A TRAWL SURVEY METHOD FOR ESTIMATING LOGGERHEAD TURTLE, *CARETTA CARETTA*, ABUNDANCE IN FIVE EASTERN FLORIDA CHANNELS AND INLETS

RICHARD W. BUTLER, WALTER A. NELSON, AND TYRRELL A. HENWOOD[1]

ABSTRACT

Five eastern Florida navigational channels were surveyed on a quarterly basis from November 1981 through August 1982. The purpose of the surveys was to provide estimates of loggerhead turtle abundance for each channel over all seasons of the year. Standard methods for estimating loggerhead turtle abundance from trawl samples were developed, and the probability of capture in a 30 m by 1,483 m substation ($\bar{P}$) was estimated to be 0.28 ± 0.05 (95% confidence level). Abundance estimates based on this probability of capture were then developed for each channel and survey. Of the channels surveyed, only Port Canaveral harbored significant concentrations of loggerhead turtles; populations ranged from 701 ± 291 turtles in February to a low of 38 ± 26 turtles in August. A few loggerhead turtles were captured in the other channels, but infrequency of occurrence suggested random encounters rather than areas of concentration.

In the western Atlantic Ocean, loggerhead turtles, *Caretta caretta*, forage throughout the warm waters of the continental shelf from Argentina northward to Nova Scotia, including the Gulf of Mexico and the Caribbean Sea (Carr 1952). On a seasonal basis, loggerheads are common as far north as the Canadian portions of the Gulf of Maine (Lazell 1980), but during cooler months of the year distributions shift to the south (Shoop et al. 1981). Sporadic nesting occurs throughout the tropical and warm temperate range of distribution, but the most important nesting areas are the Atlantic coast of Florida, Georgia, and South Carolina (Carr and Carr 1978). The Florida nesting population of *Caretta* has been estimated to be the second largest in the world (Ross 1982).

Although population levels of adult female loggerheads can be estimated from counts on nesting beaches, the remaining animals (males, subadults, and nonbreeding females) do not come ashore and are not readily available for census. To estimate the total number of loggerheads in an area, all segments of the population should be considered.

In the vicinity of Cape Canaveral, FL, loggerhead turtles congregate in the Port Canaveral ship channel (Carr et al. 1980). Because turtles can be captured and studied in this unique area throughout the year, the National Marine Fisheries Service (NMFS) has conducted surveys to monitor population levels and estimate relative turtle abundance. This study is a continuation and expansion of research efforts which began in 1978.

Presented are results of a 1-yr investigation conducted in response to requests from the U.S. Army Corps of Engineers (COE) and the U.S. Navy, to estimate sea turtle abundance and seasonality in five eastern Florida navigational channels. Animals captured in this study were subadults, adult males, and adult females. Population estimates of subadult turtles may prove to be particularly useful for management, as efficacy of conservation measures should be first evident in the population levels of the youngest cohorts.

Results of this study provide a reliable index of loggerhead turtle abundance for the study year and an alternative to population estimates based only on nesting females. Most importantly, for the first time, a standard method has been developed that provides sea turtle abundance estimates with approximate standard errors.

STUDY AREAS

Five eastern Florida navigational channels were surveyed on a seasonal basis over the study period. A description of the survey sites follows (each site is diagramed in Figure 1):

[1]Southeast Fisheries Center Mississippi Laboratories, National Marine Fisheries Service, NOAA, P.O. Drawer 1207, Pascagoula, MS 39568-1207.

Manuscript accepted February 1987.
FISHERY BULLETIN: VOL. 85, NO. 3, 1987.

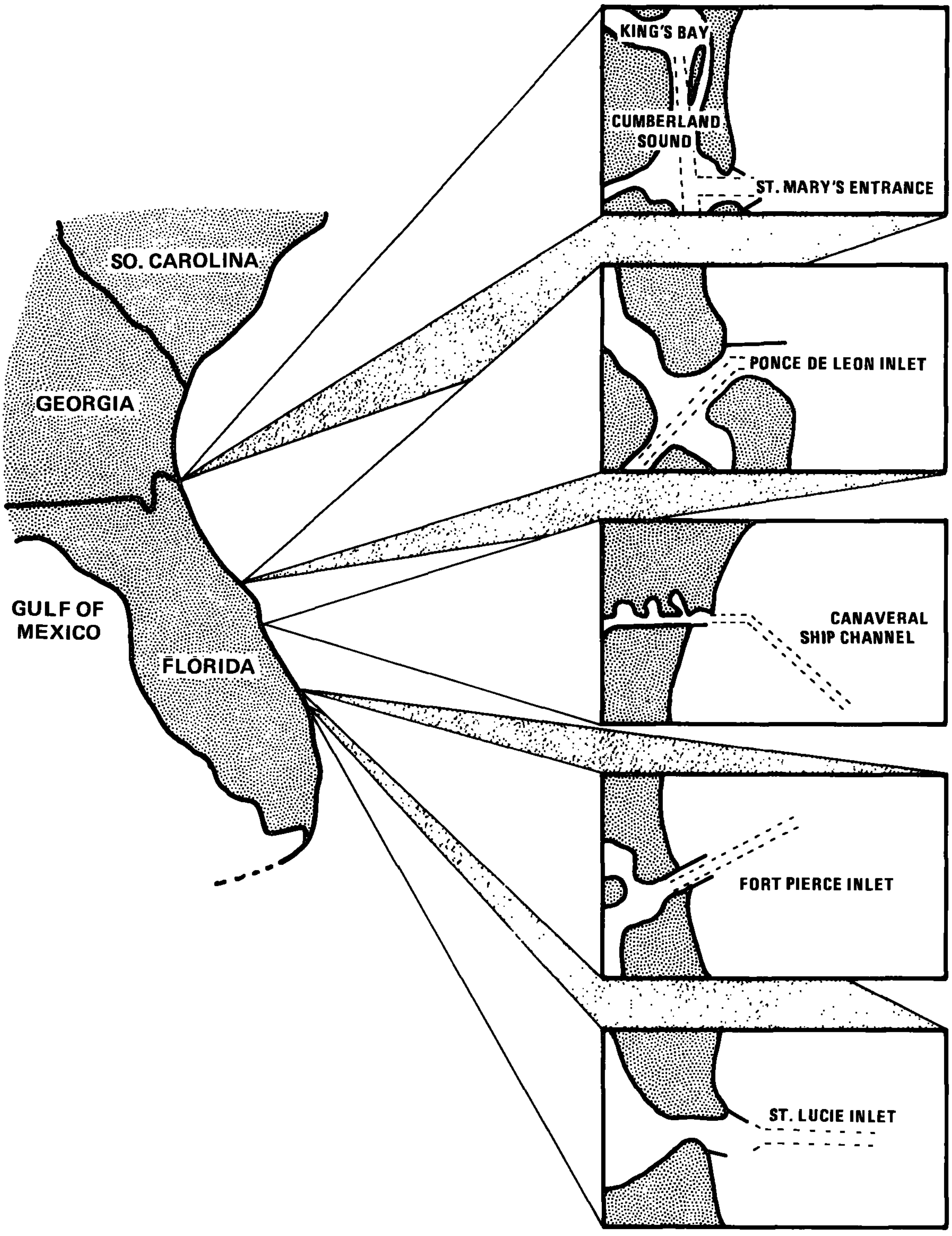

FIGURE 1.—Description of five eastern Florida navigational channels and inlets surveyed.

1) St. Mary's entrance to King's Bay (lat. 30°43'N, long. 80°20'W) is divided by the state boundary between Georgia and Florida and includes Cumberland Sound through which the Intracoastal Waterway connects King's Bay with the entrance channel. Mud predominates inside of the jetties, and mud and rock bottom are found in the channel offshore.

2) Ponce de Leon Inlet (lat. 29°04'N, long. 80°53'W), on the northeast coast of Florida, is a small inlet accessible only to small craft. A jetty protects the inlet to the north; inside the inlet a narrow channel leads to the Intracoastal Waterway. The substrate is hard sand and silt with scattered rubble.

3) The Port Canaveral ship channel is located on the central east coast of Florida (lat. 28°23'N, long. 80°33'W). The ship channel allows navigation from offshore, through a manmade inlet, into a protected harbor. A depth of 11 to 13 m is maintained by dredging. Soft mud and detritus bottom is found in the channel and sand-clay in the surrounding areas.

4) Fort Pierce Inlet (lat. 27°28'N, long. 80°16'W) is located on the south-central east coast of Florida. The channel allows navigation from offshore, through the inlet that is protected by jetties, into the Intracoastal Waterway. The bottom is hard sand and rubble.

5) St. Lucie Inlet, also on the south-central east coast of Florida (lat. 27°09'N, long. 80°07'W), is another small inlet with use limited to small craft. A completed jetty protects the north side of the inlet and a second jetty was under construction to the south during the survey periods. The substrate offshore is sloping hard sand and silt.

MATERIALS AND METHODS

Quarterly trawl surveys of the navigational channels were conducted from November 1981 through August 1982. During each survey, the Port Canaveral ship channel was sampled twice and the remaining four sites (St. Mary's entrance, Ponce de Leon Inlet, Fort Pierce Inlet, and St. Lucie Inlet) were sampled once. A standard 18 m "mongoose" fish trawl, spread by 3 m × 1 m trawl doors and equipped with mudrollers, was used throughout the study period.

Prior to the surveys, the boundaries of each channel were located using National Ocean Surveys charts and subdivided by a grid pattern for systematic sampling. Lengthwise, each channel was separated into 1,483 m stations which were divided into 30 m wide substations (Fig. 2). The number of substations in each station was dependent on channel width.

A systematic sampling scheme was devised to sample each channel substation: every other station was sampled in leapfrog fashion in one direction, and then the direction was reversed. The substation sampled within each station was determined by random drawing without replacement and sampling continued until all substations were occupied. This approach avoided the "edge effect", but allowed samples to be statistically treated as random (Milne 1959). Control stations outside the channel were sampled at all sites during each survey period.

In addition to standard survey procedures, experiments designed to estimate gear efficiency were conducted in the Port Canaveral ship channel. Following each survey, a substation with abundant loggerhead turtles was selected and a series of repetitive tows performed. All loggerheads captured during these experiments were tagged and released on station prior to the next tow. As this was essentially a "removal" method, any recaptures of loggerhead turtles tagged during the experiment were not considered as part of the catch and were excluded from analysis. Tows were continued in rapid order until two consecutive samples yielded zero catches or the working day ended.

ANALYTICAL PROCEDURES

The efficiency of the sampling gear was established before population estimates were computed. The probability of loggerhead turtle capture ($\hat{P}$) was estimated for each repetitive towing experiment using the formula:

$$\hat{P} = C_1/\hat{N}_0$$

where C_1 = catch on the first tow in the substation

$\hat{N}_0$ = estimated number of loggerhead turtles in the substation.

A regression of cumulative loggerhead turtle catch (Y) on catch per sample (X), expressed as $Y = b_0 + b_1X$, was used to estimate (N_0) based on the relationship: $\hat{N}_0 = b_0$. The estimated variance of N_0 was calculated according to procedures of Kleinbaum and Kupper (1978):

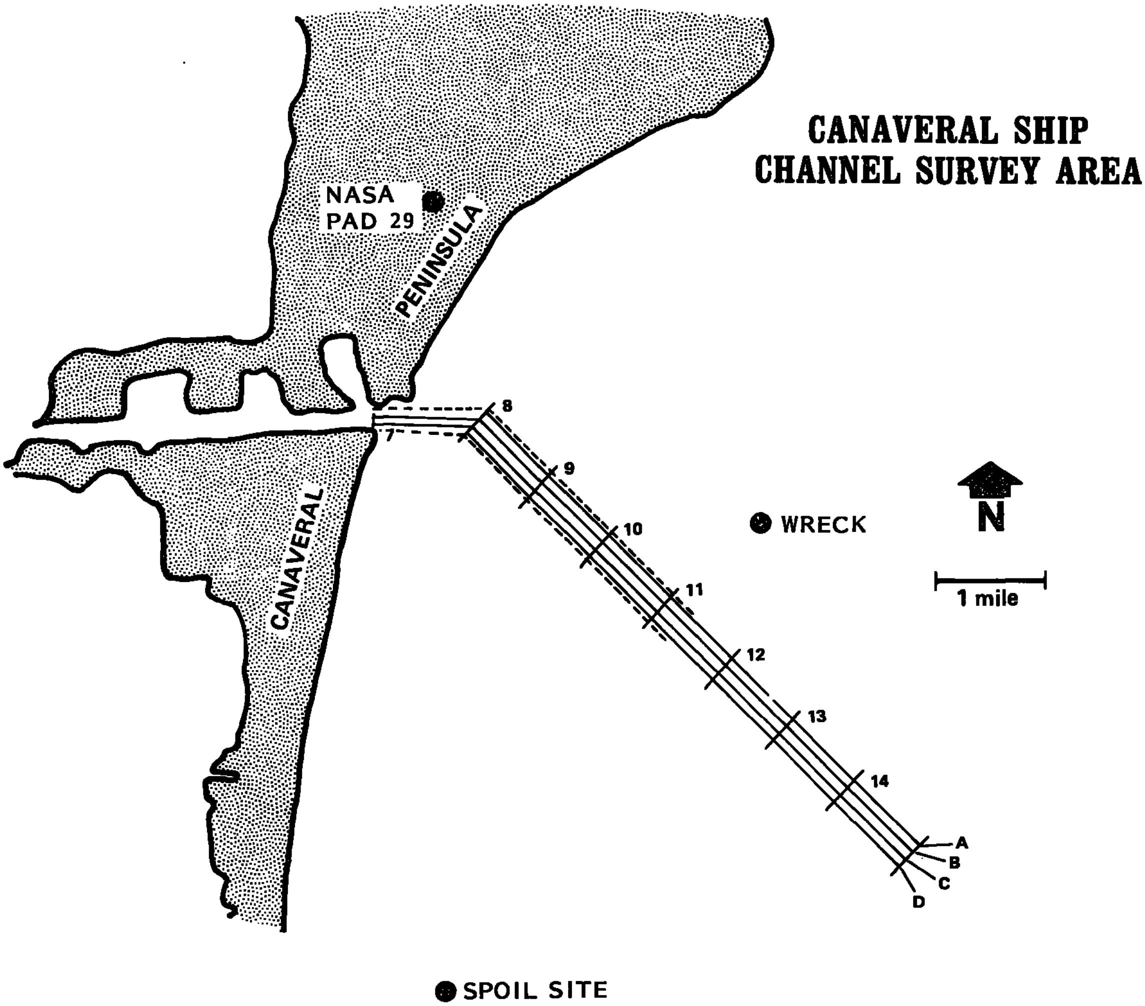

FIGURE 2.—Description of the Port Canaveral ship channel survey area. The channel was separated into 1,483 m stations (7-14), which were divided into 30 m wide substations (A, B, C, and D).

$$\text{Var}(\hat{N}_0) = (\text{SE})^2\,[1/n + \overline{X}^2/\Sigma(X_i - \overline{X})^2]$$

where SE = standard error of the estimate provided by the straight line fit
n = sample size of the catch data set
X_i = observed catch per sample in the i^{th} sample and

$$\Sigma(X_i - \overline{X})^2 = \Sigma X_i^2 - \Sigma(X_i)^2/n.$$

The estimated variance of P was then calculated using procedures of Mood et al. (1974):

$$\text{Var}(\hat{P}) = (C_1/\hat{N}_0^2)^2\ \text{Var}\ \hat{N}_0.$$

In one instance, the experiment was conducted in an area larger than the standard substation and a ratio (standard area/larger area = 0.75) was used as a constant multiplier to standardize estimates.

The mean probability of capture was calculated by combining all experimental P's using the formulae:

$$\hat{\hat{P}} = \hat{P}_i/k, \text{ and Var}(\hat{\hat{P}}) = \text{Var}(\hat{P}_i)/k^2$$

where k = number of estimates.

Once the efficiency of trawling equipment had been determined, the number of loggerhead turtles present in a substation ($\hat{N}$) was estimated using the following formula (Seber 1973):

$$\hat{N} = C/\hat{P}$$

where $\hat{P}$ = probability of capture
C = number of animals captured.

If more than one sample tow was made in a substation, the mean catch ($\overline{C}$) was substituted in the above formula. To estimate the number of loggerhead turtles in a channel substation, station, or the entire channel, the mean number captured per substation sample ($\overline{C}$) times the number of substations (s) was substituted: $\hat{N} = s\overline{C}/\hat{\overline{P}}$. The estimated variance of this estimate is (Mood et al. 1974):

$$\text{Var}(\hat{N}) = (s/\hat{\overline{P}})^2 \left[\text{Var}(\overline{C}) + (\overline{C}/\hat{\overline{P}})^2 \text{Var}(\hat{\overline{P}})\right].$$

RESULTS

Estimates of the probability of capture and associated standard error estimates from nine repetitive trawl experiments are presented in Table 1. Estimated probability of capture within a substation based on six experiments ranged from 0.21 to 0.31 ($\hat{\overline{P}} = 0.28$; 95% confidence interval = ±0.05; estimated variance = 5.18×10^{-4}). Three experiments were excluded from the analyses: two were discarded because the catch failed to decline due to low population levels, and a third was eliminated because of problems with the sampling trawl.

Estimates of loggerhead turtle abundance by survey for the Port Canaveral ship channel ranged from 701 ± 291 turtles in late February 1982 to a low value of 38 ± 26 turtles in late August 1982 (Table 2). Port Canaveral channel stations 9 through 11 (Fig. 2) exhibited the highest loggerhead turtle abundance during all seasons of the year. Mean catch for all samples in the channel was 2.55 turtles/tow and 0.50 turtles/tow for control samples, supporting the hypothesis that loggerhead turtles congregate in the Port Canaveral ship channel.

Loggerhead turtle abundance estimates for the remaining four survey sites were low during all seasons of the year (Table 3). Over the study period, a total of 18 loggerhead turtles was captured: 2 at St. Mary's entrance, 6 at Ponce de Leon Inlet, 3 at Fort Pierce Inlet, and 7 at St. Lucie Inlet.

DISCUSSION

Our estimates of the probability of capture were based on the supposition that catch-per-tow in a given substation will decrease as loggerhead turtles are removed. The regression of cumulative loggerhead turtle catch on catch per sample can then be used to estimate the orginal population size in the substation (Brownlee 1965) and using this estimate, the probability of capture can be computed. Assumptions associated with this procedure are a closed population, the trawl fishes only within the defined bounds of the substation, each tow is an equal unit of effort and the probability of capture remains constant.

TABLE 1.—Estimated probability of loggerhead turtle capture in a Port Canaveral ship channel substation using an 18 m fish trawl.

Date	Catch on first tow (C_1)	Population estimate ($\hat{N}_0$)	Probability of capture ($\hat{P}$)	SE ($\hat{P}$)	Approximate 95% C.I. (P)
11/6/81	8	20.19	0.40	0.09	±0.17
12/5/81	6	19.54	0.31	0.01	±0.02
12/7/81	13	51.48	0.28	0.03	±0.07
2/28/82	7	30.31	0.23	0.02	±0.04
3/2/82	15	72.85	0.21	0.07	±0.13
5/23/82	2	([1])			
5/28/82	2	([1])			
6/1/82	1	([1])			
8/6/82	3	11.82	0.25	0.05	±0.10
mean ($\hat{P}$)			0.28	0.03	±0.05

[1]Data set discarded.

TABLE 2.—Estimated number of loggerhead turtles ($\hat{N}$) at Port Canaveral ship channel by station and survey period (1981-1982).

Station	Nov. 3-5	Dec. 2-4	Feb. 3-6	Feb. 21-26	May 7-12	May 28-June 1	Aug. 4-5	Aug. 20-22
7	([1])	([1])	[2]0	[2]0	[2]21	[2]0	[2]14	[2]0
8	([1])	([1])	25	43	29	11	21	0
9	93	32	114	143	[2]29	21	57	7
10	64	32	254	221	32	21	61	18
11	21	7	[3]157	146	21	36	8	7
12	21	4	43	89	7	21	4	4
13	0	0	0	11	[2]10	0	0	0
14	0	0	0	4	[2]0	[2]0	0	0
Chanel	[4]200	[4]75	632	701	152	122	168	38
Approx. 95% C.I.	±129	±50	±314	±291	±86	±62	±82	±26

[1]Station not sampled.
[2]Station incompletely sampled.
[3]Includes 4 Kemp's ridley turtles, *Lepidochelys kempi*.
[4]Estimate is for stations 9-14, others are for 7-14.

TABLE 3.—Estimated loggerhead turtle abundance during quarterly surveys of St. Mary's entrance—King's Bay, Ponce de Leon Inlet, Ft. Pierce Inlet and St. Lucie Inlet.

Date	St. Mary's King's Bay	Ponce de Leon Inlet	Fort Pierce Inlet	St. Lucie Inlet
11/81	9 ± 18	0	0	0
2/82	0	11 ± 15	4 ± 7	4 ± 7
5/82	0	0	4 ± 8	11 ± 11
8/82	0	0	0	4 ± 7

Although these assumptions may not be satisfied in all cases, our estimates of probability of capture in a given substation were consistent except for the two discarded experiments conducted during periods of low loggerhead turtle densities. These findings suggest that some loggerheads encountering the trawl were able to avoid capture, presumably by moving out of the trawl path. The results also indicate that a consistent percentage of loggerheads were captured by the trawl, facilitating the estimation of turtle abundance based on number of turtles captured. It should be noted that the probability of capture in a given substation (as presented in our results) is lower than the probability of capture in a given tow. To compute the probability of capture in a single tow, the width of the substation is divided by the width of the trawl and this factor multiplied by the probability of capture in the substation.

Loggerhead turtle abundance estimates in the Port Canaveral ship channel exhibited large seasonal variation (Table 2). The estimated population levels during the month of February were significantly higher than all other quarterly surveys indicating that loggerheads were most abundant during winter months. These findings are in agreement with other NMFS surveys in the Canaveral channel from 1978 to 1983 (Table 4) and support the contention of Carr et al. (1980) that loggerhead turtles may hibernate in the Port Canaveral channel in refuge from low water temperatures. The fact that the winter of 1981-82 was unusually mild, could account for the lack of an early winter peak in loggerhead turtle abundance observed in previous years.

Data presented in Table 4, while of limited statistical value due to inconsistencies in sampling methodologies, are useful for comparisons between this study and other NMFS Canaveral channel surveys. It is worthy of note that mean catch per unit effort (CPUE) by month combining all years was in excess of 10 loggerhead turtles/hour from November through March with peak concentrations in February and March. Lowest CPUE values and presumably population levels occurred from April through September, which is in agreement with our findings.

It is evident that loggerhead turtle abundance estimates were highly variable between surveys made in the same quarter (Table 2). We speculate that these fluctuations in population levels were caused by short-term immigration and emigration in response to local weather changes. We have observed daily changes in catch rates which appear to be correlated with passage of weather fronts.

Distribution of loggerhead turtles within the Port Canaveral ship channel is also of interest. In every survey, stations 9, 10, and 11 exhibited the highest abundances, suggesting that they were preferred turtle habitat. Stations 7, 8, and 12 exhibited intermediate population levels and stations 13 and 14 had low turtle abundance levels. Stations 7, 8, 9, and 10 were those where deepest cuts into the seabed have been made by dredging. The bottom was characterized by divers as clay-silt and detritus as opposed to the harder clay-sand bottom outside the channel (Carr et al. 1980).

Interpretation of loggerhead turtle abundance estimates generated from this study is complicated by the fact that three different groups of

TABLE 4.—Summary of catch per unit effort (CPUE) of loggerhead turtles in the Port Canaveral ship channel (1978-83). Values are in turtles per hour standardized to a single 100-ft net. N = number of tows.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1978		37.74 N = 7	55.73 N = 7							18.99 N = 5	10.82 N = 10	21.64 N = 14
1979	11.56 N = 17	11.88 N = 11	8.21 N = 11	9.13 N = 3	1.33' N = 5	21.25 N = 16	13.86 N = 32		9.43 N = 28			
1980	24.82 N = 19	19.61 N = 40	28.57 N = 77		3.38 N = 22	3.77 N = 22	3.31 N = 60	3.29 N = 152	2.62 N = 189	5.44 N = 135	11.81 N = 105	5.11 N = 7
1981		15.89 N = 12		11.22 N = 16				7.88 N = 41	3.26 N = 51		22.06 N = 29	7.18 N = 42
1982		41.83 N = 99	58.53 N = 14		7.49 N = 96	4.24 N = 15		5.95 N = 83				
1983			4.86 N = 20	2.35 N = 60								
Totals	18.56 N = 36	32.61 N = 169	27.88 N = 129	4.21 N = 79	6.50 N = 123	9.18 N = 53	6.98 N = 92	4.77 N = 276	3.45 N = 268	5.92 N = 140	13.80 N = 144	10.16 N = 63

loggerheads (adult males, adult females, and subadults) utilize the channel at different times of the year (Henwood 1987). Adult males are dominant in April and May, adult females are most abundant from May through August and subadult turtles are predominant during the remainder of the year. For this reason, direct comparisons between quarterly surveys may be inappropriate.

It is unfortunate that the three discarded repetitive trawl experiments occurred in May and June when the population was comprised primarily of breeding adults. Low population levels at this time may reflect a reduced catchability coefficient in adult loggerhead turtles possibly associated with behavioral changes. The ability of loggerhead turtles to escape trawls may also be enhanced during periods of high water temperatures, but no evidence of this was noted during August or November.

Loggerhead turtle abundance in the remaining four channels was low during all quarterly surveys. These findings confirm the presence of loggerhead turtles along much of Florida's eastern coastline, but do not indicate any channel areas with turtle concentrations similar to Port Canaveral. It is of special interest that only Port Canaveral, a manmade habitat, harbors concentrations of loggerhead turtles throughout the year and particularly during winter months.

The St. Mary's entrance to King's Bay survey area was by far the largest site investigated and may have been incompletely sampled relative to the total area involved. This location was of particular interest to the U.S. Navy because of planned construction of a Trident submarine base in King's Bay. Although no concentrations of loggerhead turtles were noted over the course of this investigation, future dredging of this channel could potentially result in a situation similar to Port Canaveral, with loggerhead turtles congregating in a deepwater manmade habitat.

ACKNOWLEDGMENTS

Funding for this investigation was provided by the U.S. Army Corps of Engineers, the U.S. Navy, and the National Marine Fisheries Service. The statistical approach was based on recommendations of Al Rainosek. This manuscript benefited from the critical reviews of Steve Malvestuto, Ann Williams, Bill Davies, Bob Shipp, Andy Kemmerer, Warren Stuntz, and Brad Brown.

LITERATURE CITED

BROWNLEE, K. A.
1965. Statistical theory and methodology in science and engineering. 2d ed. John Wiley & Sons, Inc., N.Y., 590 p.

CARR, A. F.
1952. Handbook of turtles: The turtles of the United States, Canada and Baja California. Cornell Univ. Press, Ithaca, N.Y., 542 p.

CARR, A., L. OGREN, AND C. MCVEA.
1980. Apparent hibernation by the Atlantic loggerhead turtle, *Caretta caretta*, off Cape Canaveral, Florida. Biol. Conserv. 19:7-14.

CARR, D., AND P. H. CARR.
1978. Survey and reconnaissance of nesting shores and coastal habitats of marine turtles in Florida, Puerto Rico and the U.S. Virgin Islands. Report to the NMFS, St. Petersburg, FL, 34 p.

HENWOOD, T. A.
1987. Movements and seasonal changes in loggerhead turtle, *Caretta caretta*, aggregations in the vicinity of Cape Canaveral, Florida (1978-84). Biol. Conserv. 40(3):191-202.

KLEINBAUM, D. G., AND L. L. KUPPER.
1978. Applied regression analysis and other multivariable methods. Duxbury Press, Boston, MA.

LAZELL, J. D.
1980. New England waters: critical habitat for marine turtles. Copeia 1980:290-295.

MILNE, A.
1959. The centric systematic area-sampled treated as a random sample. Biometrics 15:270-297.

MOOD, A. M., F. A. GRAYBILL, AND D. C. BOES.
1974. Introduction to the theory of statistics. McGraw-Hill, N.Y.

ROSS, J. P.
1982. Historical decline of loggerhead, ridley and leatherback sea turtles. *In* K. A. Bjorndal (editor), Biology and conservation of sea turtles, p. 185-195. Smithson. Inst. Press, Wash. D.C.

SEBER, G. A. F.
1973. The estimation of animal abundance and related parameters. Hafner Press, N.Y., 506 p.

SHOOP, C., T. DOTY, AND N. BRAY.
1981. Sea turtles in the region between Cape Hatteras and Nova Scotia in 1979. *In* A characterization of marine mammals and turtles in the mid- and north-Atlantic areas of the U.S. outer continental shelf: Annual report for 1979, p. IX 1-85. Univ. Rhode Island, Kingston.