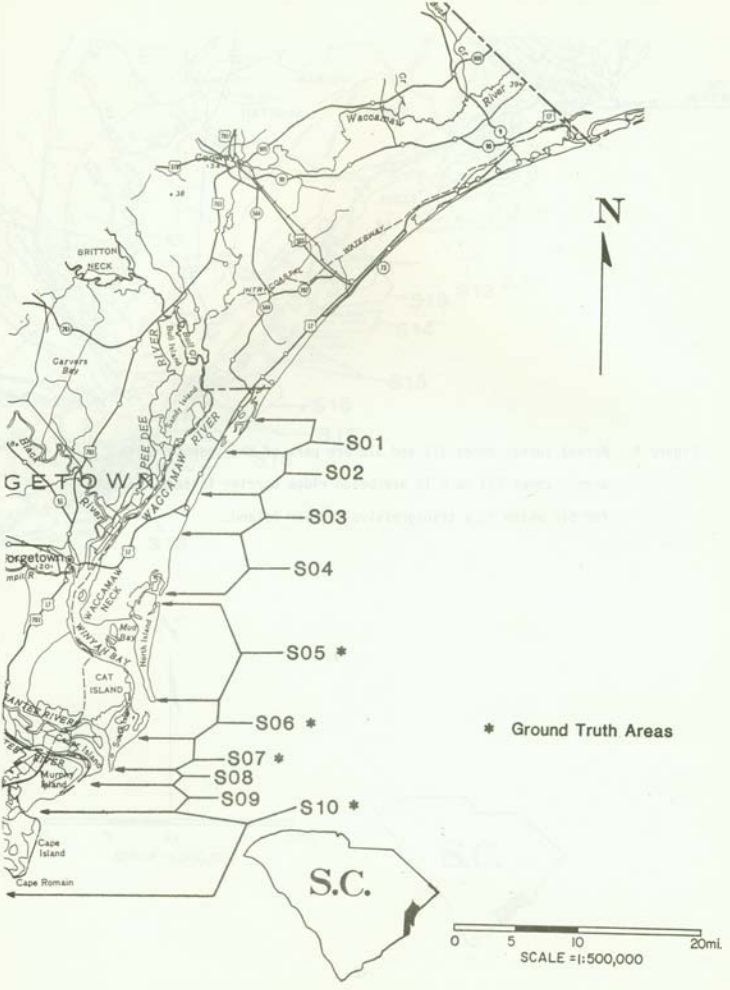

N
BRITTON NECK
Carvers Bay
PEE DEE RIVER
WACCAMAW RIVER
Sandy Island
GETOWN
Georgetown
WACCAMAW NECK
North Island
Mud Bay
WINYAH BAY
CAT ISLAND
SANTEE RIVER
Murphy Island
Cape Island
Cape Romain
INTRA COASTAL WATERWAY
Waccamaw
S01
S02
S03
S04
S05 *
S06 *
S07 *
S08
S09
S10 *
* Ground Truth Areas
S.C.
0
5
10
20mi.
SCALE =1:500,000

Figure 8. Aerial survey zones S11 and S12 are part of the cuspate delta area. Zones S13 to S 19 are beach ridge barrier islands, except for S18 which is a transgressive barrier island.

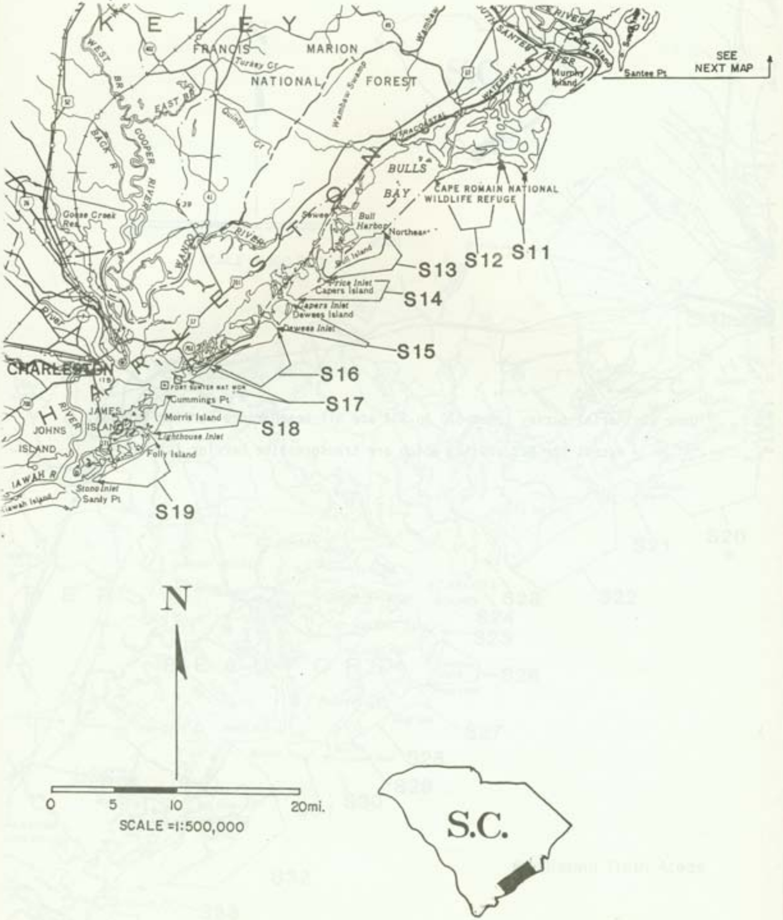
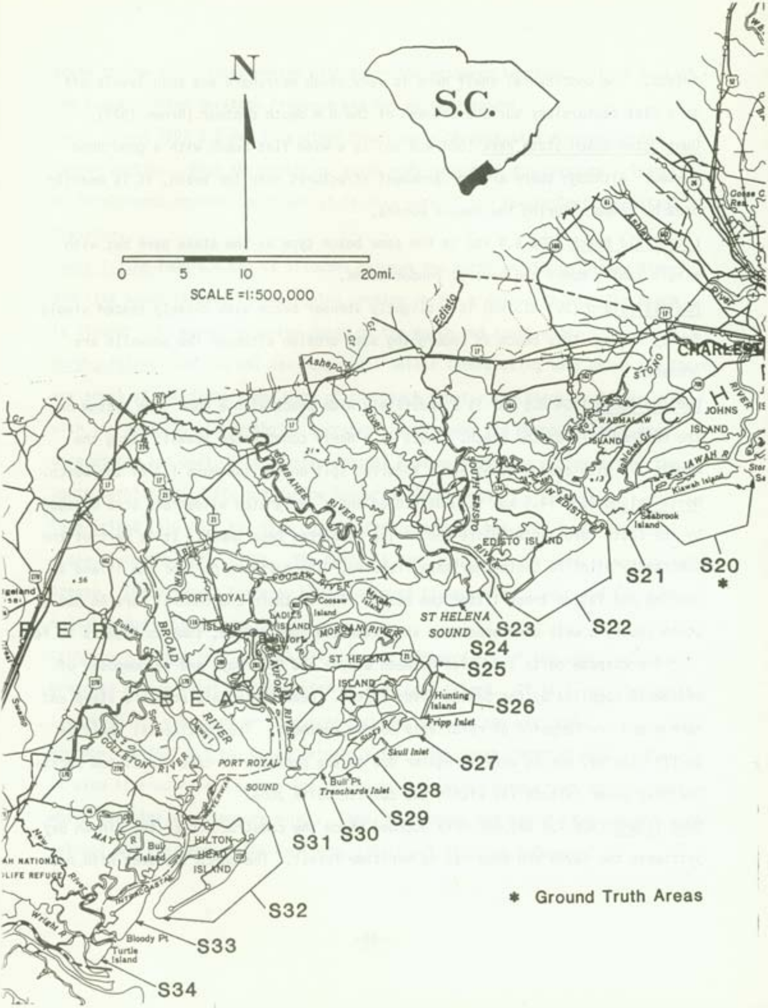

FRANCIS MARION NATIONAL FOREST
SEE NEXT MAP
Santee Pt
Murphy Island
Cape Island
BULLS BAY
CAPE ROMAIN NATIONAL WILDLIFE REFUGE
S11
S12
Bull Harbor
Northeast
Bull Island
S13
Price Inlet
Capers Island
S14
Capers Inlet
Dewees Island
Dewees Inlet
S15
S16
CHARLESTON
S17
Cummings Pt
Morris Island
S18
Lighthouse Inlet
Folly Island
JAMES ISLAND
JOHNS ISLAND
Stono Inlet
Sandy Pt
S19
Goose Creek Res.
COOPER RIVER
WANDO RIVER
Wambaw Swamp
Turkey Cr
N
0
5
10
20mi.
SCALE =1:500,000
S.C.

Figure 9. Aerial survey zones S20 to S34 are all beach ridge barrier islands, except for S22 and S29 which are transgressive barrier islands.



N
S.C.
0 5 10 20mi.
SCALE =1:500,000
CHARLESTON
JOHNS ISLAND
WADMALAW ISLAND
Kiawah Island
Seabrook Island
EDISTO ISLAND
ST HELENA SOUND
PORT ROYAL ISLAND
LADIES ISLAND
Coosaw Island
ST HELENA ISLAND
Hunting Island
Fripp Inlet
Skull Inlet
Bull Pt
Trenchards Inlet
PORT ROYAL SOUND
HILTON HEAD ISLAND
Bull Island
Bloody Pt
Turtle Island
BEAUFORT
COMBAHEE RIVER
COOSAW RIVER
MORGAN RIVER
BROAD RIVER
BEAUFORT RIVER
COLLETON RIVER
SOUTH EDISTO
EDISTO RIVER
STONO RIVER
KIAWAH R
Ashley River
Edisto
Ashepoo
S20
S21
S22
S23
S24
S25
S26
S27
S28
S29
S30
S31
S32
S33
S34
* Ground Truth Areas

inlets. The continental shelf here is very steep nearshore and then levels off to a flat featureless surface seaward of the 8 m depth contour.(Brown 1977).

Huntington Beach State Park (S01 4.8 km) is a wide flat beach with a good dune system. Although there are no permanent structures near the beach, it is heavily used by campers during the summer months.

Litchfield Beach (S02 6.4 km) is the same beach type as the state park but with single family homes and several condominiums.

Pawleys Island (S03 6.5 km) is a slightly steeper beach with closely spaced single family homes. This beach is undergoing some erosion although few seawalls are present.

Debidue Beach (S04 8.5 km) is a moderately wide beach with a good dune system on the northern 1/3 of the beach. There is a newly constructed seawall along the middle 1/3 with eroded dunes and a recurved spit on the southern 1/3 of the beach.

North Island (S05 14.5 km) is undeveloped and a designated wilderness area managed by the South Carolina Wildlife and Marine Resources Department. It is part of the Tom Yawkey Wildlife Center Heritage Preserve. The northern part of the island is eroding and fallen trees litter the beach. The southern and central portion has a steep beach, a well developed berm and extensive dune system, some as high as 50 feet.

The cuspate delta area lies between Winyah and Bull Bays and is composed of sediments supplied by the Santee River system. Beaches in this area are steep and narrow and are composed of relatively coarse sediment. The continental shelf is gently sloping, but is very irregular due to the presence of cape-associated shoals. The next seven islands lie within the cuspate delta zone.

Sand Island (S06 4.8 km) has only accrued since the construction of the Winyah Bay jettiesin the 1890s and thus has no maritime forest. The beach is steep with moderate to low dunes interspersed with extensive washover terraces. It is part of the Yawkey Center Heritage Preserve and has no development.

South Island (S07 5.6 km) is a wider beach but with extensive erosion in the center portion. Both the north and south ends have good dune systems. There is no development on this beach and it is also part of the Yawkey Center Heritage Preserve.

Cedar Island (S08 4.4 km) is situated between the North and South Santee Rivers and like South Island, is undergoing erosion in the middle portion. The beach is steeper with moderate to low dunes on the north and south ends.

Murphy Island (S09 7.0 km) has many small inlets intersecting this beach and there are areas of mud flats along some of the beach front. The beach is fairly wide with low dune and also washover terraces. Both Cedar and Murphy Islands are undeveloped and part of the Santee Coastal Reserve under the management of the South Carolina Wildlife and Marine Resources Department.

Cape Island (S10 10.1 km) is a cuspate foreland which has been in an erosional phase since the early 1940s. The beach is very steep and the sand is coarse and orange. The washover terraces have continued to expand each year and few dunes suitable for nesting remain.

Lighthouse Island (S11 3.3 km) was once the westward arc of the cape, but it was breached and an inlet now separates it from Cape Island. It is a very narrow island with low dunes and an extensive recurved spit at the west end.

Raccoon Key (S12 9.7 km) is an extremely low lying beach composed mostly of shell. It also is eroding and the entire island is overwashed during high spring tides. which coincide with onshore winds. Cape, Lighthouse and Raccoon Key are all undeveloped and are part of the Cape Romain National Wildlife Refuge.

From Bulls Bay to the Georgia border, the coast consists of numerous barrier islands separated by inlets and sounds. Most of these islands are beach-ridge barrier islands which still have dune fields, although they may be eroding in the central portion. Several areas are transgressive barrier islands which are made up of a thin layer of sand that is retreating landward in the form of washover terraces. Dunes and beach ridges are usually absent. All of the remaining beaches are beach-ridge barrier islands.unless otherwise noted as transgressive barrier islands.

Bulls Island (S13 12.1 km) is also part of the Cape Romain National Wildlife Refuge. It has a flat, wide beach with a well developed dune field along most of the front beach. Only the northern end is eroding and there is no development.

Capers Island (S14 6.2 km) is undeveloped and is managed by the South Carolina Wildlife and Marine Resources Department as a Heritage Preserve. It is highly erosional and the front beach is littered with fallen trees and roots. There is a small dune system at the north end.

Dewees Island (S15 4.7 km) is similar to Capers, but this small island was breached in the center by Hurricane David in 1979. The front beach is likewise littered with dead trees. There are a few houses but only one faces the beach front and it has been abandoned because of the severe erosion.

Isle of Palms (S16 11.5 km) is developed in the form of single family homes and condominiums. The beach is wide and flat with dunes along the southern portion. There is rock rip rap on the northern end and more is planned.

Sullivans Island (S17 6.4 km) is also developed, but with single family homes only and these are set well back from the beach. The beach is wide and flat with a broad dune field and large sandbars offshore.

Morris Island (S18 6.0 km) is a transgressive barrier island. The interior is a diked spoil area and in some places the island has eroded back to the dike. The beach is short and somewhat shelly.

Folly Beach (S19 12.1 km) is developed with single family homes and is almost completely armoured with rip rap or sea walls. In areas where there is no rip rap, the dunes are scarped.

Kiawah Island's (S20 17.9 km) recent development is proceeding from the south end of the island toward the north. Because of the length of the island, the beach is wide, fairly stable, with good dunes. Despite the development, beach disturbance at night is kept to a minimum.

Seabrook Island (S21 6.6 km) has a wide dune field on the northern end, rip rap in the center of the beach and a moderately wide flat beach on the southern end. This island is developed with condominiums, single family homes and a church camp on the south side.

Edisto Island (S22 20.3 km) includes a series of transgressive barrier island beaches including Botany Bay, Edingsville Beach and Edisto Beach. Botany Bay (3.4 km) is steep, very shelly and littered with tree roots. It is also intersected with numerous inlets and washover terraces and is backed by salt marsh. There is no development on Botany Bay. Edingsville Beach (7.6 km) is also undeveloped and is similar in description to Botany Bay. The topography immediately offshore is very irregular and appears to be eroded areas of marsh peat. Edingsville Beach was a summer resort area in the late 1800s, but the houses were destroyed by erosion from several huricanes. Edisto Beach (9.3 km) is as steep as the previous two, but is not as shelly on the southern portion. The northern end is a state park. There are wooden groins placed perpendicualr to the beach to trap sand, and this gives the beach a rolling, hilly contour. Single family homes front the beach. Although erosion is not severe, some homeowners have begun to install rip rap.

Pine Island (S23 2.4 km) is a small island situated well back in St. Helena Sound and receives low wave energy. Most of the island is fronted by salt marsh with only a few pocket beaches. It is undeveloped.

Otter Island (S24 4.4 km) is adjacent to Pine Island. This island receives only limited wave action on the northern end. The beach is narrow but stable and there is a good dune field on the southern side. There is no development.

Harbor Island (S25 3.0 km) is undergoing rapid development at this time in the form of condominiums. The portion of the beach that faces St. Helena Sound has scarped dunes, but the southern end is accreting.

Hunting Island (S26 7.9 km) is a state park. This island has a low level of development, but receives high human use during the summer months. The beach was renourished in 1980 by the Corps of Engineers. It is moderately wide and flat with new dunes being formed at snow fences and planted dune grasses.

Fripp Island (S27 6.6 km) has a serious erosion problem and homeowners and developers have continued to install rip rap so that at this time about one half of the island is armoured. The southern one half still has a fairly wide beach with good dunes.

Pritchards Island (S28 4.4 km) is also highly erosional with the beach littered with dead trees along most of its length. The north and south ends have very small areas of dunes. It is undeveloped and managed by the University of South Carolina.

Little Capers Island (S29 2.5 km) is a transgressive barrier island. It is now undeveloped since the few remaining houses have been destroyed by the sea. The beach is narrow and shelly and intersected by several inlets.

St. Phillips Island (S30 2.0 km) is recessed back on Trenchards Inlet and has a low energy beach with little or no wave action. The beach is narrow with few dunes and there are only a few houses.

Bay Point (S31 5.2 km) is at the entrance of Port Royal Sound. A small area on the northern end is erosional, but the southern side that faces the sound is stable. The beach is narrow but there are good dunes and only one house.

Hilton Head Island (S32 29.0 km) is the largest barrier island on the South Carolina coast. It is highly developed. The northern side on Port Royal Sound has low energy pocket beaches, the eastern side is rip rapped in the center portion, but the remainder has wide flat beaches with good dunes. The southern end is stable.

Daufuskie Island (S33 8.4 km) has little development on the island, and none is near the beach. Approximately one third of the island is due for development, however. Even though the beaches have low wave action, they are in an erosional state with fallen trees along much of the coastline. The other parts of the beach are narrow with no dunes.

Turtle Island (S34 3.8 km) is similar in appearance to Pine Island with salt marsh fronting most of its length and with occasional pocket beaches.

Survey methodology

Survey flights over the South Carolina coast south of Murrells Inlet were made each summer from 1980-82. All surveys were either single flights or paired flights on consecutive days and were scheduled at approximately 2-week intervals. Each survey began at Murrells Inlet and ended at the Savannah River. Seven single surveys were flown between 16 May and 13 August in 1980. In 1981, three single surveys and 2 paired surveys were flown between 4 June and 2 August for a total of 7 flights. In 1982, seven surveys were flown between 7 June and 22 July. Three were paired and one was a single flight because of a weather cancellation.

The aircraft was a Hughes 500 D helicopter with both front and rear doors removed on the observers' side for maximum visibility. Two observers were used and the rear observer acted as data recorder. The same observers surveyed in 1980 and 1981 and a new observer flew on alternate surveys during 1982.

Turtle tracks were recorded as nesting, non-nesting (false crawl) and unknown. Only fresh tracks were counted. For a more detailed account of the methodology, see Part I of this report.

RESULTS

Table 8 shows the number of tracks counted for each island, including nests, false crawls and unknowns, averaged for 2 observers. Counts during 1981 and 1982 were higher because the paired flights were made during the peak of the nesting season and because 1980 appeared to be a low nesting year rangewide (Hopkins and Richardson 1984). Based on the total tracks from Table 8, the ten islands with the highest turtle activity were: Cape, Raccoon Key, Edisto, Sand, Lighthouse, Otter, Bay Point, South, Kiawah and Pritchards. However, when the turtle activity is based on density (Table 9), a slightly different list emerges. The top islands based on density were: Cape, Lighthouse, Sand, Otter, Raccoon Key, Pritchards, Bay Point, Cedar and South. These had greater than 5 tracks/km each season during the 7 survey flights.

Neither density nor total activity gives a clear picture of the relative importance of the islands along the South Carolina coast. An index of relative importance can be found by calculating the percent of the survey area each island represents and then also the percent of the total turtle nesting activity each island was found to have. The following equation gives the value for R. I. as the relative importance of that island compared to all other islands.

$$\text{R. I. (relative importance)} = \frac{\text{\% of the total nesting activity}}{\text{\% of the total area surveyed}}$$

Table 8. Total loggerhead turtle tracks counted during three years of aerial survey, 1980-82, in South Carolina, averaged for 2 observers.

BEACH SECTION & NUMBER		1980	1981	1982	GRAND TOTALS
Huntington Beach	S01	3.0	8.5	1.0	12.5
Litchfield Beach	S02	1.5	5.5	4.0	11.0
Pawleys Island	S03	1.0	1.0	3.0	5.0
Debidue Island	S04	12.0	14.5	11.0	37.5
North Island	S05	15.0	48.0	26.5	89.5
Sand Island	S06	38.0	96.0	56.0	190.0
South Island	S07	33.5	40.0	37.5	111.0
Cedar Island	S08	27.5	29.0	36.5	93.0
Murphy Island	S09	16.5	33.5	27.5	77.5
Cape Island	S10	272.5	351.0	427.0	1050.5
Lighthouse Is. (West Cape)	S11	34.0	37.5	100.5	172.0
Raccoon Key	S12	70.0	96.0	80.5	246.5
Bulls Island	S13	18.5	49.5	16.5	84.5
Capers Island	S14	9.5	5.0	13.5	28.0
Dewees Island	S15	1.0	1.0	2.0	4.0
Isle of Palms	S16	2.5	10.5	3.0	16.0
Sullivans Island	S17	2.0	0.0	0.0	2.0
Morris Island	S18	0.0	3.5	4.5	8.0
Folly Beach	S19	4.5	6.0	3.0	13.5
Kiawah Island	S20	21.5	49.0	39.0	109.5
Seabrook Island	S21	3.0	10.0	7.0	20.0
Edisto Island	S22	60.5	82.5	78.0	221.0
Pine Island	S23	1.0	4.0	4.5	9.5
Otter Island	S24	38.0	46.0	83.5	167.5
Harbor Island	S25	6.5	12.5	10.0	29.0
Hunting Island	S26	8.0	26.0	24.5	58.5

Table 8. (continued)

BEACH SECTION & NUMBER		1980	1981	1982	GRAND TOTALS
Fripp Island	S27	20.0	28.0	21.5	69.5
Pritchards Island	S28	23.0	39.0	40.5	102.5
Little Capers Island	S29	12.0	13.0	9.5	34.5
St.Phillips Island	S30	5.0	4.5	1.0	10.5
Bay Point	S31	18.5	33.0	65.5	117.0
Hilton Head Island	S32	8.5	26.0	24.0	58.5
Daufuskie Island	S33	0.0	0.0	8.0	8.0
Turtle Island	S34	0.0	1.0	1.0	2.0
TOTALS		788.0	1210.5	1271.0	3269.5

Table 9. Mean number of tracks counted per km per season, 1980-82, in South Carolina. These densities are based on 7 flights/season and do not represent the total nesting activity obtained from ground surveys.

High Density N=9 Tracks/km>5	Mean/km	Moderate Density N=14 Tracks/km>1<5	Mean/km	Low Density N=11 Tracks/km<1	Mean/km
Cape	S10 34.67	Little Capers	S29 4.60	Huntington	S01 0.87
Lighthouse	S11 17.37	Murphy	S09 3.69	Hilton Head	S32 0.67
Sand	S06 13.12	Edisto	S22 3.63	Litchfield	S02 0.57
Otter	S24 12.69	Fripp	S27 3.51	Isle of Palms	S16 0.46
Raccoon Key	S12 8.47	Harbor	S25 3.22	Morris	S18 0.44
Pritchards	S28 7.77	Hunting	S26 2.47	Folly	S19 0.37
Bay Point	S31 7.50	Bulls	S13 2.33	Daufuskie	S33 0.32
Cedar	S08 7.05	Kiawah	S20 2.04	Dewees	S15 0.28
South	S07 6.60	North	S05 1.92	Pawleys	S03 0.26
		St. Phillips	S30 1.75	Turtle	S34 0.18
		Capers	S14 1.51	Sullivans	S17 0.10
		Debidue	S04 1.47		
		Pine	S23 1.32		
		Seabrook	S21 1.01		

An R. I. value of 1 would be the average for the survey area. The higher the R. I. value is above 1, the more important that island is relative to the others. R. I. values below 1 are less utilized beaches. For example, Cape Island represents only 3.7% of the survey area, but contains 27.7% of the turtle nesting activity. The R. I. value for Cape Island was 7.49. This means that Cape Island is about 7 and a half times more important than the average beach. The other 10 islands with R. I. values greater than 1 are listed in Table 10. All other islands on the South Carolina coast had an R. I. value of 1 or less.(Table 10).

DISCUSSION

Of the 11 islands with an R. I. value grater than 1, all are undeveloped. Seven occur in the cuspate delta zone of the state, 3 are beach ridge barrier islands and 1 is a transgressive barrier island. Other attributes these areas have in common are: narrow, fairly steep beaches and low profile beaches. By low profile we mean little or no maritime forest backing the dunes. Or if maritime forest is present, it tends to be well behind the dune field. Pritchards Island is the only exception to this.

Islands with the low R. I. values were either highly developed or did not have adequate dunes for nesting. Those with R. I. values just at or below 1 may have been developed to some degree, but they also had good nesting habitat.

The 11 islands with R. I. values greater than 1.0 represent 65.3% of the turtle nesting activity in the survey area. However, high turtle nesting may not mean high production of hatchlings. Because these islands are undeveloped, low profile and erosional beaches, nest mortality to predators, poachers and flooding by spring tides is high. So while these islands are numerically important, they may not be very important in terms of hatchling production. Their potential for hatchling production, however, is certainly important to the turtle resource. This potential could be realized better with management, some of which is already underway. The U. S. Fish and Wildlife Service has management authority over islands that represent 39.6% of the turtle nesting activity in the study area. The S. C. Wildlife and Marine Resources Department has management authority over an additional 18.4%. Thus over half of the turtle nesting activity (58%), on about one fourth of the nesting areas (26.5%), has the potential for management by state and federal wildlife agencies.

Table 10 Nesting distribution and Relative Importance by beach section based on 1530 nests counted by Observer during 21 flights during 1980-82.

(a) Beach Section	& No.	(b) Length (km)	(c) % of Nesting 1980 N=318	1981 N=622	1982 N=590	(d) % of Total Nesting N=1530	(e) % of Area 270 km	(f) R.I. (d/e)
Huntington Bch	S01	4.8	0.3	0.3	0.0	0.2	1.8	0.11
Litchfield Bch	S02	6.4	0.3	0.3	0.3	0.3	2.4	0.13
Pawleys Isl	S03	6.5	0.0	0.2	0.5	0.3	2.4	0.13
Debidue Isl	S04	8.5	1.9	1.8	0.8	1.4	3.1	0.45
North Isl	S05	15.5	3.2	4.2	2.5	3.3	5.7	0.58
Sand Isl	S06	4.8	3.2	5.5	4.9	4.8	1.8	2.67
South Isl	S07	5.6	4.4	2.7	2.2	2.9	2.1	1.38
Cedar Isl	S08	4.4	3.2	2.7	4.7	3.6	1.6	2.25
Murphy Isl	S09	7.0	3.8	3.1	3.4	3.3	2.6	1.27
Cape Isl	S10	10.1	32.4	24.6	28.5	27.7	3.7	7.49
Lighthouse Isl	S11	3.3	4.4	1.8	4.7	3.5	1.2	2.92
Raccoon Key	S12	9.7	4.4	6.1	2.9	4.5	3.6	1.25
Bulls Isl	S13	12.1	1.6	7.2	1.5	3.9	4.5	0.87
Capers Isl	S14	6.2	1.6	0.5	1.7	1.2	2.3	0.52
Dewees Isl	S15	4.7	0.3	0.2	0.2	0.2	1.7	0.12
Isle of Palms	S16	11.5	0.3	1.3	0.2	0.7	4.3	0.16
Sullivans Isl	S17	6.4	0.3	0.0	0.0	0.1	2.4	0 .04
Morris Isl	S18	6.0	0.0	0.5	0.5	0.4	2.2	0 .02

Table 10 'continued

(a) Beach Section	No.	(b) Length (km)	(c) % of Nesting 1980 N=318	1981 N=622	1982 N=590	(d) % of Total Nesting N=1530	(e) % of Area 270 km	(f) R.I. (d/e)
Folly Bch	S19	12.1	0.9	0.3	0.5	0.5	4.5	0 .11
Kiawah Isl	S20	17.9	5.4	5.6	5.6	5.6	6.6	0 .85
Seabrook Isl	S21	6.6	0.9	0.6	0.8	0.8	2.4	0 .33
Edisto Isl	S22	20.3	6.9	7.5	7.5	7.4	7.5	0 .99
Pine Isl	S23	2.4	0.3	0.5	0.2	0.3	0.9	0 .33
Otter Isl	S24	4.4	5.7	4.7	7.3	5.9	1.6	3.69
Harbor Isl	S25	3.0	0.3	1.6	0.7	1.0	1.1	0.91
Hunting Isl	S26	7.9	0.9	1.8	2.7	2.0	2.9	0.69
Fripp Isl	S27	6.6	4.1	1.9	1.9	2.4	2.4	1.00
Pritchards Isl	S28	4.4	1.9	3.5	3.9	3.3	1.6	2.06
Little Capers	S29	2.5	0.9	1.6	0.8	1.2	0.9	1.33
St.Phillips Isl	S30	2.0	0.6	0.5	0.2	0.4	0.7	0.57
Bay Point	S31	5.2	4.1	4.0	5.4	4.6	1.9	2.42
Hilton Head	S32	29.0	1.6	2.9	2.0	2.3	10.7	0.21
Daufuskie Isl	S33	8.4	0.0	0.0	0.7	0.3	3.1	0.10
Turtle Isl	S34	3.8	0.0	0.0	0.2	0.1	1.4	0.07

As mentioned before, some management is already underway on South Island and Cape Island by the South Carolina Wildlife and Marine Resources Department and the U. S. Fish and Wildlife Service, respectively. In addition, private groups and individuals are involved with nest protection projects on many islands along the coast. These include: Kiawah, Seabrook, Edisto, Hunting, Fripp, Pritchards and Hilton Head. Because of their efforts, hatchling production may be greater on these islands than on the islands with higher R. I. values. Beaches with management projects represent 54.4% of the turtle nesting activity in the study area.

Developed islands, however, continue to incur the loss of turtle nesting habitat to sea wall and rip rap groins to protect property. As more beaches become armoured with rip rap, it may tend to concentrate nesting in the remaining areas or cause shifts to other islands.

CONCLUSION

The results of this study provide baseline data. Given this baseline data, surveys in future years will be compared to the results of this study. Shifts in nesting distribution can be documented and correlated to the probable causes. As nesting habitat is altered or as management is implemented, changes in density for each island and changes in the relative importance of islands can be monitored.

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