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August 1996

Dredging Operations Technical Support Program

Effectiveness of a Sea Turtle-Deflecting Hopper Dredge Draghead in Port Canaveral Entrance Channel, Florida

by David A. Nelson, Deborah J. Shafer

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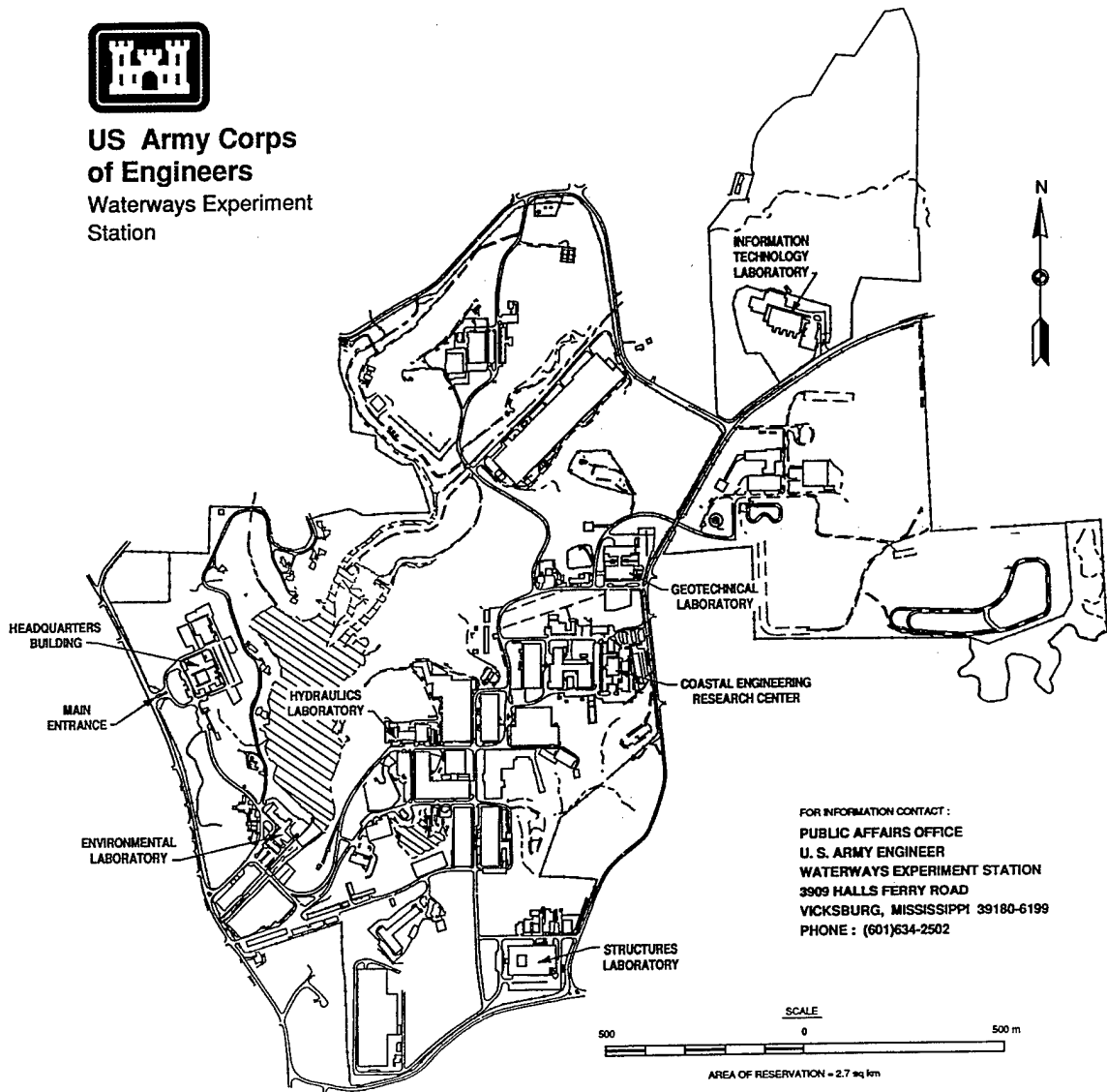
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Environmental Effects of Dredging Programs



Dredging Operations Technical Support Report Summary

Effectiveness of a Sea Turtle-Deflecting Hopper Dredge Draghead in Port Canaveral Entrance Channel, Florida (MP D-96-3)

ISSUE: Periodic maintenance dredging of coastal navigation channels is required to maintain the depth necessary for the passage of large commercial and military ship traffic. Sea turtles and other threatened and endangered species may become entrained in the hopper dredge intake pipes, causing the turtles to be crushed or drowned.

RESEARCH: To determine the effectiveness of a new rigid deflector draghead in reducing entrainment of sea turtles, a test was conducted in Canaveral entrance channel, Florida.

SUMMARY: The rate of sea turtle entrainment observed during this study, at levels of abundance which had formerly resulted in high numbers of entrainment incidents using a California draghead, indicates that the new design was effective in reducing the entrainment

of sea turtles in Canaveral Harbor entrance channel. However, this test involved hydraulic dredging of a relatively small amount of material (76,710 cu yd). Additional studies representing larger volumes of material are needed to determine if entrainment rates using the rigid deflector draghead are significantly lower than with other draghead types.

AVAILABILITY OF REPORT: The report is available on Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; telephone (601) 634-2355.

To purchase a copy, call the National Technical Information Service (NTIS) at (703) 487-4780. For help in identifying a title for sale, call (703) 487-4780. NTIS report numbers may also be requested from the WES librarians.

About the Authors: Mr. David A. Nelson and Ms. Deborah J. Shafer are biologists in the WES Environmental Laboratory. For further information about the Dredging Operations Technical Support Program, contact Mr. Thomas R. Patin, Program Manager, at (601) 634-3444.

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Preface

The work resulting in this report was conducted by personnel of the U.S. Army Engineer Waterways Experiment Station (WES) for the U.S. Army Engineer District, Jacksonville. Messrs. Mark Wolff and Mike Dupes were the environmental project managers from Jacksonville District. Field tests were conducted during September 1994. Field assistance was provided by Mr. Joe Wooley of the Environmental Characterization Branch, WES, Mr. Kevin Reine of the Coastal Ecology Branch (CEB), WES, Ms. Dean Bagley of the University of Central Florida, and Dr. John Keinath of the Virginia Institute of Marine Science. Mr. Chuck Dickerson developed the computer programs for data entry and summary. CPT Lindsey Parker, CPT Marty Higgins, and Mr. Paul Daniels of the University of Georgia Marine Extension Service research trawler *Georgia Bulldog* assisted in the capture of sea turtles for the study. Additional turtles for the behavioral studies were provided by the National Marine Fisheries Service. Messrs. Glenn E. Banks and Joe Parmen of the Estuarine Engineering Branch, WES, and Phillip Bates of the Jacksonville District monitored the operation of the draghead during dredging.

This report was written by Mr. David A. Nelson and Ms. Deborah J. Shafer, CEB, Ecological Research Division (ERD), Environmental Laboratory (EL), WES, under the supervision of Dr. John W. Keeley, Director, EL, Dr. Edwin A. Theriot, Assistant Director, EL, Dr. C. J. Kirby, Chief, ERD, and Dr. Paul Becker, Chief, CEB. Mr. E. Clark McNair, Coastal Engineering Research Center, WES, was the Sea Turtle Research Program Manager.

Funding for the technical editing and report preparation was provided by the Dredging Operations Technical Support (DOTS) Program, managed through the Environmental Effects of Dredging Program (EEDP). The DOTS Program Manager was Mr. Thomas R. Patin, and the EEDP Program Manager was Dr. Robert M. Engler.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic yards	0.7645549	cubic meters
feet	0.3048	meters
inches	2.54	centimeters
knots (international)	0.5144444	meters per second
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Problem

Periodic maintenance dredging of coastal navigation channels is required to maintain the depth necessary for the passage of large commercial and military ship traffic. Sea turtles and other threatened and endangered species may become entrained in the hopper dredge intake pipes, causing the turtles to be crushed or drowned. To prevent this entrainment, a new draghead design was developed to deflect sea turtles from the path of the draghead. Preliminary tests indicated that this design was effective in reducing entrainment of inanimate objects in the path of the draghead without compromising production (Banks and Alexander 1994). The following study was conducted to test the effectiveness of the rigid deflector draghead under field conditions in an area of probable moderate-to-high sea turtle abundance.

Purpose and Objectives

The purpose of this work was to assess the effectiveness of the rigid deflector draghead in preventing the entrainment of sea turtles during channel dredging with a hopper dredge. Specific objectives of this project were to determine sea turtle presence and relative abundance in Canaveral Harbor entrance channel, to determine the percentage of time the turtles are on the bottom, and to assess the number of sea turtles entrained on the inflow screens during dredging with the rigid deflector draghead.

2 Background

Previous Achievements

In early attempts to reduce or eliminate entrainment of sea turtles by dredges, rigid V-shaped attachments were affixed to the draghead. However, within minutes of deployment, these attachments were damaged due to the force of the moving dredge and the weight of the draghead and dragarm. Because these rigid versions proved ineffective, a scale-model flexible chain deflector was tested at the Scripps Institute of Oceanography, California, to determine design angles and attachment requirements. A prototype test of the flexible chain deflector (Figure 1) conducted at Panama City, Florida, on the dredge *McFarland* demonstrated that this modification would remain intact and deflect objects on the seafloor. The flexible chain deflector was used for several dredging projects; however, continuous maintenance was required to

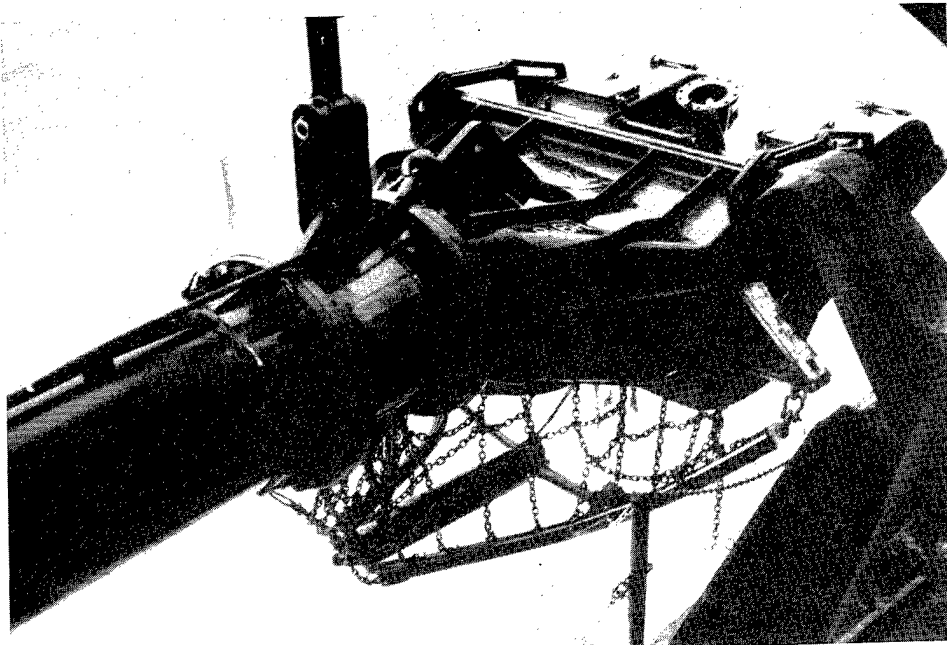


Figure 1. California draghead with flexible chain deflector

reweld chain broken in areas of debris, rocky substrates, or other snags. Additional model tests were conducted at the U.S. Army Engineer Waterways Experiment Station (WES) to develop a rigid deflector draghead that would require less maintenance.

Preliminary tests of the new rigid deflector draghead (Figure 2) were conducted at Fort Pierce, Florida, and at Fernandina Harbor entrance channel, Florida, during periods of low sea turtle abundance. At Fort Pierce, simulated sea turtles, constructed to match the average size and density of subadult loggerhead turtles, were placed on the seafloor by divers. The rigid deflector draghead was demonstrated to be effective in reducing entrainment and deflecting these objects when compared with the standard California draghead and the California draghead with flexible chain deflector (Banks and Alexander 1994). In addition, the rigid deflector did not adversely affect operation or production of the dredge. The rigid deflector draghead was field tested during the annual dredging at Fernandina Harbor entrance channel during the winter of 1993-1994. Sea turtle relative abundance during this period was expected to be very low. Since the rigid deflector draghead was demonstrated to be effective in dredging channel sediments and in deflecting simulated turtles, the U.S. Army Engineer District, Jacksonville, and the National Marine Fisheries Service (NMFS) initiated testing of the rigid deflector during a time when sea turtles should be present in moderate-to-high abundance.

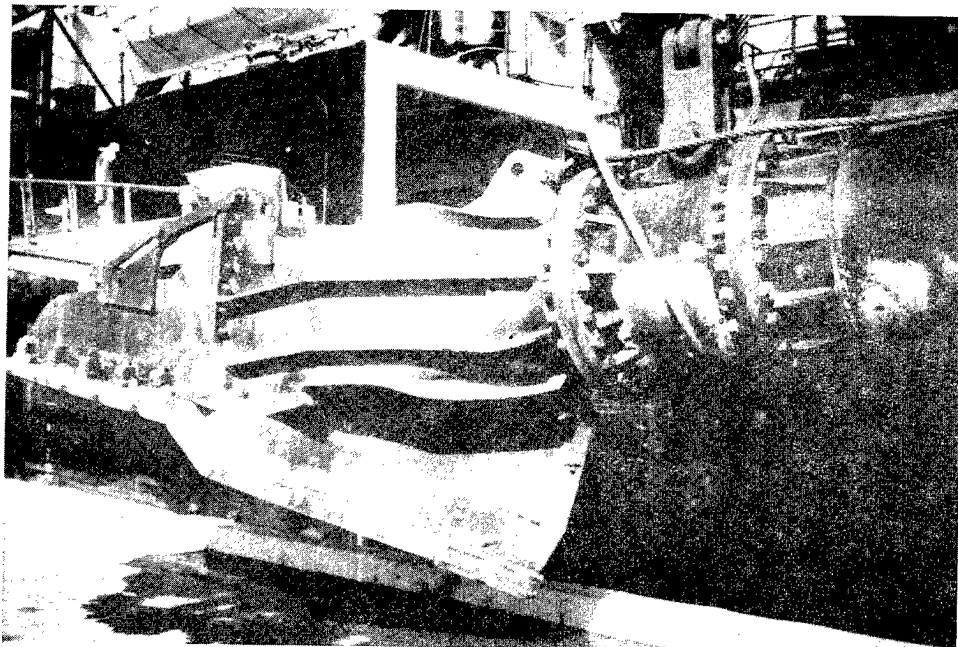


Figure 2. Rigid deflector draghead

Approach

A paired comparison test of the California draghead and the rigid deflector draghead would have been the most appropriate study design for comparing the entrainment rates of the two different dragheads. However, this approach may have resulted in unacceptably high rates of sea turtle entrainment and mortality. Documented turtle take in Canaveral Harbor entrance channel as a result of hopper dredging were 71 (1980), 13 (1983), 3 (1986), and <25 (1988), although actual entrainment rates may have been higher (Berry 1990).

Attempts to directly observe turtle response to the rigid deflector draghead through the use of underwater imaging systems proved unsuccessful due to poor water clarity and the relatively low frequency of encounter. Since sea turtle response to the draghead could not be observed directly, the effectiveness of the rigid deflector draghead was assessed indirectly by determining whether the turtles were (a) present in the channel in sufficient numbers to encounter the draghead, (b) on the channel bottom where they were most susceptible to entrainment by the draghead, and (c) entrained by the rigid deflector draghead at a lower rate than expected for a traditional (California) style draghead.

3 Materials and Methods

Study Area

This work was conducted in the Port Canaveral Harbor entrance channel located on the central Atlantic coast of Florida, midway between Jacksonville and Miami (28° 25'N, 80° 35'W). The entrance channel is 5.7 nautical miles¹ in length and 400 ft wide. The channel is maintained at a depth of 44 ft to permit passage of large commercial and military ship traffic (Studd 1987). The area supports a large population of sea turtles and was once the site of a thriving commercial sea turtle fishery (Witzell 1987).

Dredge Operation and Monitoring

The rigid deflector draghead was tested in Canaveral Harbor entrance channel from 15-30 September 1994 by WES and the Jacksonville District. Dredge operators were careful to maintain continuous contact of the draghead with the bottom since previous studies had indicated that this was critical in preventing entrainment (Banks and Alexander 1994).

To determine sea turtle entrainment rates, the Jacksonville District contract observers monitored the dredge for evidence of sea turtle encounters. The inflow screens and the draghead were inspected for sea turtles and sea turtle parts on each return trip from the dredged material disposal area. The times during which the dredge was pumping material, raising and lowering the dragarm, and moving to and from the disposal area were recorded.

Permits

Monitoring was conducted under National Marine Fisheries Endangered Species Permit No. 777, issued to David A. Nelson, WES.

¹ A table of factors for converting non-SI units of measurement to SI units is presented on page x.

Trawling Specifications

To establish the presence of sea turtles in the Canaveral Harbor entrance channel, a series of trawl surveys was conducted. Survey methods and equipment were standardized to the extent possible including data sheets (Appendix A), nets (Appendix B), trawling speed and direction to tide, length of segment, length of tow, and number of tows per segment. Trawling was conducted with repetitive 15- to 30-min (total time) tows in the channel. The trawler (Figure 3) was fitted with two 60-ft trawling nets constructed from 8-in. mesh (stretch) as specified in Appendix B. Trawling was conducted with the tidal flow at speeds of approximately 2.5 to 3.0 knots. Positions at the beginning and end of each tow were determined from Loran or Global Positioning System (GPS) positioning equipment. Tow speed was recorded at the approximate midpoint of each tow.

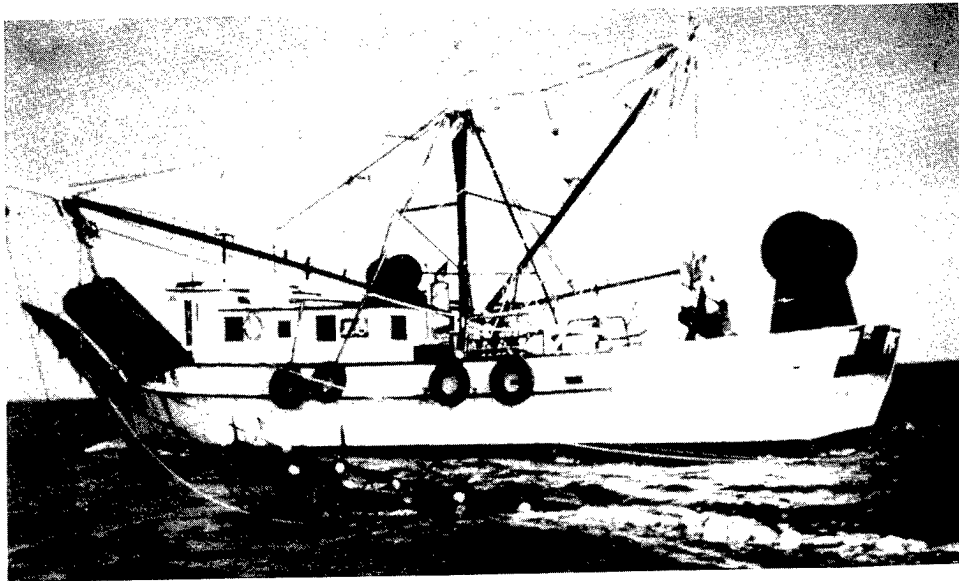


Figure 3. Trawling vessel used for sea turtle capture

The Canaveral Harbor entrance channel was divided into four segments of equal length. There were 24 tows made per survey, 6 tows in each of the 4 segments. Each segment was trawled for a distance of 2 km. Tow times were adjusted from 15 to 30 min to achieve the 2-km tow length. Trawling was conducted daily until the minimum number of tows were made. Surveys were conducted according to a randomized design consistent with the NMFS survey protocol.

Turtle Tagging, Handling, and Measurements

All captured turtles were identified, measured, and tagged on each front flipper with an NMFS Inconel tag. All turtles are referred to by their NMFS

Inconel tag number. In addition, a Trovan Passive Integrated Transponder (PIT) tag was injected subcutaneously in the wrist area of the right front flipper. Straight line length, straight line width, tail length, and weight were recorded. Measurements were taken according to Pritchard et al. (1983). Turtles were released into the channel near the point of capture as soon as possible following measurement and tagging.

General Telemetry Specifications

Captured turtles were instrumented with both radio and sonic transmitters for biotelemetry studies. Radio tags (Advanced Telemetry Systems (ATS), 151 MHz) transmit data only while turtles are at the surface and were used to pinpoint the location of turtles at the surface. Depth-sensitive sonic transmitters (Sonotronics DT88) were used to locate turtles underwater and determine their position in the water column. Separate frequencies were used to distinguish individual turtles. The radio and sonic tags were embedded in syntactic foam for flotation and attached to the posterior marginal scute of the turtle by a short tether containing an erodible link and a breakaway link (Figure 4). The variable sized magnesium erodible links dissolved after 7-14 days, allowing the tag to float to the surface for later recovery. The breakaway link was designed to pull free with a minimum of force in case of accidental entanglement.

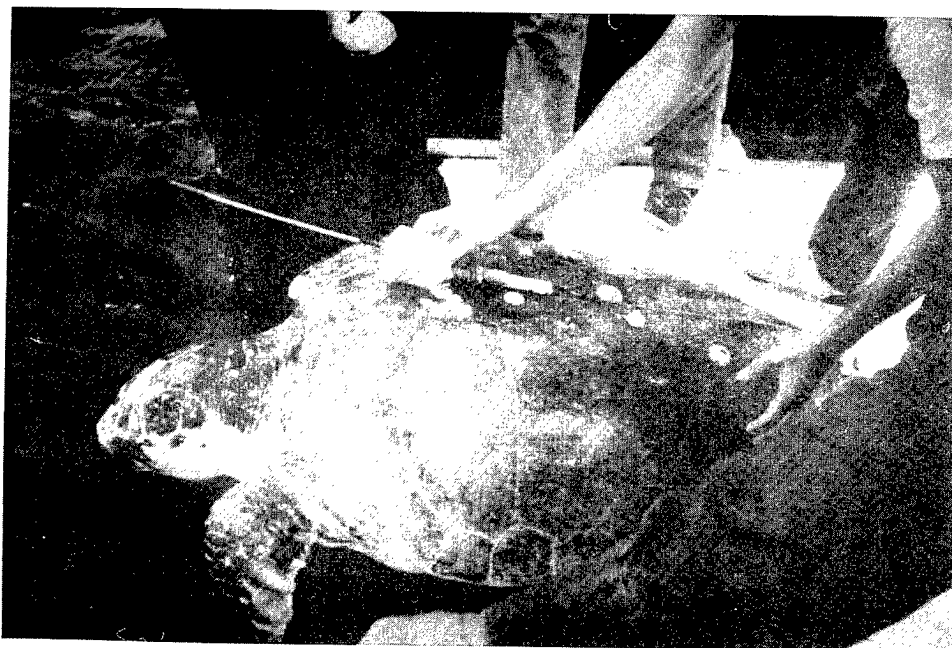


Figure 4. Radio and sonic tags attached by tether with erodible and breakaway links

Telemetry studies were conducted for 11 days just prior to dredging and for 13 days during dredging. Initially each day, the channel was surveyed for

the presence of instrumented turtles. Locations were determined by positioning a boat directly over an instrumented turtle and recording the GPS coordinates. Each turtle was then monitored for continuous 4- to 12-hr periods. To reduce the effects of capture on behavior results, telemetry data were not used for analysis until at least 12 hr after the initial release of the tagged turtle.

Pulsed signals were received from the sonic tags into a Sonotronics receiver and decoder unit and then logged into a portable microcomputer where times and counts were recorded automatically onto both a hard drive and a removable diskette (Figure 5). Data were also recorded manually into a data book from the display on the decoder unit. Radio transmitters were monitored with ATS R4000 receivers modified for sea turtle telemetry. The transmission and cessation of a signal from the radio tag were entered manually into the computer and data book as surfacings (up) and descents (down) from the surface, respectively. Data from the sonic tags provided values for time spent at different positions within the water column.

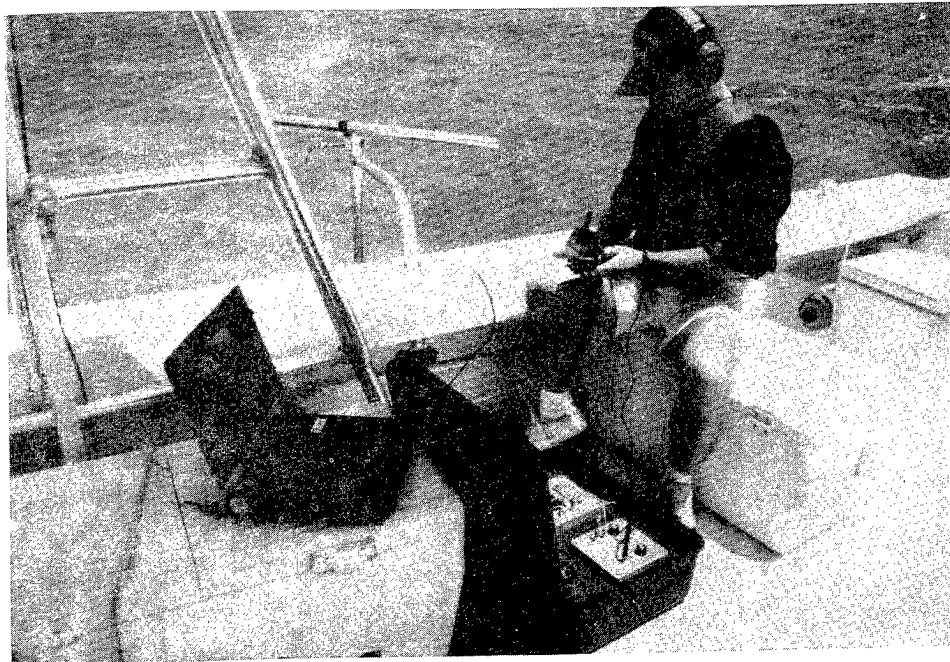


Figure 5. Telemetry data collection

A typical dive profile plotted from telemetry data is illustrated in Figure 6. Points of ascent, surface, descent, and dive depth (bottom) are shown. For the purposes of this study, **bottom time** began immediately following a descent to the bottom and ended when the turtle began its ascent to the surface. Thus, bottom times listed in this report include only those periods during which the turtle was actually on or very near the bottom. **Submergence time** refers to that period of time beginning with a descent from the surface and ending at the start of the next surface interval. Submergence time differs from bottom time in that it may also include those periods during which the turtle remained in the water column and was not on or near the

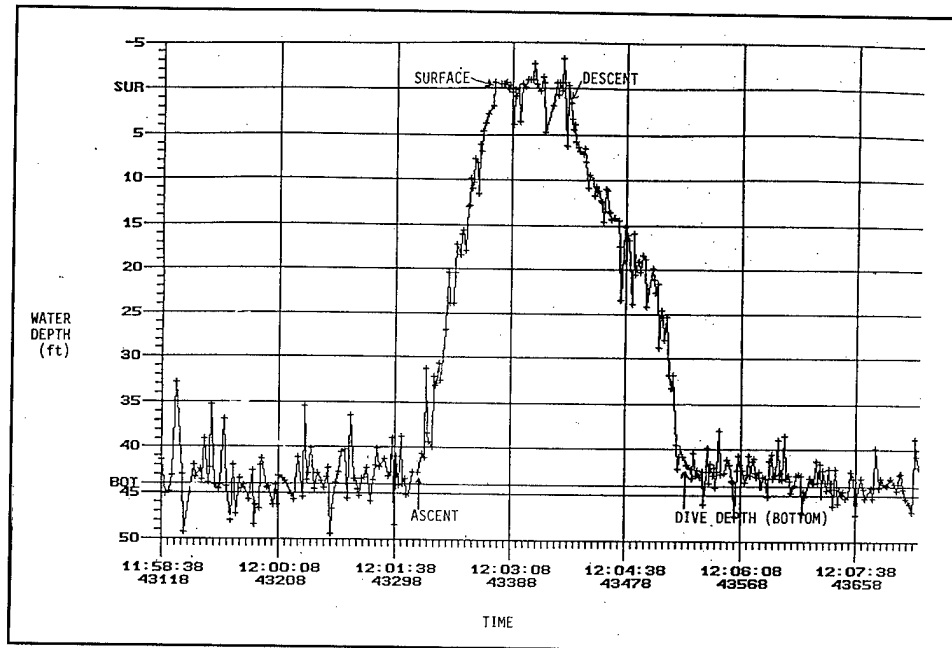


Figure 6. Sample dive profile from telemetry data

bottom. **Surface time** was defined as that period of time beginning immediately following an ascent to a point within 1.5 ft of the surface and ending when the turtle descended to a point greater than 1.5 ft from the surface. **Ascent time** refers to the amount of time spent in a complete ascent from the bottom to the surface. Likewise, **descent time** refers to the amount of time spent in a complete descent from the surface to the bottom. Partial ascents and descents were not used in the calculation of ascent and descent times. To compare differences in dive cycles between day and night, data collected during the period of time from 0600 to 1800 were considered to have been collected during daylight hours.

Physical Measurements

Water temperatures were measured at the surface, middepth, and bottom using a Yellow Stone Instruments (YSI) water quality meter. Readings were recorded daily during periods of data collection. Wind speed, direction, current velocity, and wave height were also estimated and recorded. Tidal stages were recorded from local tide charts.

Data Analysis

Dive patterns (surface time and bottom time) were compared using analysis of variance (ANOVA) with alpha set at 0.05. All time intervals were measured in seconds. Raw data were transformed prior to analysis in order to

stabilize the variances. Surface interval data were transformed using the log ($x + 1$) transformation. Bottom time intervals were transformed using the square root ($\text{sqrt}(x + 0.5)$) transformation (Zar 1984). Tukey's multiple comparison test was used to determine significant differences in surface interval and bottom time among individual turtles. Analyses were conducted using Minitab, Inc., Release 9 for Windows.

4 Results and Discussion

Sea Turtle Abundance

In order to establish the presence of sea turtles in Canaveral Channel and estimate their abundance, three standardized sea turtle trawl surveys were conducted. Catch per unit effort (CPUE) data were determined by the USACE Sea Turtle Trawling Survey Protocol Committee to be the best index for comparing sea turtle abundance within and between channels (Dickerson et al. 1995). Five loggerheads (*Caretta caretta*) (0.56 turtle/hour) were captured prior to initiation of dredging; seven loggerheads (0.71 turtle/hour) and one loggerhead (0.11 turtle/hour) were captured during dredging. Thirteen loggerhead turtles (0.47 turtle/hour) were captured during these three surveys; no other species were captured. These numbers are well within the range reported by recent surveys of Canaveral Channel (Table 1), but are considerably lower than those reported by Butler, Nelson, and Henwood (1987) or similar trawl surveys conducted in Canaveral Channel during the period 1979-1981. However, the number of turtles captured in relative abundance surveys since 1980 has declined (Bolten et al. 1994).

Table 1
CPUE Data for Selected South Atlantic Channels

CPUE Turtle/Hour	Location	Date	Source
0.30	Canaveral, FL	Sept. 1993	Bolten et al. (1994)
3.26	Canaveral, FL	Sept. 1981	Butler, Nelson, and Henwood (1987)
2.62	Canaveral, FL	Sept. 1980	Butler, Nelson, and Henwood (1987)
9.43	Canaveral, FL	Sept. 1979	Butler, Nelson, and Henwood (1987)
0.12	Charleston, SC	Sept. 1991	Dickerson et al. (1995)
0.42-0.56	Charleston, SC	Sept. 1990	Van Dolah and Maier (1993)
0.85	Fernandina, FL	Sept. 1992	Dickerson et al. (1995)
0.93	Savannah, GA	Sept. 1992	Dickerson et al. (1995)
0.774	Brunswick, GA	Sept. 1991	Dickerson et al. (1995)

Additional trawling was conducted to collect more turtles for behavioral studies. For all surveys combined, a total of 21 turtles were captured by trawling in the Canaveral ship channel during the study period 5-30 September 1994 (Table 2). NMFS contributed 12 additional loggerheads captured during Turtle Excluder Device (TED) tests in Canaveral Channel (Table 3). These were instrumented with sonic and radio tags and monitored as part of the behavioral studies. Morphometric data are included for these additional turtles; however, only those turtles captured during standard trawling surveys were included in the abundance estimates.

Rate of Sea Turtle Entrainment

A single sea turtle, a small green turtle (*Chelonia mydas*), was entrained during the 15 days (69.3 hr) of dredging. The green turtle was found on the inflow screen and appeared uninjured. It was transported to Sea World in Orlando, FL, for further observation.

Entrainment rates are difficult to accurately assess and compare. No studies have been conducted to determine the relationship between entrainment rates, volume of material dredged, and sea turtle relative abundance. Simultaneous estimates of dredge entrainment rates and sea turtle relative abundance (CPUE) are extremely limited and were only available for Savannah, GA, and Brunswick, GA, during the years 1991-1992 (Table 4). Estimates of the number of turtles entrained per day of dredging are subject to error if the exact number of hours of actual dredging is unknown (all down time must be accounted for). Estimates of entrainment rates per unit volume of material removed are also subject to unknown amounts of error due to differences in dredge equipment and operation, bottom type, etc.

Estimated rates of entrainment from dredging Canaveral Harbor entrance channel from 1980 to 1988 (for 5 dredging seasons which included the fall months) ranged from 0.15 to 0.59 turtle/day (average 0.35 turtle/day, 128 turtles during 306 days of dredging) (calculated from unpublished NMFS data cited in Dickerson et al. 1995). These values should be considered conservative (likely to be less than the number of turtles actually entrained) because during these 8 years, turtle monitoring was conducted at various levels of intensity (at times less than 100 percent) and monitoring procedures were not standardized.

An indication of the effectiveness of the rigid deflector draghead in reducing sea turtle entrainment can be seen in the results of trawling surveys conducted during dredging operations in Brunswick and Savannah Harbor entrance channels in 1991 (Table 4). A total of 22 turtle incidents were recorded in Brunswick, GA, during dredging operations conducted from 23 March through 20 June 1991 (1.39 turtle/100,000 cu yd). CPUE results from trawl surveys in this channel in June 1991 were 0.62 turtle/hour (Dickerson et al. 1995). Similarly, 17 turtle incidents were recorded in Savannah,

Table 2
Turtles Captured by Trawling in Canaveral Channel, September 1994 (SCL = straight-line carapace length, SCW = straight-line carapace width)

NMFS Tag No.	PIT Tag No.	Capture/Release	Lat/Long Release	SCL cm	SCW cm	Weight kg
QQJ159/BBE135	000010-1961	09/05	28° 24.20 80° 33.90	61.6	53.9	NA
SSE601/SSE602	000013-B740	09/06	28° 22.04 80° 30.94	94.3	71.9	82.1
SSE603/SSE604	000010-772E	09/06	28° 22.13 80° 31.04	89.5	66.8	82.1
SSE605/SSE606	000013-C4DC	09/06	28° 22.05 80° 30.96	70.9	58.9	28.0
SSE607/SSE608	000010-6E90	09/06	28° 23.93 80° 33.54	62.4	50.8	17.5
SSE645/SSE646	NA	09/15	28° 21.22 80° 29.58	76.0	57.0	NA
SSE641/SSE642	NA	09/15	28° 21.22 80° 29.58	64.0	54.0	NA
SSE643/SSE644	NA	09/15	28° 21.22 80° 29.58	73.0	59.0	NA
SSE647/SSE648	000013-C5EV	09/16	28° 23.08 80° 32.58	68.8	56.4	22.4
SSE639/SSE638	000010-68FB	09/15	28° 21.22 80° 29.58	73.3	58.8	31.7
SSE651/SSE652	000013-B7CO	09/16	28° 22.50 80° 31.57	48.4	42.2	NA
SSE649/SSE650	000010-7848	09/16	28° 23.08 80° 32.58	74.7	60.6	32.7
SSE662/SSE661	000013-C344	09/22	28° 24.22 80° 33.76	64.5	52.8	35.5
SSE653/SSE654	000010-75F7	09/16	28° 23.62 80° 33.23	67.8	52.1	24.3
X1040/X1039	000010-734E	09/22	28° 23.37 80° 32.77	65.8	52.2	42.0
SSE657/SSE658	000013-C332	09/22	28° 23.37 80° 32.77	57.8	50.5	28.0
SSE659/SSE660	000010-6EBE	09/24	28° 23.25 80° 32.48	57.5	49.3	NA
SSE670/SSE669	000013-CA85	09/23	28° 20.89 80° 32.71	65.7	58.6	23.9
SSE668/SSE667	000010-7532	09/29	28° 20.89 80° 32.71	76.8	61.9	37.7
SSE664/SSE663	000010-6BC6	09/23	28° 20.89 80° 32.71	65.2	53.1	38.0
SSE665/SSE666	000010-657E	09/23	28° 20.89 80° 32.71	83.3	64.9	47.0

Note: NA = Data not available.

Table 3
Loggerhead Turtles Captured by NMFS During TED Tests and Released in Canaveral Channel

NMFS Tag No.	PIT Tag No.	Capture/Release	Lat/Long Release	SCL cm	SCW cm	Weight kg
SSE636/SSE637	000010-7772	09/14	28° 32.08 80° 30.71	92.6	71.7	NA
SSE632/SSE633	000013-BA68	09/14	28° 32.08 80° 30.71	62.4	51.6	NA
SSE630/SSE631	000010-6D95	09/14	28° 23.17 80° 32.21	59.1	49.7	NA
SSE634/SSE635	000010-6FC3	09/14	28° 22.44 80° 31.84	67.7	55.6	NA
SSE628/SSE629	000010-657E	09/13	28° 22.89 80° 32.71	65.8	55.8	NA
SSE626/SSE627	NA	09/12	28° 23.56 80° 32.57	66.3	55.9	NA
SSE621/SSE622	000010-72BE	09/11	28° 23.56 80° 32.57	62.2	50.2	NA
SSE624/SSE625	000010-69AO	09/08	28° 22.60 80° 31.55	83.9	66.9	61.6
SSE615/SSE616	000013-C220	09/08	28° 22.60 80° 31.70	55.5	46.4	17.2
SSE611/SSE612	000013-C449	09/07	28° 22.60 80° 31.70	62.4	52.6	16.8
SSE609/SSE610	000010-6755	09/07	28° 22.60 80° 31.70	93.0	69.6	80.2
SSE613/SSE614	000010-6AC8	09/08	28° 22.60 80° 31.70	49.6	42.4	12.9

Note: NA = Data not available.

Table 4
Number of Hopper-Dredge Related Sea Turtle Incidents and Associated CPUE Data

Location	Dredging Date	Cubic Yards Dredged	No. Turtle Incidents	No. Turtle Incidents/ 100,000 cu yd	Trawl Survey Date	Trawl Survey CPUE
Brunswick, GA ¹	23 Mar-20 Jun 1991	1,583,000	22	1.39	Jun 1991	0.62
Savannah, GA ¹	20 Jun-14 Aug 1991	1,104,991	17	1.54	Jun-Aug 1991	0.36-0.40
Canaveral, FL ²	15-30 Sept 1994	76,710	1	1.30	Sept 1994	0.47

¹ Dickerson et al. (1995).

² This study.

GA, during dredging operations conducted from 20 June through 14 August 1991 (1.54 turtle/100,000 cu yd). CPUE results from trawl surveys conducted in June and August 1991 were 0.36 and 0.40 turtle/hour, respectively (Dickerson et al. 1995). The number of turtle incidents was lower in this study (1.30 turtle/100,000 cu yd), at similar levels of turtle abundance (mean CPUE = 0.47 turtle/hour). These data appear to indicate that the rigid deflector draghead may be effective in reducing the rate of sea turtle entrainment, but this test involved a relatively small amount of material (76,710 cu yd).

It should be noted that although only loggerhead turtles were captured during trawling surveys, indicating a higher loggerhead relative abundance, a juvenile green turtle was the only turtle entrained during the dredging. Due to the small size of this turtle, it is possible that this turtle was entrained through a water intake opening in the upper surface of the draghead rather than passing under the deflector. No further entrainments occurred after a 4-in. square grate was installed over this opening. Additional studies using larger volumes of material are needed to determine if entrainment rates using the rigid deflector draghead are significantly lower than with other draghead types.

Sea Turtle Size Distribution

Straight-line carapace lengths (SCL) for the 21 turtles captured by trawling in the Canaveral Harbor entrance channel ranged from 48.4 cm to 94.3 cm with an average SCL of 69.6 cm. The loggerhead sea turtle population in the Canaveral Channel area was strongly dominated by individuals in the size class 60-80 cm (Figure 7). Following Bolten et al. (1994), turtles with a SCL less than 80 cm were classified as juveniles. This size was selected based on the observed frequency distributions and the minimum recorded size of nesting Florida loggerheads (Bolten et al. 1994). Juveniles accounted for 81 percent of the turtles captured in the Canaveral channel. The remaining three adults ranged from 83.3- to 94.3-cm SCL and averaged 89.0-cm SCL.

Similar size distributions for Canaveral Channel have been reported by Bolten et al. (1994); Bolten and Bjorndal (1991); Dickerson et al. (1995); Henwood (1987); and Standora, Morreale, and Bolten (1993a, 1993b). However, the ratio of adults/juveniles varies considerably with season. Breeding adults are most abundant during the months of April, May, and June, with subadults predominating during the months of August through March (Henwood 1987). Juveniles are believed to overwinter in the Cape Canaveral channel area, moving northward in spring as the breeding adults begin to arrive in March and April (Henwood 1987).

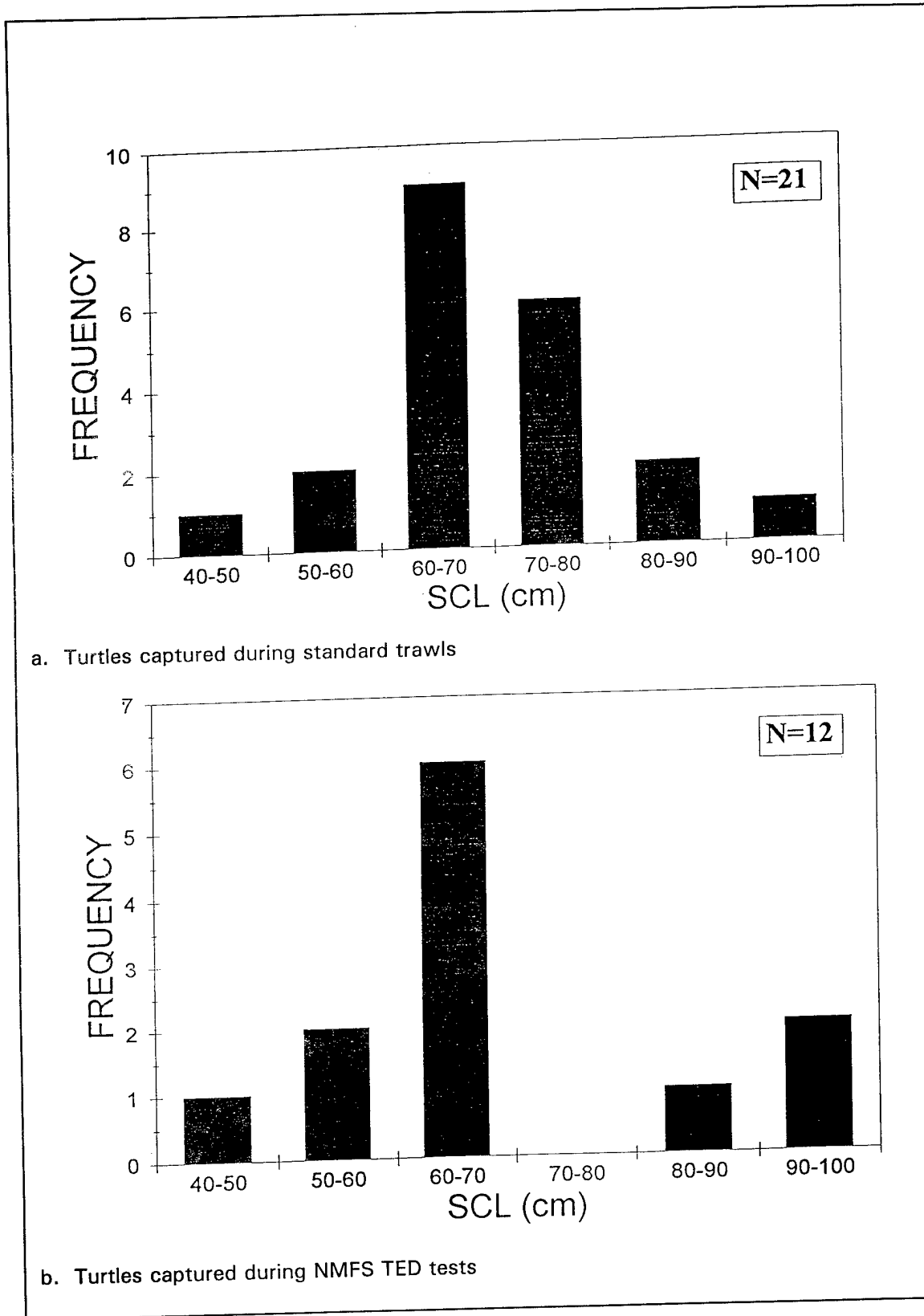


Figure 7. Size distribution for turtles captured in Canaveral Channel, Florida, September 1994

Environmental Data

Water temperatures ranged from 28.2 °C (9 September 1994) to 25.9 °C (29 September 1994). Surface temperatures differed little from bottom temperatures (Figure 8), indicating a well-mixed water column with no distinct thermocline. Overall water temperatures in the area decreased by approximately 2 °C during the study period (Figure 9).

Water temperatures may be used as a general indicator of potential sea turtle abundance, however, other factors should also be considered, including the location and the availability of other physical and biological data. For channels along the southeastern Atlantic coast, moderate-to-high levels of sea turtle abundance may be expected when water temperatures exceed 21 °C (Dickerson et al. 1995). Water temperatures during this study remained well above this level.

Diving and Submergence Behavior

Twenty-six turtles were instrumented with radio and sonic tags in the Canaveral Harbor entrance channel during the study period 5-30 September 1994 (Table 5). Seven of the transmitters were prematurely broken off or removed; at least five were broken off during subsequent recaptures by trawlers. All seven of these transmitters were later recovered. Data were collected for 12 of the remaining instrumented turtles. With the exception of one adult male (SSE609), all of these were juveniles. The other seven turtles probably emigrated from the area, as evidenced by the lack of radio contact and the recovery of two of the transmitters on beaches 130 miles to the north, 9 days and 29 days after release of the turtles. Approximately 154 hr of telemetry data were analyzed for 12 individual turtles. Data were collected both prior to and during dredging operations.

The proportion of time spent at different depths for each turtle was calculated using data obtained from the depth-sensitive sonic tags. For all turtles combined, 83.2 percent of the time was spent on the bottom, at depths of 30-50 ft (Table 6). Estimates of the proportion of time spent on the bottom ranged from 47.3 percent to 95.9 percent. The percent of time spent at mid-depth primarily reflects ascent and descent time, although one turtle (SSE647) was observed to spend nearly equal amounts of time on the bottom (47.3%) and at middepth (46.8%). On average, less than 5 percent of the time was spent on the surface. Other telemetry studies on loggerhead turtles also support the conclusion that these turtles spend only a small percentage of time (4-10%) on the surface (Nelson, Benigno, and Burkett 1987, Renaud and Carpenter 1994).

Diving patterns varied widely among individual turtles (Table 7). Bottom time for individual turtles ranged from 12.4 to 52.6 min, with an average of 21.1 ± 1.0 min (mean \pm SE). Mean surface interval ranged from 0.7 to

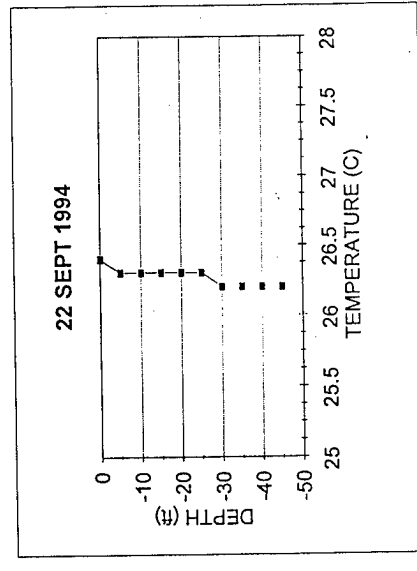
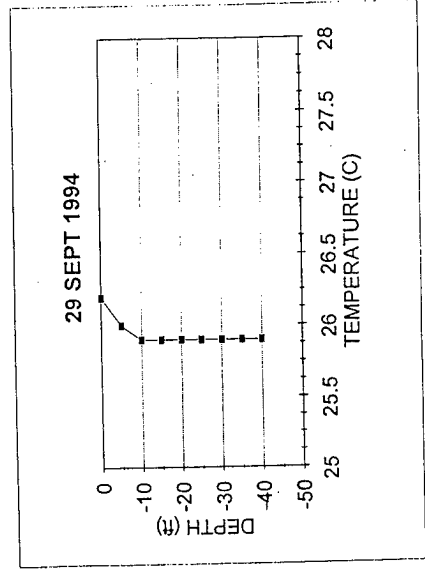
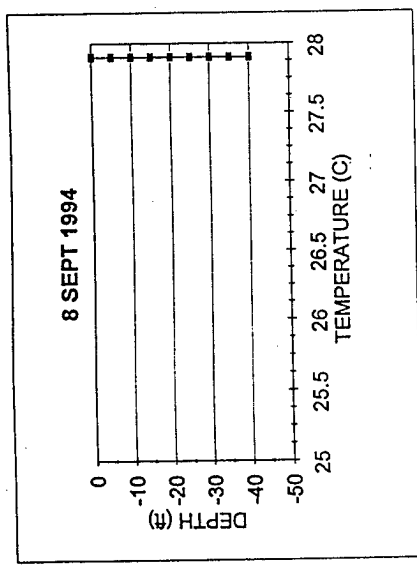
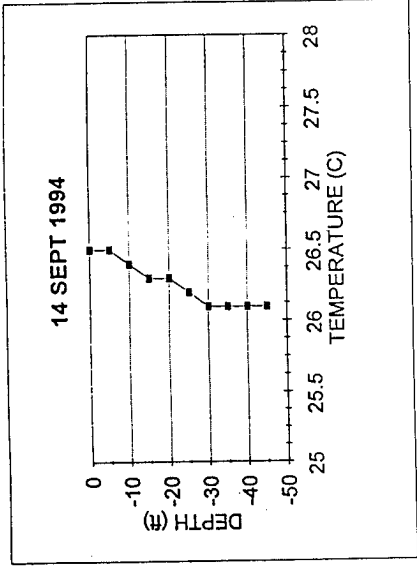


Figure 8. Vertical water temperature profiles, Canaveral, Florida, September 1994

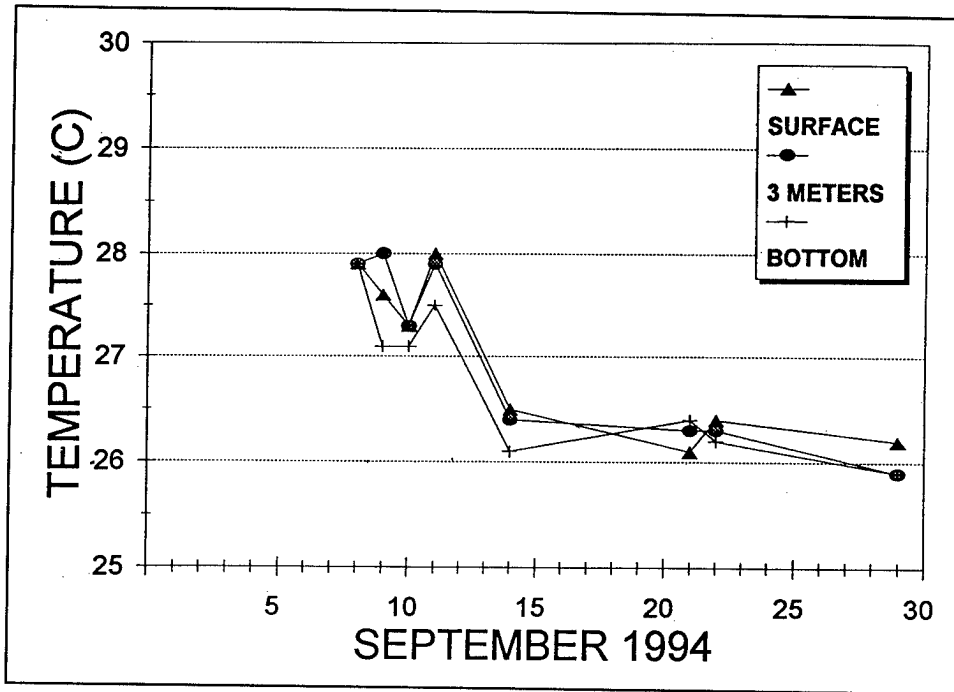


Figure 9. Surface, mid-water, and bottom temperature profiles, Canaveral, Florida, September 1994

2.3 min, with an average of 1.5 ± 0.2 min (mean \pm SE). Ascent and descent times were less variable, with descents usually more rapid than ascents. The mean ascent and descent times were 1.2 ± 0.01 and 0.8 ± 0.01 min, respectively (mean \pm SE). Surfacing frequency, or the number of surface events per hour, ranged from 0.9 to 3.8, with an average of 2.1 ± 0.2 (mean \pm SE) surface events per hour. Nelson, Benigno, and Burkett (1987) reported lower values for surfacing frequency (mean = 1.3 surface events/hour) for turtles monitored in spring 1982, but surface intervals were longer (2.7 ± 0.22 min). These longer surface intervals may have been an indication of basking behavior in an attempt to absorb solar heat in cooler spring water temperatures (Carr 1952, Nelson¹).

Diving patterns of turtles recorded prior to the commencement of dredging operations were compared with those recorded during dredging operations to determine differences in surface time, submergence time, and/or bottom time. Results of the ANOVA indicated no significant differences in surface time, submergence time, or bottom time ($p = 0.76$, $p = 0.53$, and $p = 0.64$) for data collected prior to and during dredging operations. These results should not be considered conclusive, however, due to the variable nature of the data and the difficulty of monitoring turtles in the immediate vicinity of the dredge.

¹ Unpublished data, David A. Nelson, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 5
Loggerhead Turtles Instrumented with Radio and Sonic Tags, Sep-
tember 5-30, 1994

NMFS Tag No.	Sonic Tag No.	Sonic Freq.	Radio Freq.	SCL cm	Hours of Telemetry Data
QQJ159	963 ?	40.0	0.982	61.6	
SSE601	968* D	36.0	0.622	94.3 F	
SSE603	744* B	32.0	0.032	89.5 F	
SSE605	960* T	35.0	0.327	70.9	
SSE607	376* D	33.0	0.720	62.4	12.3
SSE609	962* D	34.0	0.230	93.0 M	11.2
SSE611	389* T	37.0	0.068	62.4	6.5
SSE613	960 ?	35.0	0.327	49.6	20.0
SSE621	389* T	37.0	0.068	62.2	12.8
SSE626	961* T	38.4	0.522	66.3	
SSE630	966 * B	36.0	0.882	59.7	
SSE634	966* T	36.0	0.882	67.7	
SSE636	964 ?	34.0	0.940	92.6 F	
SSE639	811 ?	40.0	0.192	73.0	9.8
SSE647	961* D	38.4	0.522	68.8	13.0
SSE649	389* D	37.0	0.068	74.7	
SSE651	966* D	36.0	0.882	48.4	23.0
SSE653	376 ?	33.0	0.720	67.8	
SSE658	967* D	37.0	0.782	57.8	5.8
SSE659	544* B	32.9	0.132	57.5	7.5
SSE662	696 ?	35.0	0.920	64.5	
SSE665	638* D	32.7	0.840	83.3 F	
SSE664	965* D	38.4	0.858	65.2	
SSE670	371* B	36.0	0.578	65.7	
SSE669	391 ?	37.0	0.171	76.8	17.6
X1040	646* D	34.0	0.683	65.8	14.0

Note: * = Tags retrieved; T = Tag removed by trawler; D = Dissolved link; B = Tag broken off; M = Male; F = Female.

Table 6
Percent of Time Individual Turtles Spent at the Surface, Middepth, and Bottom During the Rigid Deflector Draghead Test, Canaveral, Florida, September 1994

Turtle ID	SCL, cm	Surface, %	Middepth, %	Bottom, %
SSE607	62.4	3.3	9.6	86.9
SSE609	93.0	1.5	2.6	95.9
SSE611	62.4	2.0	9.5	88.5
SSE613	49.6	10.1	10.4	79.5
SSE621	62.2	1.3	3.4	95.3
SSE639	73.0	3.4	28.7	67.9
SSE647	68.8	5.9	46.8	47.3
SSE651	48.4	5.0	14.0	80.9
SSE658	57.8	2.4	3.4	94.2
SSE659	57.5	5.5	3.8	90.7
SSE669	65.7	5.5	8.4	86.1
X1039	65.8	4.3	12.5	83.2
MEAN	63.9	4.3	12.5	83.2

Diving patterns recorded during daylight hours (0600-1800) were compared with those recorded at night. There were no significant differences in surfacing frequency or bottom time between day and night ($p = 0.20$, $p = 0.36$). Surface intervals, however, were significantly longer at night (mean = $2.6 \text{ min} \pm 0.9 \text{ (SE)}$, $n = 55$) than during the day (mean = $1.2 \pm 0.08 \text{ (SE)}$, $n = 275$) ($p < 0.01$). A single outlier observation corresponding to a surface interval of 51 min during the night was recorded. Since removal of the outlier did not affect the significance of the results, it was not eliminated from the data set.

Turtles have been shown to exhibit both seasonal and diurnal variation in diving behavior (Renaud and Carpenter 1994; Standora, Morreale, and Bolten 1993a, 1993b; Nelson, Benigno, and Burkett 1987). Factors that may influence diving behavior include water temperature and the sex and size class of the turtles. Since water temperature measurements indicated very little vertical stratification of the water column and overall water temperatures decreased by only $2 \text{ }^\circ\text{C}$ during the study period, differences in diving patterns in this study are unlikely to be temperature related. There were insufficient data to compare differences in diving behavior between juveniles and adults (two adults were tagged, only one was monitored).

Table 7
Mean Ascent Time, Bottom Time, Descent Time, and Surface
Time by Individual Turtles (all times listed in seconds)

Activity	Turtle ID	Mean	Std. Dev.	Min.	Max.	Number
Ascent Time	SSE607	56	29	30	140	25
	SSE609	57	20	28	101	13
	SSE611	83	32	38	141	10
	SSE613	68	27	27	160	62
	SSE621	51	19	30	114	16
	SSE639	119	64	66	281	10
	SSE647	98	20	76	155	11
	SSE651	59	30	26	173	67
	SSE658	58	18	34	99	8
	SSE659	72	15	47	110	11
	SSE669	99	35	45	168	34
	X1039	56	42	31	213	23
	Average	70	36	26	281	290
	Bottom Time	SSE607	1,322	655	100	3,173
SSE609		3,153	2,125	39	5,865	12
SSE611		1,584	1,166	28	3,031	11
SSE613		741	656	3	2,448	69
SSE621		2,339	1,027	142	4,576	17
SSE639		941	1,259	34	3,586	18
SSE647		1,051	784	18	2,151	18
SSE651		1,010	395	16	1,795	67
SSE658		1,933	645	1,221	2,660	4
SSE659		2,028	753	94	2,686	11
SSE669		1,224	1,170	42	3,201	40
X1039		1,572	691	207	2,746	19
Average		1,264	1,056	16	5,865	312
Descent Time		SSE607	49	21	11	124
	SSE609	51	42	27	183	11
	SSE611	62	25	31	112	12
	SSE613	48	17	24	129	62
	SSE621	53	21	25	106	15
	SSE639	81	44	46	175	10
	SSE647	62	7	52	76	18

(Continued)

Table 7 (Concluded)						
Activity	Turtle ID	Mean	Std. Dev.	Min.	Max.	Number
Descent Time (Continued)	SSE651	36	12	21	88	69
	SSE658	53	35	24	146	9
	SSE659	42	4	34	48	11
	SSE669	49	12	32	90	36
	X1039	44	20	27	109	25
	Average	48	22	11	183	305
Surface Time	SSE607	52	21	15	107	26
	SSE609	60	46	6	135	13
	SSE611	43	22	4	84	14
	SSE613	129	133	11	841	64
	SSE621	43	23	3	85	17
	SSE639	81	52	8	237	15
	SSE647	99	52	12	255	28
	SSE651	57	32	5	229	70
	SSE658	60	11	35	76	9
	SSE659	137	120	77	512	11
	SSE669	134	493	10	3,087	37
	X1039	78	30	6	128	25
	Average	87	183	3	3,087	329

Turtle Locations and Movements

All captured turtles were released into the channel at the approximate point of capture. Of the 26 tagged turtles, 12 were monitored; data collection periods for each individual turtle ranged from a minimum of 6 hr to several days. Approximate positions of each turtle at the beginning and end of the monitoring period were plotted from GPS coordinates obtained from the tracking vessel (Table 8). Estimates of distance traveled are conservative values that reflect the shortest distance between two points; the actual distance traveled by each turtle may be greater.

Six of the twelve monitored turtles (SSE609, SSE611, SSE621, SSE651, SSE658, and X1039) remained in the immediate vicinity of the channel during the study period (Figure 10). SSE609, SSE611, and SSE621 were monitored prior to the initiation of dredging activity and remained within a 1.5-km radius of the channel during the period 8-15 September 1994. SSE658, SSE651, and

Table 8
GPS Position Data for Turtles During the Rigid Deflector Draghead
Test, Canaveral, Florida, September 1994

Turtle ID	Start Date	GPS Lat.	GPS Long.	End Date	GPS Lat.	GPS Long.
SSE607	9/07/94	28° 22.49	80° 33.45	9/10/94	28° 21.61	80° 32.69
SSE609	9/14/94	28° 23.47	80° 32.81	9/14/94	28° 23.23	80° 32.88
SSE611	9/08/94	28° 23.26	80° 32.89	9/08/94	28° 23.25	80° 32.86
SSE613	9/09/94	28° 23.93	80° 33.55	9/11/94	28° 14.77	80° 33.11
SSE621	9/12/94	28° 23.61	80° 32.92	9/15/94	28° 22.89	80° 32.51
SSE639	9/16/94	28° 21.23	80° 30.76	9/16/94	28° 20.78	80° 30.87
SSE647	9/20/94	28° 22.16	80° 30.02	9/21/94	28° 20.17	80° 30.88
SSE651	9/17/94	28° 22.78	80° 32.23	9/22/94	28° 23.00	80° 32.23
SSE658	9/26/94	28° 23.15	80° 32.69	9/26/94	28° 23.10	80° 32.26
SSE659	9/26/94	28° 23.73	80° 32.42	9/27/94	28° 20.98	80° 32.35
SSE669	9/27/94	28° 17.87	80° 32.26	9/29/94	28° 19.33	80° 31.45
X1039	9/25/94	28° 23.32	80° 33.56	9/29/94	28° 23.44	80° 33.40

X1039 were monitored during dredging operations conducted from 16-30 September. These turtles also remained in or very near the channel, traveling less than 1.5 km during the monitoring period. These turtles were probably present in or very near the channel during the time dredging operations were conducted. The fact that these turtles did not leave the channel area following capture and release suggests that they were, at least, short-term channel residents and would have been susceptible to entrainment by hopper dredging activities.

The remaining six turtles (SSE607, SSE613, SSE639, SSE647, SSE659, and SSE669) traveled more than 2 km from the channel during the monitoring period (Figure 11). With the exception of SSE669, all of these moved southward. SSE613 traveled the farthest distance, moving about 15 km south during the 48-hr monitoring period (0.3 km/hr). SSE659 also traveled due south, at an average velocity of 0.6 km/hr. SSE669 moved approximately 3 km to the northeast during the 33-hr tracking period.

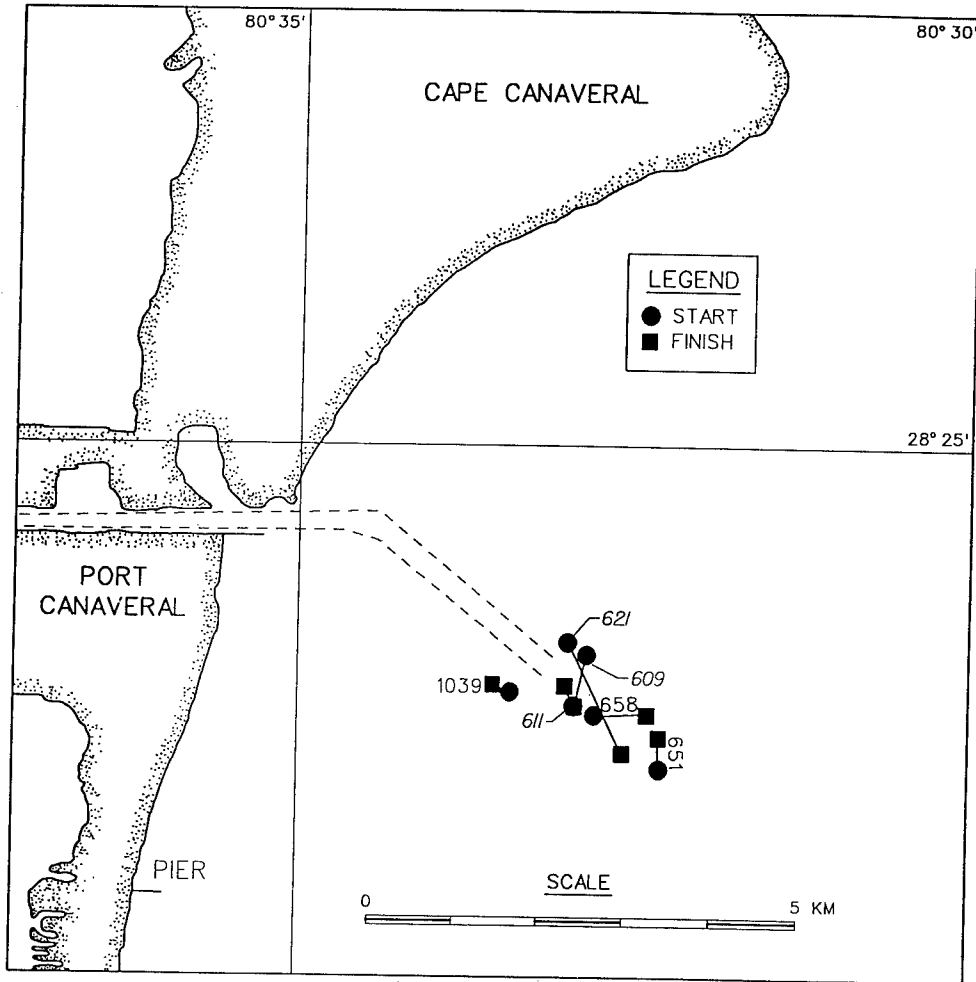


Figure 10. Locations of turtles, indicated by NMFS tag numbers, that remained in or very near the channel during the monitoring period

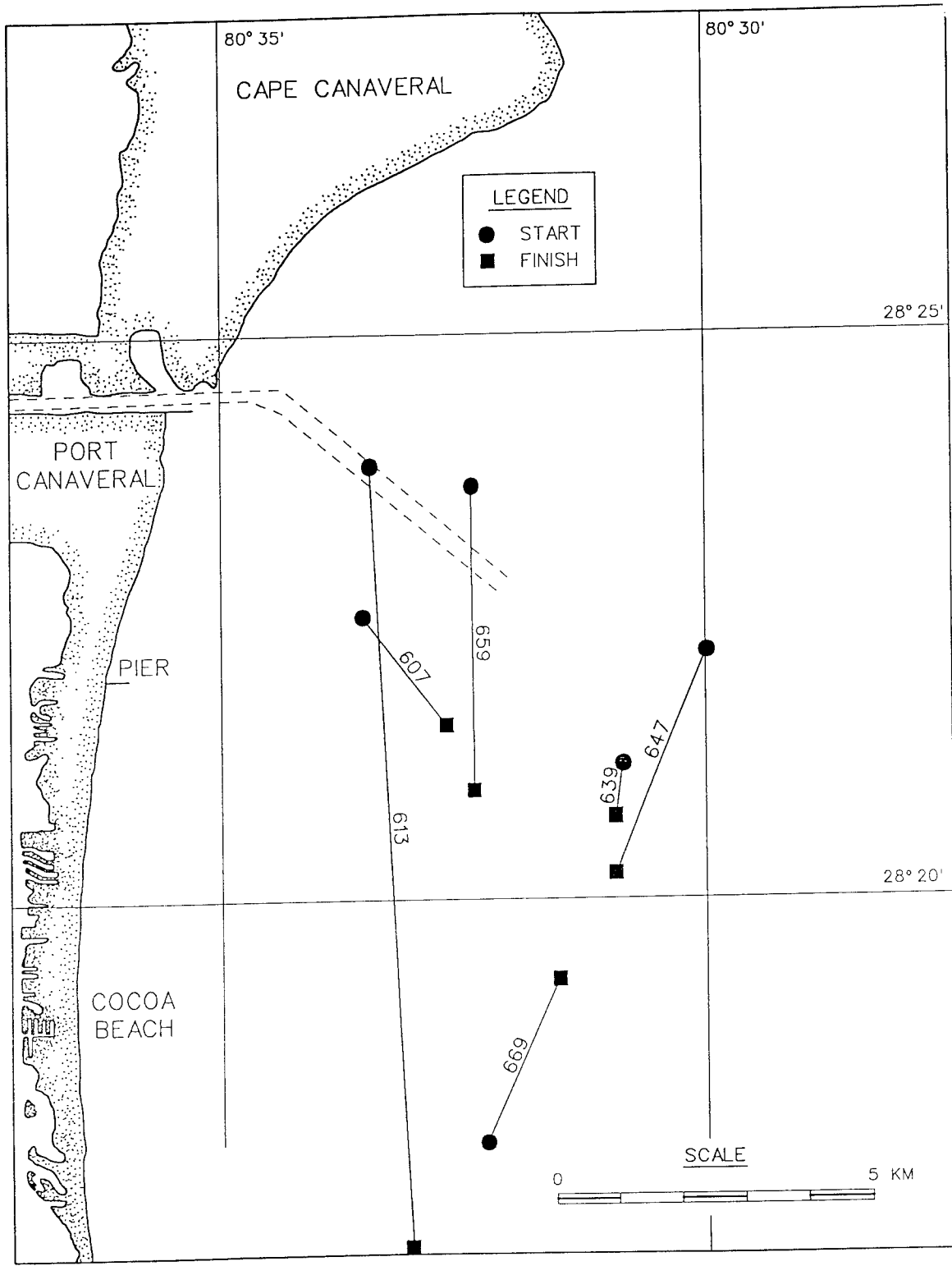


Figure 11. Locations of turtles, indicated by NMFS tag numbers, that traveled distances greater than 2 km from the channel during the monitoring period

5 Summary and Conclusions

Turtle response to the rigid deflector draghead could not be directly observed due to poor water clarity and a low frequency of encounter. Therefore, the effectiveness of the rigid deflector draghead was assessed indirectly by determining:

- a. That the level of abundance of turtles in the channel was similar to that observed in other southeastern Atlantic channels which had recorded a high number of turtle entrainment incidents during dredging operations with the California draghead.
- b. That the turtles spend most of the time on the bottom where they would be most susceptible to entrainment.
- c. If the rate of entrainment for the rigid deflector draghead was lower than for the California draghead at similar levels of sea turtle abundance.

Since the efficiency of the trawl nets in capturing turtles has not been established, the relationship between CPUE and the total channel population is not known. Thus the trawling survey CPUE is an index of abundance which can only be used for comparing the results of surveys conducted using comparable methods. Recent surveys conducted in Canaveral Channel, Brunswick Channel, and Savannah Channel, using comparable trawling methods, resulted in CPUE values similar to those recorded for this study.

Results of behavioral studies have established that although diving patterns may be subject to slight seasonal and diel variation, in general, sea turtles spend very little time at the surface, remaining on or near the bottom for the majority of the time. This aspect of their behavior makes them susceptible to entrainment by hopper dredge.

While no studies have been conducted to determine the relationship of sea turtle relative abundance and rates of entrainment, the entrainment rate for this study (1.30 turtle/100,000 cu yd) was lower than entrainment rates for Brunswick, GA (1.39 turtle/100,000 cu yd), and Savannah, GA (1.54 turtle/100,000 cu yd). Dredging in these channels was conducted using a California draghead at levels of abundance similar to those recorded in this study.

The rate of sea turtle entrainment observed during this study, at levels of abundance which had formerly resulted in numerous entrainment incidents using the California draghead, indicates that the rigid deflector draghead may be effective in reducing the entrainment of loggerhead sea turtles in Canaveral Harbor entrance channel. However, this test involved hydraulic dredging of a relatively small amount of material (76,710 cu yd). The difficulties inherent in obtaining precise measures of entrainment rates, combined with the limited data available on which to base comparisons, preclude robust statistical analysis of the dragarm. Additional studies representing larger volumes of material are needed to determine if entrainment rates using the rigid deflector draghead are significantly lower than with other draghead types.

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Appendix A Data Sheets

TRAWLING INFORMATION:

Channel: _____ Vessel: _____ Captain: _____
 Crew: _____

Date: _____
 Tow #: _____
 Shift #: _____
 Dredge Location: _____
 Total Tow Time: _____ Min.

Survey:
 Relocation:
 PreDredge:

Substrate: Mud:
 Sand:
 Rocks:
 Snag:

Low Tide Time: _____
 High Tide Time: _____
 Ebb:
 Flood:
 Slack Ebb: Slack Flood:

Water Temp. (B: °C) (M: °C) (S: °C)
 Wave Height: _____ ft.
 Air Temperature: _____ °C
 Wind Speed/Direction: _____
 Barometric Pressure: _____

Dir: In Out Loc: Green Center Red

Begin Tow:
 Time: _____
 Depth: _____ ft.
 Speed Mid-Tow: _____ knots
 Latitude: _____
 Longitude: _____
 Loran: _____
 Station/Buoys: _____

End Tow:
 Time: _____
 Depth: _____ ft.
 Total Tow Distance: _____ ft.
 Latitude: _____
 Longitude: _____
 Loran: _____
 Station/Buoys: _____

Number of Turtles	
Port Net:	Starboard Net:
Logger: _____	Logger: _____
Kemp: _____	Kemp: _____
Green: _____	Green: _____

Bycatch/Comments: _____

Page #: _____

SEA TURTLE INFORMATION:

Channel:
Date:
Tow #:

_____ of _____

Turtle Species:	Net: Port <input type="checkbox"/>	Starboard <input type="checkbox"/>
-----------------	------------------------------------	------------------------------------

Flipper Tag #	
Left:	
Right:	
Recapture:	This effort: <input type="checkbox"/>
	Previous effort: <input type="checkbox"/>

Sex:	
Male:	<input type="checkbox"/>
Female:	<input type="checkbox"/>
Unk:	<input type="checkbox"/>

Weight:	
	kg
	lbs

Head Width:	
	cm
	in

Carapace S.L. Length:	
	cm
	in

CCL: _____ cm.

S.L. Width:	
	cm
	in

CCW: _____ cm.

Tail Length	
	(from plastron to tip:)
	cm

Photos Taken:	
Yes	<input type="checkbox"/>
No	<input type="checkbox"/>

Blood Taken:	
Yes	<input type="checkbox"/>
No	<input type="checkbox"/>
Time:	

of vials: _____

_____ Mhz
_____ Khz

Telemetry Tag:	
Radio	<input type="checkbox"/>
Sonic	<input type="checkbox"/>
Satellite	<input type="checkbox"/>

General condition of Turtle:

CPL: _____ cm.

CPW: _____ cm.

PIT TAG# _____

Turtle Released	
Date:	
Time:	

Release Location	
Lat:	
Long:	
Location:	

Appendix B

Turtle Trawl Net Specifications

Design: 4 seam, 4 legged, 2 bridle trawl net

Webbing: 4-in. bar, 8-in. stretch

Top: 36-gauge twisted nylon dipped

Side: 36-gauge twisted nylon dipped

Bottom: 84-gauge braided nylon dipped

Net Length: 60 ft from cork line to cod end

Body Taper: 2 to 1

Wing End Height: 6 ft

Center Height: Dependent on depth of trawl, 14 to 18 ft

Cod End: Length: 50 meshes \times 4 in. = 16.7 ft

Webbing: 2-in. bar, 4-in. stretch, 84-gauge braid nylon dipped, 80 meshes around, 40 rigged meshes with 1/4- \times 2-in. choker rings, 1 each 1/2 \times 4 in. at end.

Cod end cover: none, Chaffing gear: none

Head Rope: 60 ft of 1/2-in. combination rope (braid nylon with stainless cable center)

Foot Rope: 65 ft of 1/2-in. combination rope

Leg Line: Top: 6 ft, Bottom: 6 ft

Floats: Tuna floats (football style), Diameter: 7 in., Length: 9 in., Number: 12 each, Spacing: center on top net 2 in. apart

Mud Rollers: Diameter: 5 in., Length: 5.5 in., Number: 22 each, Spacing: 3 ft, attached with 3/8-in. polypropylene rope (replaced with snap-on rollers when broken)

Tickler Chains: NONE (discontinued, but previously used 1/4-in. × 74-ft galvanized chain)

Weight: 20 ft of 1/4-in. galvanized chain on each wing, 40 ft per net (looped and tied)

Door Size: 8 ft × 40 in. (or 9 ft × 40 in.), **Shoe:** 1 × 6 in., **Bridles:** 3/8-in. high test chain

Bridle Length: 7/16 in. × 240-300 ft (varies with bottom conditions)

Float Ball: none

Lazy Lines: 1-in. nylon

Pickup Lines: 3/8-in. polypropylene

Whip Lines: 1-in. nylon

Additional Supplies for Repairs on the Trawler Recommended:

- 3 Rolls #84 braid twine
- 3 Rolls #36 C-1 green twine
- 4 Each 10-in. needles
- 100 Meshes #84, 8-in. stretch mesh
- 100 Meshes #36, 8-in. stretch mesh
- 1 Reel 3/8-in. polypropylene line
- 6-10 Each snap-on mud rollers
- 12 Each 9/16-in. shackles

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13. ABSTRACT (Maximum 200 words)

The rigid deflector draghead was tested on a hopper dredge in Port Canaveral Harbor entrance channel from 16-30 September 1994. The effectiveness of the draghead was assessed by determining if turtles were: (a) present in the channel in sufficient numbers to encounter the draghead, (b) on the channel bottom where they were most susceptible to entrainment by the draghead, and (c) entrained by the rigid deflector draghead at a lower rate than by the California draghead. A total of 13 turtles (0.47 turtle/hour) were captured during three standardized sea turtle trawl surveys. The activities of 12 loggerhead turtles (*Caretta caretta*) were monitored intermittently from 5-30 September 1994 using radio tags and depth-sensitive sonic tags. These behavioral studies showed that loggerhead turtles spent most of their time (83.2 percent) on the seafloor. No loggerhead turtles were entrained during the dredging operations; however, one small green turtle (*Chelonia mydas*) was entrained during the dredging (0.09 turtle/day). Based on the observed levels of sea turtle abundance, a preponderance of bottom time for loggerhead sea turtles, and a low rate of sea turtle entrainment, the rigid deflector draghead may be effective in reducing sea turtle entrainment by hopper dredge in Port Canaveral Harbor entrance channel.

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