US Army Corps of Engineers
Waterways Experiment Station

Technical Report CHL-97-31
November 1997

Sea Turtle Research Program Summary Report

by U.S. Army Engineer Waterways Experiment Station

Approved For Public Release; Distribution Is Unlimited

Prepared for U.S. Army Engineer Division, South Atlantic
and U.S. Naval Submarine Base, Kings Bay

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Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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Prepared for U.S. Army Engineer Division, South Atlantic
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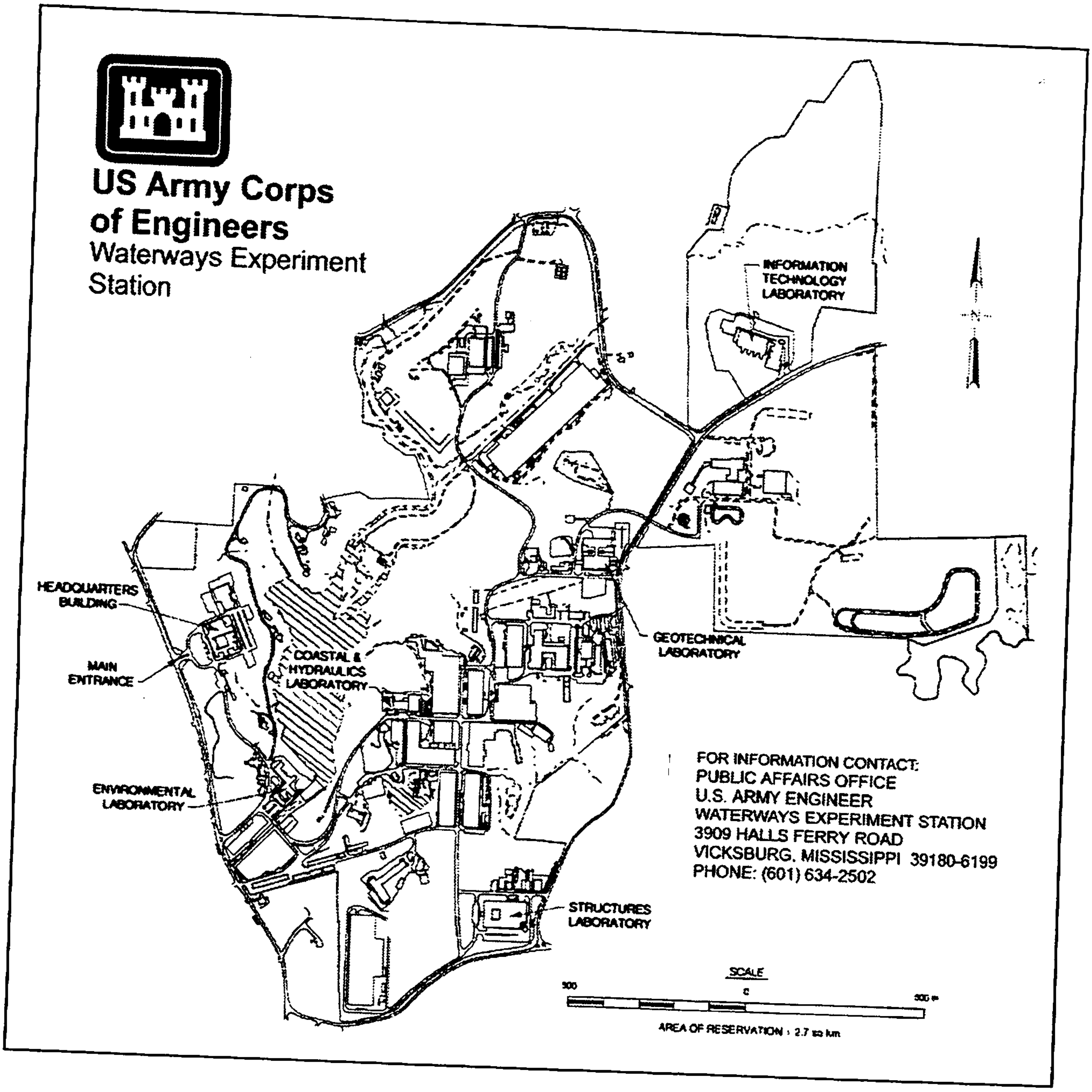
U.S. Naval Submarine Base, Kings Bay
Kings Bay, GA 31547-2606



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US Army Corps of Engineers

Sea Turtle Research Program Report Summary

Sea Turtle Research Program: Summary Report (TR CHL-97-31)

ISSUE: The U.S. Army Corps of Engineers (USACE) has a congressional mandate for maintaining coastal navigation channels of the United States by dredging. A major concern is entrainment of endangered sea turtles by hopper-dredge dragheads. The purpose of the USACE Sea Turtle Research Program (STRP) was to minimize the risk to sea turtle populations in channels along the southeast Atlantic region of the United States from hopper-dredging activities. Achieving this goal would have the effect of widening dredging operation windows previously established by USACE and the National Marine Fisheries Service that restrict dredging to specific times of the year in certain channels.

RESEARCH: The STRP was formulated using a biological approach and an engineering approach. The biological approach employed spatial and temporal surveys and telemetry, which together provided data to establish indices of turtle abundance and behavioral patterns. The engineering approach made use of physical model studies, engineering and structural analyses, acoustics, and field demonstrations to develop and evaluate technology and procedures that make dredging operations safer for sea turtles.

SUMMARY: Relative-abundance studies determined indices of sea turtle abundance at six harbor entrance channels maintained by hopper dredges; (a) Canaveral, FL, (b) Fernandina/Kings Bay, FL, (c) Brunswick, GA, (d) Savannah, GA, (e) Charleston, SC, and (f) Morehead City, NC. Behavioral studies monitored movement of sea turtles over time and distance with telemetry techniques. Acoustic-detection studies evaluated acoustic techniques for faster sea turtle surveys. Bioacoustic studies determined acoustic thresholds and auditory behavior of sea turtles and manatees. Acoustic-dispersal studies evaluated a technique for dispersing sea turtles. Dredging equipment studies developed a rigid deflector for the California-style hopper dredge draghead. Prototype field tests demonstrated that the deflector was effective in deflecting model (mock) sea turtles with no adverse impact on dredge production. Effectiveness in reducing entrainment of live sea turtles was confirmed during actual production dredging operations in Canaveral entrance channel.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service (NTIS) report numbers may be requested from WES Librarians. To purchase a copy of the report, call NTIS at (703) 487-4780.

Further Information: The Sea Turtle Research Program (STRP) was managed by the U.S. Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory. For further information about the STRP, contact Mr. E. Clark McNair, Jr., Manager, STRP, at (601) 634-2070.

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Preface

This report summarizes research conducted under the U.S. Army Engineer Waterways Experiment Station (WES) Sea Turtle Research Program (STRP). The STRP was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), USACE South Atlantic Division (SAD) (Charleston, Savannah, Jacksonville, and Mobile Districts), and the U.S. Naval Submarine Base, Kings Bay, GA. Technical Monitor for SAD was Mr. Tucker Russel (retired). HQUSACE Technical Monitors were Messrs. William Rushing (retired) and Barry Holliday. Chief Technical Monitor was Mr. Robert H. Campbell (retired), HQUSACE.

This summary report was reproduced verbatim (with spelling corrections where necessary) from technical reports prepared by WES STRP principal investigators, and by STRP researchers under contract to WES, with no interpretation of the authors' intent.

STRP studies were conducted by, or contract studies were performed under technical oversight of, the following WES Principal Investigators:

Environmental Laboratory (EL)--Ms. Dena D. Dickerson and Mr. David A. Nelson, Principal Investigators, Coastal Ecology Branch (CEB), Ecological Research Division (ERD), and Mr. Richard L. Kasul, Principal Investigator, Aquatic Ecology Branch (AEB), ERD. Additional supervision was provided by Messrs. Jack Pullen (retired) and Paul Becker, former and present Chiefs, CEB, respectively; Dr. Edwin A. Theriot, Chief, AEB; Dr. Conrad J. Kirby, Chief, ERD; Dr. John W. Keeley, Assistant Director, EL; and Dr. John Harrison, Director, EL.

Coastal and Hydraulics Laboratory (CHL)--Messrs. Glynn E. Banks and Michael P. Alexander, Principal Investigators, Estuarine Engineering Branch (EEB), Estuaries Division (ED). Additional supervision was provided by Mr. William D. Martin, Chief, EEB; Mr. William H. McAnally, Jr., Chief, ED; Messrs. Richard A. Sager and Charles C. Calhoun, Assistant Directors, CHL; Mr. Frank A. Herrmann, Jr. (retired), former Director, CHL, and Dr. James R. Houston, Director, CHL.

Geotechnical Laboratory (GL)--Mr. Robert F. Ballard, Jr., Acoustic Dispersal Program Manager, and Messrs. Jeff Zawila and Don Yule, former and present Principal Investigators, respectively, Earthquake Engineering and Seismology

Branch (EE&SB), Earthquake Engineering and Geophysics Division (EE&GD). Additional supervision was provided by Dr. Mary E. Hynes, Chief, EE&SB; Dr. Arley G. Franklin, Chief, EE&GD; Dr. Paul F. Hadala (retired), former Assistant Director, GL; Mr. S. Paul Miller, Acting Assistant Director, GL; and Dr. William F. Marcuson, III, Director, GL.

Contractors to WES who contributed to the STRP include Buffalo State College, Buffalo, NY (E. A. Standora, M. D. Eberle, J. M. Edbauer, T. S. Ryder, and K. L. Williams); Cornell University, Ithaca, NY (S. J. Morreale); Okeanos Ocean Research Foundation, Inc., Hampton Bays, NY (S. J. Morreale); Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, FL (A. B. Bolten, K. A. Bjorndal, P. J. Eliazar, and L. F. Gregory); Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA (M. L. Lenhardt, S. E. Moein, J. A. Keinath, J. A. Musick, D. E. Barnard, and R. George); Florida Atlantic University, Manatee Research Center, Boca Raton, FL (E. R. Gerstein); Lowry Park Zoo, Tampa, FL; and J. O'Hara, Aiken, SC.

Mr. E. Clark McNair, Jr., CHL, was Manager of the STRP. Messrs. Richard A. Sager and Charles C. Calhoun, Jr., were Assistant Directors of CHL, and Dr. James R. Houston was Director of CHL, which managed the STRP.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Robin R. Cababa, EN.

For further information on this report
or on the Sea Turtle Research Program,
please contact Mr. E. Clark McNair, Jr.,
STRP Program Manager, WES, at (601) 634-2070.

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Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
cubic inches	16.387	cubic centimeters
cubic yards	0.7645549	cubic meters
feet	0.33048	meters
gallons	0.00379	cubic meters
inches	2.54	centimeters
knots	1.852	kilometers per hour
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4535924	kilograms
yards	0.91463	meters

Summary

The U.S. Army Corps of Engineers (USACE) has a congressional mandate to maintain coastal navigation channels of the United States by dredging. A major concern is entrainment of endangered sea turtles by hopper-dredge dragheads. The purpose of the USACE Sea Turtle Research Program (STRP) was to minimize the risk to sea turtle populations in channels along the southeast Atlantic region of the United States from hopper-dredging activities. Achieving this goal would have the effect of widening dredging operation windows previously established by USACE and the National Marine Fisheries Service that restrict dredging to specific times of the year in certain channels.

The STRP was formulated using a biological approach and an engineering approach. The biological approach employed spatial and temporal surveys and telemetry, which together provided data to establish indices of turtle abundance and behavioral patterns. The engineering approach made use of physical model studies, engineering and structural analyses, acoustics, and field demonstrations to develop and evaluate technology and procedures that make dredging operations safer for sea turtles, and consisted of two different kinds of investigations; (a) acoustic studies, and (b) dredging equipment development and evaluation.

Relative-abundance studies determined indices of sea turtle abundance at six harbor entrance channels maintained by hopper dredges; (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL, (c) Brunswick Harbor ocean bar channel, GA, (d) Savannah Harbor ocean bar channel, GA, (e) Charleston Harbor entrance channel, SC, and (f) Morehead City Harbor entrance channel, NC. Behavioral studies monitored movement of sea turtles over time and distance with telemetry techniques. Acoustic-detection studies evaluated acoustic techniques for faster quantitative sea-turtle surveys. Bioacoustic studies determined acoustic thresholds and auditory behavior of sea turtles and manatees (a mammal which may be affected by sea turtle dispersal techniques). Acoustic-dispersal studies evaluated a technique for acoustically dispersing sea turtles.

Dredging-equipment studies developed and evaluated a rigid deflector for the Corps' California-style hopper dredge dragheads. Field tests aboard the *McFarland* during June 1993 demonstrated that the deflector was effective in deflecting mock sea turtles with no adverse impact on dredge production. Following these successful field tests, a second rigid deflector was constructed and installed on the other

dragarm of the *McFarland* for actual dredging operations. Both rigid deflectors were used at Fernandina/Kings Bay, FL, during the winter of 1993-1994 when turtle population was minimal. No entrained turtles were documented. The rigid-deflector dragheads were also evaluated at Canaveral channel during September 1994. A single small green sea turtle was entrained during 15 days of maintenance dredging at Canaveral channel.

The low rate of sea-turtle entrainment, the moderate sea-turtle relative abundance, and the preponderance of time (83 percent) sea turtles spent on the bottom during dredging at Canaveral channel support the conclusion that the rigid-deflector draghead is effective in reducing sea-turtle entrainment. Additional tests are needed in various substrates and at different channel depths before the rigid-deflector draghead can be implemented throughout the United States to reduce hopper-dredge entrainment of sea turtles.

1 Introduction

Statement of the Problem

Five species of sea turtles regularly spend part of their lives in southeastern U.S. coastal waters of the Atlantic Ocean and the Gulf of Mexico; loggerhead (*Caretta caretta*), green (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempi*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*) (National Research Council 1990). Sea turtles (Figure 1) are now endangered or threatened, and are so listed and protected under the Endangered Species Act (ESA) of 1973 and subsequent amendments. Kemp's ridleys, leatherbacks, and hawksbills are listed as endangered throughout their ranges; green turtles are endangered in Florida and are threatened in all other locations; loggerheads are listed as threatened throughout their entire range.

Figure 1. Loggerhead (*Caretta caretta*) sea turtle

The U.S. Army Corps of Engineers (USACE) has a congressional mandate for maintaining the navigability of entrance channels to harbors, seaports, and military facilities along the southeastern Atlantic coast of the United States by periodic dredging activities. Most of these channels are inhabited for at least part of the year by threatened or endangered sea turtles. A major concern is entrainment of sea turtles by hopper-dredge dragheads. The USACE maintenance-dredging operations comply with the ESA.

The U.S. Army Engineer Waterways Experiment Station (WES) has determined that, because of their life cycle and behavioral patterns, the loggerhead, green, and Kemp's ridley are put at risk by maintenance-dredging activities. Kemp's ridley is of primary concern among these sea turtles; it is considered to be the most critically endangered of sea turtles worldwide. Studies indicate the sea turtles are attracted to and seek refuge in dredged channels, especially during the winter. Mortalities due to entrainment during hopper-dredging operations for these three species have been documented since 1980. The relative abundance and activities of sea turtles associated with ship channel habitats were virtually unknown prior to execution of the USACE Sea Turtle Research Program (STRP) by WES.

Purpose of the Sea Turtle Research Program (STRP)

By letter of 21 August 1991 from Headquarters, USACE (HQUSACE), Corps districts were instructed to implement measures that would lead to reduced impacts on sea turtles. Those measures included avoidance and reduction of impact through dredging operation windows and equipment modification as well as improved techniques to measure and monitor incidental take. USACE districts were directed to explore options to refocus and expand research efforts on new draghead designs and operational controls to further avoid impacts on turtles in navigation channels. HQUSACE stated that significant field studies, well coordinated with the U.S. National Marine Fisheries Service (NMFS), should be conducted to better understand turtle behavior around ship channels.

The purpose of the STRP was to minimize the risk to sea turtle populations in channels along the southeast Atlantic region of the United States from hopper-dredging activities. Achieving this goal would have the effect of widening dredging operation windows previously established by USACE and NMFS that restricted dredging to specific times in certain channels.

2 Sea Turtle Research Program (STRP)

Pursuant to the 21 August 1991 directive from HQUSACE to Corps districts regarding the development of measures that would lead to greatly reduced impacts on sea turtles, a meeting was held at WES on 12-13 September 1991 between WES scientific staff and Corps South Atlantic Division (SAD) personnel. Here was reiterated the need for immediate and long-term efforts, and the necessity for a divisionwide strategy to define and develop alternatives to minimize the impact of USACE hopper dredging on sea-turtle populations. The mandate from HQUSACE to this meeting was to assemble a team of experts from WES to develop and implement a multifaceted interdisciplinary program that would provide equipment, techniques, and knowledge that could be used to minimize the harm that dredging activities cause sea turtles. The program should be performed in accelerated mode to minimize impacts to the SAD navigation mission. The program would be coordinated with and accepted by HQUSACE, SAD, and NMFS.

In an expeditious manner, a coordinated research program (Figure 2) adequate to address the sea-turtle problem on a nationwide basis was developed that was divided into two interrelated components; (a) a biological approach, and (b) an engineering approach. Each approach provided a series of products that served to reduce the effects of dredging operations on sea turtles (McNair 1992). The biological approach consisted of two distinct research tasks; (a) relative-abundance investigations, and (b) behavioral studies. The engineering approach consisted of four distinct research tasks; (a) acoustic-detection investigations, (b) bioacoustic studies, (c) acoustic-dispersal evaluations, and (d) dredging-equipment development and evaluation.

The 2-year STRP was authorized by HQUSACE and initiated by WES in November 1991. The six distinct research tasks of the STRP were conducted by, or contract studies were performed under technical oversight of, the investigators of WES laboratories shown in Table 1. Contractors to WES who contributed to the STRP include Buffalo State College, Buffalo, NY (E. A. Standora, M. D. Eberle, J. M. Edbauer, T. S. Ryder, and K. L. Williams); Cornell University, Ithaca, NY (S. J. Morreale); Okeanos Ocean Research Foundation, Inc., Hampton Bays, NY (S. J. Morreale); Archie Carr Center for Sea Turtle Research, University

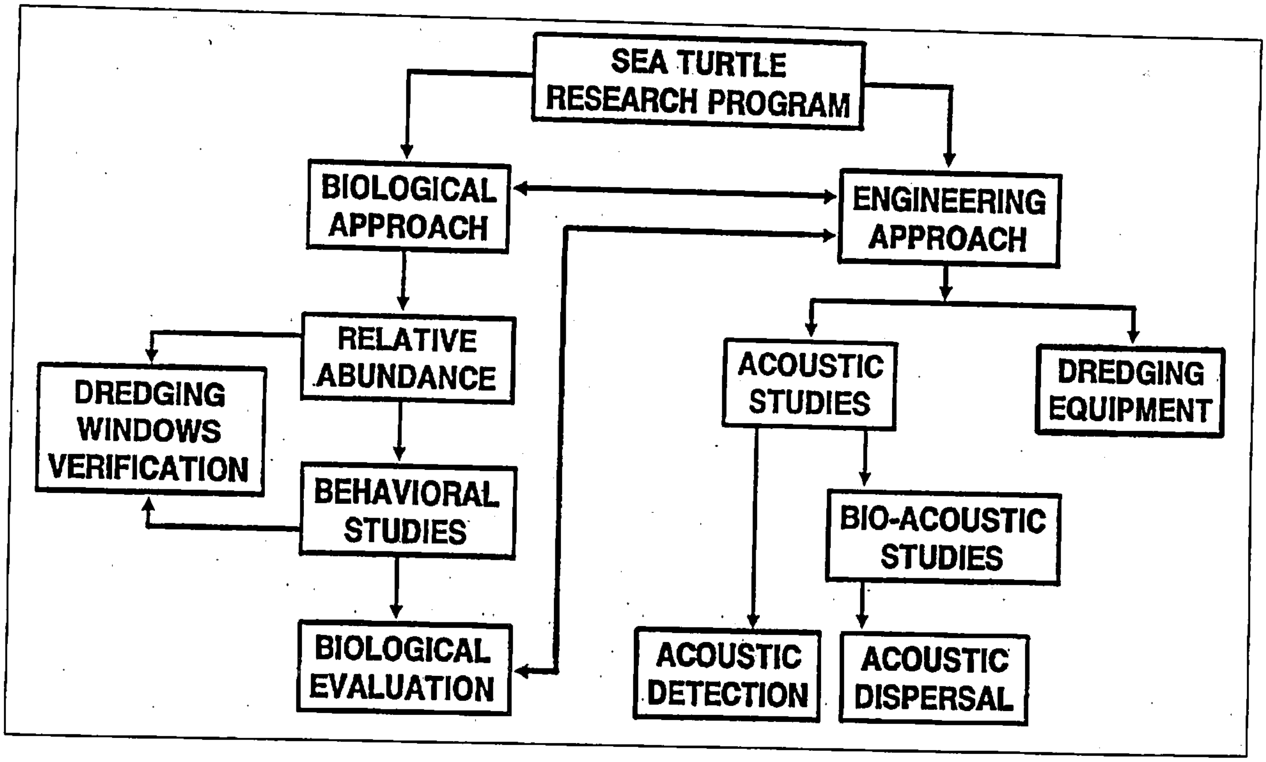

Figure 2. Sea Turtle Research Program (STRP)

of Florida, Gainesville, FL (A. B. Bolten, K. A. Bjorndal, P. J. Eliazar, and L. F. Gregory); Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA (M. L. Lenhardt, S. E. Moein, J. A. Keinath, J. A. Musick, D. E. Barnard, and R. George); Manatee Research Center, Florida Atlantic University, Boca Raton, FL (E. R. Gerstein); Lowry Park Zoo, Tampa, FL; and J. O'Hara, Aiken, SC.

Biological Approach

The biological approach employed spatial and temporal surveys and telemetry that provided statistical representations of data to establish meaningful indices of turtle abundance and behavioral patterns.

Relative-abundance investigations

The objective of the relative-abundance investigations was to determine indices of sea turtle abundance at six southeast Atlantic harbor entrance channels maintained by hopper dredges; (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL, (c) Brunswick Harbor ocean bar channel, GA, (d) Savannah Harbor ocean bar channel, GA, (e) Charleston Harbor entrance channel, SC, and (f) Morehead City Harbor entrance channel, NC.

Table 1
Research Tasks of the USACE Sea Turtle Research Program

Research Task	WES Laboratories and Investigators
Relative-Abundance Investigations	Environmental Laboratory
	D. D. Dickerson D. A. Nelson K. J. Reine C. E. Dickerson, Jr.
Behavioral Studies	Environmental Laboratory
	D. D. Dickerson D. A. Nelson
Acoustic-Detection Investigations	Environmental Laboratory
	R. L. Kasul D. D. Dickerson
Bioacoustic Studies	Environmental Laboratory
	D. D. Dickerson D. A. Nelson
Acoustic-Dispersal Evaluations	Geotechnical Laboratory
	R. F. Ballard, Jr. J. S. Zawila D. Yule
Dredging Equipment Development	Coastal and Hydraulics Laboratory
	G. E. Banks M. P. Alexander
Dredging Equipment Evaluation	Environmental Laboratory
	D. A. Nelson D. J. Shafer

This task established an index of relative abundance of sea turtles of various species in a navigation channel. The study was accomplished through trawling a channel in a set pattern with standardized trawling equipment over a specified time period. As turtles were captured in the trawl, they were brought aboard the trawling vessel, examined, measured, tagged for identification, and released. A detailed log of all physical and environmental conditions was maintained, including time of day, air and water temperature, weather conditions, tide and wave conditions, and other physical and environmental parameters. All physical and biological information recorded for each trawl and turtle captured were entered into computerized databases for statistical analyses. Analysis included capture and recapture rates per unit time and per unit area for each channel.

Relative abundance investigations were conducted by the WES Environmental Laboratory (EL) (D. D. Dickerson, K. J. Reine, D. A. Nelson, and C. E. Dickerson, Jr.) and the Archie Carr Center for Sea Turtle Research, University of Florida (A. B. Bolten, K. A. Bjorndal, P. J. Eliazar, and L. F. Gregory), under the technical oversight of the WES EL (D. D. Dickerson and D. A. Nelson), and are reported in Chapter 3.

Behavioral studies

The objective of the behavioral studies was to monitor movement of sea turtles over time and distance with biotelemetry techniques in the vicinity of four southeast Atlantic harbor entrance channels maintained by hopper dredges; (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Mary River entrance channel, FL, (c) Savannah Harbor ocean bar channel, SC, and (d) Charleston Harbor entrance channel, SC. Biotelemetry is the process of attaching radio, sonic, and/or satellite transmitters to the shell of captured sea turtles and documenting their behavior through detailed observation. Highly trained observers followed the instrumented turtles in survey boats equipped with sensitive receivers to record their behavior.

Behavioral studies were conducted by a consortium of Buffalo State College (E. A. Standora, M. D. Eberle, J. M. Edbauer, T. S. Ryder, and K. L. Williams), Cornell University (S. J. Morreale), Okeanos Ocean Research Foundation (S. J. Morreale), and the Archie Carr Center for Sea Turtle Research, University of Florida (A. B. Bolten); Virginia Institute of Marine Science, College of William and Mary (J. A. Keinath, D. E. Barnard, and J. A. Musick); and the WES Environmental Laboratory (D. A. Nelson and D. J. Shaffer), under the technical oversight of the WES EL (D. D. Dickerson and D. A. Nelson), and are reported in Chapter 4.

Engineering Approach

The engineering approach made use of physical model studies, engineering and structural analyses, acoustics, and field demonstrations to develop hardware modifications that would make dredging operations safer for sea turtles. This approach consisted of two basically different kinds of investigation; (a) acoustic studies, and (b) dredging-equipment development and evaluation.

Acoustic-detection investigations

The objective was to evaluate acoustic-detection techniques for faster, more reliable, and quantitative sea-turtle surveys. The task was conducted to determine if the presence and numbers of turtles in channels can be assessed through hydro-acoustic means. Mine-detection and fish-locating technologies were pursued to determine hydro-acoustic signatures that might provide a discrimination of sea turtles submerged in a navigation channel.

Acoustic-detection investigations were conducted by the WES EL (R. L. Kasul and D. D. Dickerson) and are reported in Chapter 5.

Bioacoustic studies

The objectives of the bioacoustic studies were to determine acoustic thresholds, frequency range, and auditory behavior of sea turtles and manatees (mammals which occupy the same coastal waters as sea turtles, and may be impacted by sea turtle dispersal techniques). Controlled tests on live loggerhead sea turtles at the Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA, established acoustic thresholds and frequency-range baseline information for sea-turtle acoustic-dispersal studies. Controlled tests on live West Indian manatees by the Manatee Research Center, Florida Atlantic University, Boca Raton, FL (tests conducted at Lowry Park Zoo, Tampa, FL), established acoustic thresholds and auditory behavior of manatees.

Bioacoustic studies were conducted by the Virginia Institute of Marine Science, College of William and Mary (M. L. Lenhardt, S. E. Moein, J. A. Musick, and D. E. Barnard) and the Manatee Research Center, Florida Atlantic University (E. R. Gerstein), under the technical oversight of the WES EL (D. D. Dickerson and D. A. Nelson), and are reported in Chapter 6.

Acoustic-dispersal evaluations

The objective was to evaluate a safe acoustic technique for dispersing sea turtles from the vicinity of hopper-dredge dragheads. Air- and water-guns meeting turtle-response auditory-range requirements were field tested aboard the Corps hopper dredge *McFarland*; no sea turtles were present. Controlled tests using live sea turtles were conducted at the Virginia Institute of Marine Science; turtles responded with apparently no detrimental effects.

Acoustic-dispersal evaluations were conducted by the Virginia Institute of Marine Science, College of William and Mary (S. E. Moein, J. A. Musick, J. A. Keinath, D. E. Barnard, M. L. Lenhardt, and R. George), J. O'Hara, and the WES Geotechnical Laboratory (GL) (J. S. Zawila), under the technical oversight of the WES GL (R. F. Ballard, Jr., J. Zawila, and D. Yule), and are reported in Chapter 7.

Dredging-equipment development and evaluation

The objective was to develop, field test, and evaluate an effective sea-turtle deflector for the Corps' California-style hopper-dredge draghead. Three draghead configurations were field tested; (a) California-style draghead unmodified, (b) California-style draghead with chain deflector, and (c) California-style draghead with rigid deflector. The California-style draghead with rigid deflector was evaluated under actual prototype dredging operations at Canaveral harbor entrance channel.

Dredging-equipment development (rigid-deflector draghead) and field tests of the rigid-deflector draghead were conducted by the WES Coastal and Hydraulics Laboratory (G. E. Banks and M. P. Alexander). The rigid-deflector draghead was evaluated under actual performance dredging operations by WES EL (D. A. Nelson and D. J. Shafer). These research studies are reported in Chapter 8.

3 Relative-Abundance Evaluations

Introduction

As part of the biological approach to understanding the life history and behavioral patterns of sea turtles and to develop long-term management plans and conservation strategies, monthly surveys were conducted in six channels along the southeastern Atlantic U.S. coast (Dickerson et al. 1995). An assessment of sea turtle relative abundance at Canaveral was performed by Bolten et al. (1993). Appropriate sections of those documents pertaining to relative-abundance investigations are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the studies are given in the original documents.

Assessment of Sea-Turtle Abundance in Six South Atlantic U.S. Channels

Introduction[1]

The U.S. Army Corps of Engineers (USACE) is responsible for maintaining the navigability of entrance channels to harbors, seaports, and some military facilities along the southeastern U.S. coast (Figure 1).[2] Most of these channels are inhabited for at least part of the year by sea turtles classified as federally threatened or endangered; however, the highest concentrations of sea turtles are found along the Atlantic beaches of central and southern Florida (National Research Council 1990). The relative abundance and activities of sea turtles associated with ship channel habitats are virtually unknown. Sea turtles are listed as threatened or endangered because their population levels have declined severely throughout the world over the

[1] This section of Chapter 3 was reproduced verbatim from Dickerson, D. D., Reine, K. J., Nelson, D. A., and Dickerson, C. E., Jr. (1995), "Assessment of sea turtle abundance in six South Atlantic U.S. channels," Miscellaneous Paper EL-95-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

[2] Refers to tables or figures in Dickerson et al. (1995), not reproduced here.

last 20 to 30 years (National Research Council 1990). Their population decline is the result of numerous factors such as incidental capture during fishing, habitat destruction, and uncontrolled slaughter for leather, jewelry, and meat. Documented sea turtle mortalities due to entrainment during hopper dredging operations have been reported since 1980 from some South Atlantic channels (Joyce 1982; Dickerson et al. 1991). A Sea Turtle/Dredging Task Force was formally established by the U.S. Army Engineer Jacksonville District in May 1981 to address the issue of dredging impacts on sea turtles (Studt 1987). Although a total of five sea turtle species occur along the southeastern U.S., the National Marine Fisheries Service (NMFS) has determined that loggerhead (*Caretta caretta*), green (*Chelonia mydas*), and Kemp's ridley (*Lepidochelys kempi*) sea turtles are the species most at risk from hopper dredging (NMFS Regional Biological Opinion 1991).

The Endangered Species Observer Program was established in 1980 and evolved through consultation between the NMFS and USACE, in accordance with the Endangered Species Act. Endangered species observers have been employed during hopper dredging projects whenever biological data suggest potential negative impacts on sea turtles. Observer records document the intake of turtle or turtle parts through the vessel's dragheads and subsequently into the ship's hopper. Sampling for entrained turtles is accomplished through observation and inspection of the hopper and the dragheads and screening of dredged material from the intake structures or hopper overflow. Recovery, accurate identification, and documentation of sea turtle parts are vital to the evaluation of dredging impacts, success of conservation management procedures, and the development of alternative dredging equipment.

A significant problem in interpreting and analyzing observer records is variation in sampling efficiency and observer monitoring (Dickerson et al. 1991). Guidelines set forth in the NMFS Regional Biological Opinion (1991) addressed these inconsistencies. The Endangered Species Observer Program is reviewed in Dickerson et al. (1991, 1993).

Summaries of both killed and living/injured sea turtle incidents from all available records are given in Table 2 (Joyce 1982; National Research Council 1990; Dickerson et al. 1991; unpublished data from dredging logs and endangered species observer reports to USACE). During dredging along the South Atlantic U.S. coast from 1980 to April 1994, 236 incidents (dead and injured) involving three species of sea turtles (loggerhead, green, and Kemp's ridley) were reported. Entrainments of sea turtles during dredging operations were documented only from hopper dredges and primarily in Canaveral Harbor entrance channel, FL; Fernandina Harbor St. Marys River entrance channel (Kings Bay), FL; Brunswick harbor ocean bar channel, GA; and Savannah Harbor ocean bar channel, GA. A low number of incidents were also documented at Charleston Harbor entrance channel, SC; Port Royal Harbor, SC; Ft. Pierce Inlet, FL; and Morehead City Harbor entrance channel, NC. The lack of reported impacts on turtles in other hopper dredged channels and on other types of dredges may be a result of reduced turtle occurrences in the channels during the time of dredging, reduced potential of turtle impingement by the dredge, or a lack of monitoring for documentation of incidents during dredging.

Table 2
Summary of South Atlantic Hopper Dredging Projects with Documented Sea Turtle Incidents (1980-1994)* (Source: Dickerson et al. 1995)

Date	Amount Dredged (Cubic Yards)	Vessel(s)	Total Sea Turtle Incidents
Canaveral Harbor, Florida			
1980 11 Jul-13 Nov	1,400,000	*Long Island* *Dodge Island* *Sugar Island*	71
1981 13 Aug-22 Sep	257,400	*McFarland*	6
1983 ? Feb-? May ? Aug-? Dec	609,000 (Inside jetties) 914,000 (Seaward of dogleg)	*McFarland* *Sugar Island* *McFarland*	NA NA
1984 26 Nov-18 Dec	2,700,000	*Sugar Island* *McFarland*	12
1985 15 Jan-31 Jan	370,000	*McFarland*	0
1986 2 Sep-6 Oct	350,000	*Ouachita*	5
1988 24 Aug-21 Oct	1,408,000	*Dodge Island* *Atchafalaya* *Mermentau*	34
1989/1990 6 Dec-16 Jan	290,000	*McFarland*	11
1990/1991 14 Dec-18 Jan	212,848	*Sugar Island*	8
FY 92/93 - No hopper dredging was performed.			
Fernandina Harbor (Kings Bay), Florida			
1986 May	250,000	*Sugar Island*	4
1987 15 Jul-31 Dec	910,000	*Eagle I* *Manhattan Is.* *Jim Bean* *Sugar Island*	5
1988 1 Jan-24 Jul/ 31 Oct-9 Dec	5,456,000	*Eagle I* *Sugar Island* *Dodge Island* *Manhanttan Is.* *Mermentau* *Atchafalaya* *Ouachita*	11

(Sheet 1 of 3)

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page x.

Table 2 (Continued)

Date	Amount Dredged (Cubic Yards)	Vessel(s)	Total Sea Turtle Incidents
Fernandina Harbor (Kings Bay), Florida (Continued)			
1989 31 May-11 Jun	152,000	*McFarland*	3
11 Nov-18 Dec	720,000	*Atlantic American*	6
1990 23 Oct-13 Dec	754,000	*Sugar Island*	4
1991 24 Jan-23 Mar	766,685	*Sugar Island*	1
1991/1992 18 Dec-12 Feb	640,237	*McFarland*	0
1992 6 Feb-5 Mar	229,336	*Eagle I*	0
1993 18 Jan-13 Feb	253,585	*McFarland*	0
1994 3 Dec 93-15 Jan 94 3 Mar-20 Mar	419,060 350,550	*McFarland* *Ouachita*	1 1
Brunswick Harbor, Georgia			
1988 Jun-Aug	907,673	*Dodge Island* *Manhattan Is*	1
1989 Oct-Nov	1,027,400	*Eagle I*	0
1991 23 Mar-20 Jun	1,583,000	*Sugar Island* *Dodge Island*	22
1993 15 Jan-8 Apr	1,472,239	*Atchafalaya* *Ouachita* *Mermentau*	0
Savannah Harbor, Georgia			
1989 Nov-Dec	648,948	*Eagle I*	1
1991 20 Jun-14 Aug	1,104,991	*Sugar Island* *Dodge Island*	17
1992 1-23 Dec	554,707	*Eagle I* *Ouachita*	1
			(Sheet 2 of 3)

Table 2 (Concluded)			
Date	Amount Dredged (Cubic Yards)	Vessel(s)	Total Sea Turtle Incidents
Savannah Harbor, Georgia (Continued)			
1994 13 Dec 93-24 Mar 94	2,825,926	*R. N. Weeks* *Ouachita*	2 2
Charleston Harbor, South Carolina			
1991 1 Aug-14 Apr	3,030,000	*Sugar Island* *Dodge Island*	3
Port Royal Harbor, South Carolina			
1992 16 Feb-29 Mar	700,000	*Padre Island*	2
Morehead City Harbor, North Carolina			
1994 23 Nov 93-3 Apr 94	2,900,000	*Ouachita* *Mermentau* *Eagle I*	1
Ft. Pierce Inlet, Florida			
1994 6 Nov 93-28 Jan 94	62,000	*Sugar Island*	1
			(Sheet 3 of 3)

A significant reduction in sea turtle entrainments has been documented since the first reported incidents in 1980. This may have resulted from modifications in management and operational practices or may be a reflection of seasonal occurrences and annual fluctuations in sea turtle populations. The National Workshop on Methods to Minimize Dredging Impacts on Sea Turtles in 1988 examined potential dredging and management alternatives, as well as identified biological studies and information gaps (Dickerson and Nelson 1990). A number of management alternatives are currently being implemented to minimize impacts to sea turtles including seasonal restrictions, rescue and relocation operations, and modified dredging equipment (Nelson et al. 1989; Dickerson, Nelson, and Banks 1990). The information gathered by the Endangered Species Observer Program was used as the foundation for management decisions and recommendations. Consistent and thorough documentation of sea turtle incidents, as well as an understanding of sea turtle utilization of dredged channels, are necessary for the development of better management strategies.

Since the first reported incidents of sea turtle deaths from dredging operations, resource managers have recognized the need for more complete sea turtle life history information (Dickerson and Nelson 1990). The majority of information available on these animals concerns the small portion of their life spent on the beach during nesting (National Research Council 1990). Spatial and temporal distributions have historically been based on nesting distributions, stranding reports, and pelagic aerial surveys. There is very little information available pertaining to their specific use of channels. The large number of sea turtle mortalities in 1980 at Canaveral Harbor prompted trawling surveys to assess sea turtle abundance in some South Atlantic channels during 1981-1982. Trawling surveys have been periodically conducted in Canaveral Harbor since the late 1970's (Butler, Nelson, and Henwood 1987; Henwood 1987; Henwood and Ogren 1987; Bolten and Bjorndal 1988, 1991).

Without more information on sea turtle utilization of these channels, it is difficult to develop sound, long-term management and conservation plans. To develop management strategies, a multifaceted sea turtle research program was initiated in 1991 along the South Atlantic coast by the USACE (Dickerson et al. 1993). These studies have included both biological and engineering research approaches and cooperative participation between the academic community and state and Federal agencies.

As part of the biological studies, monthly surveys were conducted in six channels along the southeastern Atlantic U.S. coast (Figure 2).[1] The six channels selected were (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Marys River entrance channel (Kings Bay), FL, (c) Brunswick Harbor ocean bar channel, GA, (d) Savannah Harbor ocean bar channel, GA, (e) Charleston Harbor entrance channel, SC, and (f) Morehead City Harbor entrance channel, NC. Although surveys were conducted only in the outer portion of each harbor project, this report refers to each of these channels as "harbor" for clarity and consistency. This report documents the results of trawling surveys performed from June 1991 to March 1993. The results of relocation efforts conducted during this time are also included. The objectives of these surveys were to evaluate species composition, population structure, and spatial and temporal (seasonal) distributions. This information may be used to help define and refine seasonal windows when sea turtles are least likely to be present and hopper dredging may occur.

Discussion[1]

Species composition, size frequency, relative abundance

Loggerheads dominated species composition in all six channels. Since only three loggerheads were captured at Morehead City Harbor, very little can be concluded except that there was a low abundance of sea turtles in the dredged portion of this channel during the monitoring period. Only 20 Kemp's ridleys were captured within the deeper dredged areas surveyed during this study. The presence of Kemp's ridleys, however, may be higher in shallower areas which potentially serve as an important habitat (National Research Council 1990). Kemp's ridleys occur along the South Atlantic coastal area; however, little information is available on their utilization of deeper dredged areas within the channels. The extremely low relative abundance of Kemp's ridleys seen during this study may be a result of their infrequent use of the deeper channel or a reflection of a rare occurrence by an extremely endangered animal. Only five green turtles were captured during this study. Smaller green turtles exist in the shallower areas, as do the Kemp's ridleys, and may not frequent the deeper waters of the channels (Mendonca and Ehrhart 1982;

Ehrhart 1983; Mendonca 1983; Renaud et al. 1993; Landry et al. 1993). Juvenile and adult Kemp's ridley and green turtles do not appear to utilize the deeper dredged portions of the six channels surveyed; however, both species occur throughout the South Atlantic and periodically are found within the deeper channels.

Very little can be determined from the small numbers of Kemp's ridley and green turtles captured. However, 17 of the 20 Kemp's ridleys captured were at Fernandina Harbor and Brunswick Harbor. Fernandina, Brunswick, and Savannah Harbors are the only channels in which documented Kemp's ridley mortalities or injuries from hopper dredges have occurred (Table 2).[2] Green turtle mortalities or injuries are documented at Canaveral, Fernandina, and Ft. Pierce Harbors, FL; however, during this survey a total of only three green turtles were captured from Canaveral Harbor and Fernandina Harbor. Previous dredging records from Canaveral Harbor indicate that most of the green turtles killed or injured were very small juveniles which were potentially taken by the dredge inside the jetties or near the turning basin of the submarine base (unpublished Endangered Species Observer reports; personal communication, C. Slay). This location has many submerged rocks and debris which prevents trawling. Tangle netting techniques used at this location have yielded a large number of small juvenile green turtles presumably using the submerged structures for protection and feeding (Mendonca 1983). Dredging records from Fernandina Harbor are inconclusive as to the locations where green turtles were killed or injured.

The species distributions of reported turtle entrainments summarized in Table 2[2] show that the majority of identified entrained turtles were loggerheads (63 percent), with green turtles accounting for 12 percent, and Kemp's ridleys 2 percent. Unidentified turtles accounted for 23 percent of the total entrainment incidents reported and were identified as turtles by portions of the body or internal viscera. Most of these specimens were assumed to be loggerheads but were not counted in the loggerhead totals. Loggerheads dominated these entrainment totals and this domination was also demonstrated by the trawling survey catches.

Loggerheads smaller than 40 cm were not captured during this study. This may be a result of smaller animals occupying the shallower areas outside the deeper dredged areas which was reported for smaller Kemp's ridley and green turtles. Juvenile loggerheads less than 40 cm do not appear to utilize any of the surveyed channels; however, it is not known whether this reflects habitat use different from that in shallower habitats of the surrounding areas. The size frequency of loggerheads captured in the five channels surveyed north of Canaveral Harbor is strongly dominated by the 50- to 70-cm juvenile size class. Van Dolah and Maier (1993) reported similar species composition and size-class distributions from their trawling surveys in Charleston Harbor.

Analysis of the relative contribution of an individual of a given age to the growth rate of the population (reproductive value) provides valuable insight for management decisions in the conservation of sea turtles, because it indicates which individuals contribute most to future populations and also, by inference, where protection is likely to be the most effective (Richardson and Richardson 1982; Crouse, Crowder, and Caswell 1987). Richardson and Richardson (1982) analyzed reproductive value of loggerhead eggs and hatchlings, small juveniles, large juveniles, subadults, and nesting adults at Little Cumberland Island, GA, and determined the highest reproductive value was with the older stages, particularly the large juveniles 58-79 cm long. This was the dominant size-class captured in the surveyed channels. Increased efforts to protect this group are considered extremely important in conservation practices (Richardson and Richardson 1982; National Research Council 1990).

Although only 34 (7 percent) of the 470 loggerheads captured at Fernandina, Brunswick, Savannah, and Charleston Harbors were adults, this does not preclude the occurrence of adult loggerheads throughout the surrounding coastal area outside the channel. Adult loggerheads are known to occur in these areas in significant numbers, especially with respect to nearby nesting beaches (National Research Council 1990). The low relative abundance of adult loggerheads seen in this study may reflect low abundance relative to juvenile loggerheads, infrequent use of the deeper channels, or avoidance of the trawl nets. Without additional information, the trawl survey information can only be assumed to indicate a low relative abundance of adult loggerheads within the deeper dredged areas of Fernandina, Brunswick, Savannah, and Charleston Harbors.

Size class distribution at Canaveral Harbor was dramatically different than the other channels surveyed. Whereas only a small number of adults were captured in the channels north of Canaveral Harbor, 48.3 percent of the loggerheads captured at Canaveral harbor were considered adults. Unlike the other channels, the deeper dredged portions of Canaveral Harbor were heavily used by both male and female adult loggerheads. Large numbers of adult loggerheads are also known to nest at nearby beaches (National Research Council 1990).

Fritts et al. (1983) indicated that the distributions of large loggerheads were related to water depth rather than to distance from shore. Data on depth distribution are scarce; however, limited aerial surveys in the Gulf of Mexico indicate sea turtles are most abundant in waters less than 50 m. Limited trawling and biotelemetry data indicate that juvenile and adult sea turtles off the South Atlantic and Gulf coasts are most abundant in waters less than 27 m deep but seldom inhabit water less than 4 m deep (Bullis and Drummond 1978; Byles 1988).

Seasonal distribution

Surveys conducted in Fernandina, Brunswick, Savannah, and Charleston Harbors show similar results. Loggerhead captures begin in late spring, catch per unit of effort (CPUE, turtles per hr) steadily increases throughout the summer to a peak in fall, then dramatically decreases as the sea turtles leave in winter. CPUE rates indicate that fall (September, October, November) is the time of highest relative abundance for loggerheads and October is the peak month for juvenile and adult loggerheads. Additional sampling is necessary to confirm the fall trend of peak occurrence.

Even though the nesting season at nearby beaches is primarily May through August, adults do not appear to utilize deeper portions of these channels before this time and may only use it as a temporary post-nesting habitat before leaving. Van Dolah and Maier (1993) also noted very few adult females in Charleston Harbor even though they are commonly found nesting in the area during spring and summer. Data from Canaveral Harbor show a very different seasonal distribution for both juvenile and adult loggerheads. Juveniles occupy Canaveral Harbor year round in relatively constant numbers, whereas adults move into the channel and surrounding area during the spring/summer breeding season. Adult female loggerheads appear to use Canaveral Harbor as an inter-nesting habitat and adult males are found in the channel in late spring prior to arrival of females. Similar conclusions were reached by Henwood (1987).

A sharp increase in the number of juveniles in January at Canaveral Harbor (this study and Henwood 1987) may represent juvenile turtles migrating south during cooler temperatures. Biotelemetry studies may aid in understanding the migratory and behavioral patterns of juvenile and adult loggerheads.

Spatial (station) distribution

The spatial distribution of loggerheads within Canaveral, Fernandina, and Savannah Harbors indicates differential use between the stations surveyed; however, it is difficult to interpret these data without an understanding of what factors attract sea turtles to these channels. The distribution may be correlated with factors such as temperature, turbidity, current regime, bottom topography, substrate, depth, or availability of food organisms. These factors may also be highly variable between channels, seasons, and years. Although no conclusions can be drawn, the relative abundance of turtles between stations suggests a preference for station 2 at Fernandina Harbor, station 3 at Canaveral Harbor, and station 4 (furthest offshore) at Savannah Harbor. Van Dolah and Maier (1993) showed differences in density of loggerhead turtles among stations; however, this was not seen in this study. This suggests some feature(s) within the channels which may attract these animals; however, further studies would be needed to identify the factor(s).

Relocation

During early dredging projects at Canaveral Harbor, trawling was utilized to relocate turtles from the dredged area of the channel. In 1980, at Cape Canaveral, 1,250 loggerheads were relocated 5 miles south of the channel during four months of relocation efforts (Joyce 1982). Many of these displaced animals returned to the channel during the same dredging project. Relocation efforts in December 1989 and January 1990 at Canaveral Harbor relocated 36 turtles (31 loggerheads, 4 green turtles, and 1 Kemp's ridley) with no animals recaptured during the 15 days of trawling (Bolten and Bjorndal 1991). Ninety-three turtles (91 loggerheads and 2 green turtles) were caught and removed from the vicinity of the dredging operation at Canaveral Harbor with no recaptures from 30 December 1990 to 15 January 1991 (Bolten and Bjorndal 1991). Relocation efforts in Brunswick, Savannah, Fernandina, and Charleston Harbors during this study relocated a total of 160 turtles (155 loggerheads, 4 Kemp's ridley, and 1 green turtle) with only one displaced turtle recaptured during the trawling activities. Additionally, a reduced number of entrained turtles were reported by observers on the dredges when relocation trawling was utilized (unpublished Endangered Species Observer reports; personal communication, C. Slay).

The relative success of relocation efforts in channels with high densities of sea turtles is uncertain because of the inability to move the large numbers of turtles found in the channel in some years and the tendency for some turtles to return to the channel once removed. The success of trawling operations is difficult to evaluate; however, relocation of turtles out of the channel may be feasible when there are low densities of turtles. Recapture rate of relocated turtles may also be reduced by releasing the turtles at greater distances than 5 to 12 nm. To increase the potential for reducing the number of entrained turtles in future dredging projects, trawling operations used to relocate turtles should begin shortly before or at least at the onset of the dredging operation and not delayed until the latter portion of the project.

Although turtles may be present throughout these channels, the trawlers usually have difficulty pulling nets inside jetties or nearshore because of rocks, old pilings, or debris which may snag and tear the nets. Turtle relocation operations are limited to areas in the channels where trawling is possible; however, trawling should be done throughout as much of the channel as possible.

Recaptures

The low number of recaptures throughout the study may be explained several ways. The number of sea turtles in the area may actually be large but only a small portion of the sea turtle population is being sampled. The individuals captured may temporarily move out of the surveyed area of the channel upon release (Standora et al. 1993a; Nelson, unpublished data, USACEWES). Once captured by trawling nets, the sea turtles may also exhibit an avoidance behavioral response to subsequent encounters with the nets. Behavioral studies using biotelemetry techniques suggest an avoidance response in some individuals (Standora et al. 1994). No quantitative information is available from these low numbers of recaptures but there is some evidence that some individuals may stay in the channel area for an extended period of time, as well as migrate back to the same general area from their warmer winter retreats. Recaptures of individuals from multiple channels confirm the fact that these animals migrate wide latitudinal distances along the Atlantic coast.

Water temperature and relative abundance

Sea turtles are ectothermic; therefore, the temperature of their immediate surroundings is an important factor in their physiological requirements. Hypothermia in sea turtles is known to cause a comatose condition and may result in death (Wilcox 1986; Witheringon and Ehrhart 1989; Schroeder et al. 1990). Sea turtles may respond to colder water temperatures by migrating to warmer water either in more southerly locations or offshore to the Gulf stream (Thompson 1988). They may also spend more time basking at or near the surface to increase their body temperature through solar heating (Carr 1952; Nelson, unpublished data, USACEWES). It has been suggested that sea turtles may be able to survive cold temperatures during winter months by burying themselves in the channel bottom and going into a state of protected hibernation (brumation) (Felger, Cliffton, and Regal 1976; Carr, Ogren, and McVea 1980; Cliffton, Cornejo, and Felger 1982; Lutz 1990). During two unusually cold winters in 1978 and 1979 at Canaveral Harbor, the presence of large numbers of loggerhead sea turtles in the channel was brought to the attention of the scientific community by fishermen who had incidentally captured a number of turtles in a torpid condition by trawling. Loggerheads were reported to be buried in the anoxic mud for undetermined periods of time in Canaveral Harbor and in the Gulf of California (Felger, Cliffton, and Regal 1976; Carr, Ogren, and McVea 1980). Since potential brumation in sea turtles is reported only rarely in the literature and the trawling surveys in this study did not capture turtles with evidence of having been buried in mud during times of cold water temperature, this is believed to be a very rare event. This rare event may occur during short periods of unusually cold water temperatures with those turtles which overwinter at Canaveral Harbor; however, since sea turtles do not appear to overwinter in the channels north of Canaveral Harbor, it is unlikely this would occur in those channels. Richardson and Hillestad (1979) also reported no evidence of sea turtles overwintering in navigation channels in South Carolina and Georgia.

Sea turtle abundance has been found to be higher in southeastern Atlantic channels during the warmer months. A gradual northward expansion of the sea turtle's range during spring and summer months may be a result of physiological dependence on warmer temperatures, as well as a reflection of increased food availability (Shoop, Doty, and Bray 1981). Henwood and Ogren (1987) noted higher concentrations of Kemp's ridleys occurred near Canaveral Harbor from December to March suggesting that these turtles overwinter in this area and disperse along the Atlantic coastline with increasing water temperatures. Biotelemetry studies of migrating loggerheads in offshore waters revealed they spent more time at the surface than individuals in estuarine foraging habitats (Keinath, Musick, and Byles 1987). These offshore migrating turtles may be nearer the surface to benefit from the warmer surface water as well as to breathe more frequently.

Water temperature may serve as a preliminary mechanism for predicting the potential for sea turtle occurrence in an area. There is no evidence in this data set, as suggested by Van Dolah et al. (1992), that a regression relationship exists for sea turtle capture rate and water temperature. Rather there is an apparent threshold below which the chance of sea turtle capture is remote. This can also be demonstrated with the results presented by Van Dolah et al. (1992). For the channels surveyed north of Canaveral Harbor, 16 °C water temperature was used as the dividing point. During this study, 1,008 trawls conducted at or below 16 °C resulted in a total of 22 (4.4 percent) captures while 1,791 trawls conducted above this temperature resulted in a total 473 (95.6 percent) captures. This clearly indicates a reduced relative abundance when water temperature is at or below 16 °C. This relationship was absent at Canaveral Harbor because water temperature did not drop below 16 °C. The higher critical minimum water temperatures found in Florida throughout the year may be a major factor supporting sea turtle occurrences year-round (Fritts et al. 1983).

Although the lower critical temperature limits may be different for each species and size-class, temperatures below 16-20 °C may be used as a conservative indicator of time periods in channels north of Canaveral Harbor which have reduced sea turtle occurrence. Caution should be taken when temperature is used as the only indicator of potential sea turtle activities in a given area until further studies can be performed. Additional work is also needed to understand the behavioral patterns of these animals during the colder seasons.

Caution should be taken when using absolute dates from this study for arrival and departure of sea turtles. Extensive weekly surveying efforts need to be conducted in the spring and fall months to better define temporal movement patterns for the turtles. Since water temperature may vary significantly between years, mean water temperature should be used as a relative index in addition to CPUE indices from trawl survey and historical trends for predictions of relative abundance and seasonal occurrence of sea turtles. Successful interpretation of potential relative abundance of sea turtles is dependent on conducting trawling surveys to assess CPUE rates and to collect water temperature measurements. Once these data are collected, the potential relative abundance of sea turtles (primarily loggerheads) within the channel may be assessed.

Low sea turtle relative abundance was seen primarily during the winter months when water temperatures were ≤16 °C. High sea turtle relative abundance was documented during summer and early fall when water temperatures were high. As a tool for resource managers, these extremes are easy to interpret and utilize to determine time of the year when hopper dredging activities should or should not be implemented. Those CPUE rates and water temperature combinations which may be designated as a medium or moderate level of sea turtle relative abundance were primarily seen during early spring and late fall. This assessment of potential sea turtle occurrence is the most difficult to use by the resource manager; therefore, additional factors such as channel (compiler's note: this sentence was incomplete).

As a conservative and precautionary measure, moderate to high sea turtle abundance may be expected when water temperature is ≥21 °C; however, this may not be a correct assessment for channels with very low CPUE rates. Channel location and previously documented physical and biological data should also be considered if the trawl survey yields a very low CPUE even at high water temperature. This can be illustrated using the September 1992 (CPUE turtles/hour = 0, mean water temperature = 27.7 °C) data from Charleston Harbor. Although no turtles were captured during this survey, a high relative abundance of sea turtles apparently were within the channel during the September 1992 survey based on trawling surveys conducted during July 1992 (CPUE turtles/hour = 0.490, mean water temperature = 26.6 °C) and October 1992 (CPUE turtles/hour = 1.067, mean water temperature = 21.3 °C). Van Dolah and Maier (1993) also documented sea turtle presence in Charleston Harbor during September 1990 and 1991. It is unclear why no turtles were captured during the September 1992 trawl survey in this study.

Spatial (station) distribution was not random. A significantly higher number of turtles were captured in at least one of the sampling stations within all surveyed channels except Morehead City Harbor. However, no conclusions can be determined without further investigation into factors which may influence sea turtle behavior such as bottom topography, substrate, depth, food organisms, etc.

Recaptures of sea turtles throughout this 21-month study suggest month-to-month and year-to-year site fidelity of some individuals. Recaptures of turtles tagged between multiple channels suggest channel utilization during migratory activities.

The success of relocation efforts is difficult to evaluate; however, relocation of turtles out of the dredging area may be most feasible when there are low densities of turtles. Trawling operations used to relocate turtles may have increased success if begun shortly before or at least at the onset of the dredging operation and not during the latter portion of the project. Turtle relocation operations are limited to areas in the channels where trawling is possible; however, trawling should be done throughout as much of the channel as possible.

For the five channels surveyed north of Canaveral Harbor, very few sea turtles were captured when water temperatures were at or below 16 °C. Although the lower critical temperature limits may be different for each species and size-class, temperatures below 16 °C may be used as a conservative indicator of time periods in these channels which have reduced sea turtle occurrence or activities. The relationship between sea turtle occurrence and water temperature was not seen at Canaveral Harbor as was shown in the other channels surveyed.

Assessment of Sea Turtle Relative Abundance in Port Canaveral Ship Channel, Florida

Introduction[3]

In 1991, the Waterways Experiment Station (U.S. Army Corps of Engineers) developed an integrated program to evaluate relative abundance of sea turtles in a number of channels in the southeastern U.S. that are maintained by the U.S. Army Corps of Engineers. It was recognized that we needed to learn more about the sea turtle populations in these channels so that appropriate management plans could be developed. This final report summarizes the results from monthly surveys of the sea turtle populations in the Port Canaveral Ship Channel, FL (28°23'N, 80°33'W), from March 1992 through February 1993. The objectives of this aspect of the program were to evaluate species composition, size class frequencies, relative abundance, and

[3] This section of Chapter 3 was reproduced verbatim from Bolten, A. B., Bjorndal, K. A., Eliazar, P. J., and Gregory, L. F. (1993). "Assessment of sea turtle relative abundance in Port Canaveral Ship Channel, Florida," Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, FL. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

seasonal and spatial distributions. In addition, baseline blood chemistry parameters were determined for loggerhead sea turtles (*Caretta caretta*).

The Port Canaveral Ship Channel has been recognized as an important habitat for sea turtles (Carr, Ogren, and McVea 1980; Ogren and McVea 1982; Henwood 1987; Henwood and Ogren 1987; Witzell 1987). The need to maintain the Channel for navigation for both commercial and military vessels has resulted in the take of turtles from dredging operations (Dickerson and Nelson 1990).

Since the late 1970's sea turtle populations in the Channel have been periodically surveyed using commercial trawling vessels. Henwood (1987) summarized the data from surveys conducted from 1978 to 1984 with respect to species, size frequency distribution, and seasonality. From March 1988 until March 1991, periodic surveys of sea turtle populations in the Channel have been conducted by researchers at the Archie Carr Center for Sea Turtle Research, University of Florida (Bolten and Bjorndal 1990 and unpublished reports).

This project accomplished the immediate goal of the U.S. Army Corps of Engineers to obtain information to reduce negative effects of dredging on sea turtles. In addition, this study provided the opportunity to collect data on an in-water sea turtle population throughout an annual cycle. A number of federally sponsored task forces, organized to evaluate issues in conservation and management of sea turtles, have stressed the need for more studies on in-water sea turtle populations (National Research Council 1990; Tucker and Associates 1990; National Marine Fisheries Service and U.S. Fish and Wildlife Service, in press).

Discussion[3]

Species composition

The sea turtle populations in Port Canaveral Ship Channel are dominated by loggerheads. The loggerhead population is discussed in greater detail in the following sections.

Although only one Kemp's ridley was captured during the survey year, other surveys have indicated that the Channel is important habitat for immature Kemp's ridleys (Henwood and Ogren 1987; Bolten and Bjorndal 1990 and unpublished reports). Relative abundance of Kemp's ridleys in the Channel appears to be the result of water temperatures and the migratory patterns of Kemp's ridleys north and south along the east coast of the U.S. (Henwood and Ogren 1987).

Henwood and Ogren (1987) suggested that the small numbers of green turtles that inhabited the Port Canaveral Ship Channel represented an itinerant population, including a number of green turtles that had recently left the pelagic habitat and were recruiting to benthic foraging areas. Our earlier surveys (Bolten and Bjorndal, unpublished reports) indicated that small green turtles in the area congregate close inshore around the jetties and in the submarine basin. A study of the green turtles in this area is now underway (L. M. Ehrhart, University of Central Florida).

Due to the inherent limitations of surveys conducted with bottom trawling techniques, the assessments of potential sea turtle relative abundance using CPUE rate and water temperature would best reflect the occurrence of sea turtles on or near the channel bottom. This is also the area of most concern for potential dredging impacts to sea turtles.

Summary[1]

A total of 76 monthly trawling surveys were conducted for sea turtle relative abundance from June 1991 through March 1993 in the Canaveral Harbor entrance channel, FL (12 surveys), Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL (14 surveys), Brunswick Harbor ocean bar channel, GA (9 surveys), Savannah Harbor ocean bar channel, GA (17 surveys), Charleston Harbor entrance channel, SC (11 surveys), and Morehead City Harbor entrance channel, NC (13 surveys).

A combined total of 645 loggerheads (*Caretta caretta*), 20 Kemp's ridley (*Lepidochelys kempi*), and 5 green turtles (*Chelonia mydas*) were captured. Loggerheads were consistently the most abundant species in all six channels. Although only a very low number of Kemp's ridleys were captured during this study, the majority were captured at Fernandina and Brunswick Harbors. No quantitative conclusions can be made from the low sample size of green turtle captures.

Kemp's ridley and green turtles did not appear to utilize the deeper dredged areas of the channels. Although not investigated in this study, the shallower areas outside the channels may serve as an important habitat to Kemp's ridley and green turtles. The dredged section of the channels which were not surveyed because of rock substrate and debris (such as near rock jetties) may also be inhabited by very small loggerheads, Kemp's ridley, and green turtles. Further studies are needed in these locations using alternative sampling techniques.

Catch per unit effort was calculated as indices to compare spatial and temporal sea turtle abundance within and between the six channels.

Juvenile loggerheads 50-70 cm in length were the predominant size-classes in the five channels north of Canaveral Harbor. Very few adult loggerheads were present in the deeper dredged section of these channels. Both adult and juvenile loggerhead size-classes utilized the deeper dredged section of Canaveral Harbor; however, differences in seasonal occurrence were seen.

For the five channels surveyed north of Canaveral Harbor, loggerhead (primarily juveniles) captures began in late spring (April, May), increased throughout summer (June, July, August), peaked in fall (September, October, November), then dramatically declined during winter (December, January, February). Peak month for loggerhead captures in these channels appeared to be October. In Canaveral Harbor, adults were primarily present during late spring through summer whereas peak occurrence for juveniles was midwinter (January).

Our capture of an adult female green turtle that nested a short time later on Melbourne Beach increases the value of the Channel habitat for green turtles. Green turtles apparently use the Channel as an inter-nesting habitat. The capture of adult breeding green turtles may be a rare event in Port Canaveral Ship Channel because the endangered Florida green turtle nesting population is very small (Witherington and Ehrhart 1989; National Research Council 1990).

Size frequency, seasonal distribution, and relative abundance

The size frequency of loggerheads captured in Port Canaveral Ship Channel has a strong bimodal distribution (Figure 6).[4] The distribution suggests that the two size classes may use the Channel habitat for different purposes, and that they may move in and out of the Channel at different times. Following Henwood (1987), we divided these two size classes at 82.5 cm maximum straight carapace length, and designated the two size classes as juveniles and adults. For 114 nesting loggerheads on Melbourne Beach, the smallest maximum straight carapace length measured was 82.5 cm (Witherington 1986). Although it is possible that a few immature loggerheads were included in the adult class and that a few sexually mature loggerheads were included in the juvenile class, a few misclassified turtles would have no effect on the results reported here because the analyses are limited to questions at the population-level, rather that at the individual-level.

From the monthly distribution of the two size classes (Figure 19),[4] it is clear that the two size classes have different seasonal distributions. When numbers of loggerheads in the two size classes were combined into four three-month seasons to allow statistical comparison, a significant difference between the distribution of the two size classes was found. Juveniles occupy the channel year-round in relatively constant numbers and apparently use the channel as an area in which to rest and/or feed. Adults essentially move into the Channel during the breeding season and use the Channel as an area in which to mate (copulating pairs have been observed in earlier surveys in the Channel) and females use the area as an inter-nesting habitat. This last use was confirmed by the reports of three turtles (two loggerheads and one green turtle) nesting on Florida beaches within a few weeks of capture in Port Canaveral Ship Channel. The significant correlation of adult abundance with water temperature (Figure 23)[4] is a reflection of the fact that loggerheads breed during the warm months of the year.

The sharp increase in number of juvenile loggerheads in the Channel in January (Figure 19)[4] probably represents a group of juvenile turtles migrating south away from cooler northern temperatures. Juvenile loggerheads apparently have a similar migratory pattern to that reported for Kemp's ridleys (Henwood 1987; Henwood and Ogren 1987). As waters along the eastern U.S. coast begin to warm in the spring and summer months, they move north, and then move south as temperatures cool in fall and winter months. Apparently the appearance of these migrating

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[4] Refers to tables or figures in Bolten et al. (1993), not reproduced here.

loggerheads is determined more by water temperature than by absolute time of year. Thus, these peaks can appear in almost any month from late fall to early spring.

The seasonal distribution of juveniles and adults described above is the same as that reported by Henwood (1987) for loggerheads in the Port Canaveral Ship Channel based on surveys conducted between 1978 and 1984. Adjusting the CPUE data in Table 2[4] to include only juvenile loggerheads and correcting for net size differences between this study and Henwood's study, we can compare relative abundances. Our maximum CPUE (in January in Stations A, B and C) is 2.15 juvenile loggerheads caught per hour per 30.5 m net. Our minimum CPUE (in September in Stations A, B, C and D) is 0.082 juvenile loggerheads caught per hour per 30.5 m net. The comparable range of CPU from Henwood (1987) is 2.0 to 12.05 juvenile loggerheads caught per hour per 30.5 m net. Based on these CPUE values, the relative abundance of loggerheads in Port Canaveral Ship Channel has declined between the time of Henwood's study and the present.

Spatial distribution

There was significant differential use of the four stations in the Channel by loggerheads (Figure 5).[4] Turtles were present in higher numbers in Stations B and C than in Station A, and only one turtle was captured in Station D. Because we do not know what factors attract loggerheads to Port Canaveral Ship Channel, it is difficult to interpret this differential distribution. The distribution may be correlated with bottom type. Stations B, C and D have softer substrates than Station A, and Station D does not have the steep-sided channel of the other Stations, which may provide shelter to the turtles or act to concentrate organisms on which the turtles feed.

Blood chemistry

Blood samples were collected from 168 loggerheads, and plasma samples were evaluated for 26 analytes. It is important to establish baseline values for blood chemistries to monitor physiological status of loggerhead populations.

In this study, 22 of the 26 analytes had a significant seasonal effect; only chloride, alkaline phosphatase, gamma-glutamly transferase, and total iron did not (Table 4).[4] There was a trend for values to increase in warmer months, except for urea nitrogen (BUN), which decreased in warmer months (Table 3).[4] Lutz and Dunbar-Cooper (1987) also evaluated blood chemistry of loggerheads in Port Canaveral Ship Channel. Seven chemical parameters--glucose, sodium, potassium, chloride, magnesium, calcium, and urea--were evaluated in both studies. Of the seven parameters, we found that only chloride did not vary significantly by month. Although Lutz and Dunbar-Cooper (1987) did not test statistically for a seasonal effect, they reported that concentrations of sodium, potassium, and chloride showed seasonal trends.

Concentrations of 22 of the 26 analytes are significantly related to body size in the loggerheads in this study. In a study of plasma samples from 100 juvenile green turtles from the southern Bahamas, only 13 of the 23 analytes determined in common between the two studies showed a significant correlation with body size (Bolten and Bjorndal 1992). The greater effect of body size reported here for loggerheads may result from the fact that the loggerhead samples included many reproductively active adults, whereas the green turtle sample included only immature turtles.

Additional studies

Other studies based on blood samples collected during the course of this project-at no additional cost to this project--include the following; (1) analysis of stress hormones in blood plasma of loggerheads (Lisa Gregory, Masters Thesis, University of Florida), (2) analysis of insulin-like growth factor (IGF-I) in blood plasma of loggerheads (Drew Crain, Masters Thesis, University of Florida), (3) population genetics and sequencing of mitochondrial DNA in loggerheads (Bjorndal, Bolten, and Bowen, University of Florida), and (4) analysis of the immune system from plasma samples of loggerheads (Larry Herbst, PhD Dissertation, University of Florida).

Recommendations[3]

a. The sea turtle populations in Port Canaveral Ship Channel should be surveyed with trawlers at regular intervals to monitor changes in the population. It is important to continue to monitor the Port Canaveral Ship Channel sea turtle population, not only because of its large size, but also because it is one of only a few in-water populations that has a long-term monitoring history. Because it has been demonstrated that population level in Port Canaveral Ship Channel can change, populations must be surveyed to update their status and potential for negative impacts from dredging.

b. To understand and predict patterns of relative abundance and distribution of turtles within the Channel, the basic biology (particularly behavior, nutrition, and physiology) of the turtles should be studied to determine why the turtles are in the Channel and how they use the habitat.

c. Although water temperatures affect turtle abundance in the Channel, dredging windows should not be based on temperature data alone. Prior to dredging, pre-dredge surveys should be conducted to establish what species of sea turtle are present and at what level of abundance. Because the critically endangered Kemp's ridley and Florida green turtle inhabit the Channel on a less predictable basis than do loggerheads, the pre-dredge surveys would be particularly important to determine the presence and abundance of these two species.

4 Behavioral Studies

Introduction

Knowledge of the diving activity of sea turtles and their local vertical and horizontal movements is useful for devising a strategy to decrease the numbers of turtles injured or killed by hopper dredges. Telemetry systems in general have been greatly refined in the past few years, and many studies have utilized this proven technique to better understand sea turtle activities.

Sea turtles used in telemetry studies were captured by trawling. After capture, critical measurements were taken and a general physical examination of each turtle was performed. Blood samples were obtained for later analyses. Turtles were then tagged, and radio and sonic transmitters were attached to the posterior scutes. The turtles were then released and monitoring was initiated. Data obtained during the first 24-hr period were not used.

Sea turtle baseline behavior was established by Standora et al. (1993a) in Canaveral channel during summer 1992, and daily movements were determined here during spring 1993 by Standora et al. (1993b). The behavior of turtles in St. Simons Sound was investigated by Keinath, Barnard, and Musick (1992), and the behavior of turtles in Savannah and Charleston shipping channels also was investigated by Keinath, Barnard, and Musick (1995) during the spring and autumn of 1993. Nelson (1993) studied subadult loggerhead behavior in Fernandina/Kings Bay entrance channel during spring, summer, and fall seasons. Appropriate sections of those documents pertaining to sea turtle behavior are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the studies are given in the original documents.

Assessment of Sea Turtle Baseline Behavior and Trawling Efficiency in Canaveral Channel, Florida

Introduction[5]

(Compiler's note: repetitive background material has not been duplicated here.)

Seasonal influences notwithstanding, it is important to realize that behavioral activities of sea turtles can change within a much shorter time scale. Studies conducted in both Cape Canaveral and New York have reported strong diurnal patterns for surfacing times of sea turtles. Working with Cape Canaveral loggerheads, Nelson, Benigo, and Burkett (1987) observed that turtles spent 8 percent of the time on the surface during the daylight hours and half this amount of time on the surface at night. Similar patterns were observed for Kemp's ridleys in a study conducted over a four-year period in New York (Morreale and Standora 1989, 1990, 1991). Other behavioral components, such as foraging, swimming, and resting on the bottom, also vary throughout the day. A critical goal of this research is to understand which aspects of daily sea turtle behavior are directly relevant to the dredging operations.

To address this goal, two different suites of behavior exhibited by turtles were evaluated; (a) site fidelity within the Cape Canaveral channel area, and (b) the vertical movements within the water column. The specific objectives were to:

a. Use telemetry techniques to determine the normal pattern of usage of the channel and compare this to time spent outside the channel.

b. Telemetrically monitor vertical movements of turtles to determine the relative amounts of time spent in different portions of the water column.

A secondary goal of this study was to assess the effectiveness of trawling, both as a censusing technique of turtle populations and as a potential removal method to mitigate dredging impacts. Specifically, the objective of this portion of the study was to determine trawler efficiency in the collection of artificial targets and relate the findings to trawls of wild, telemetrically-monitored sea turtles.

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[5] This section of Chapter 4 was reproduced verbatim from Standora, E. A., Eberle, M. D., Edbauer, J. M., Ryder, T. S., Williams, K. L., Morreale, S. J., and Bolten A. B. (1993a), "Assessment of sea turtle baseline behavior and trawling efficiency in Canaveral Channel, Florida," Buffalo State College, Buffalo, NY; Okeanos Ocean Research Foundation, Inc., Hampton Bays, NY; and University of Florida, Gainesville, FL. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

Results and discussion[5]

Population description

As a result of trawl surveys within the confines of the Cape Canaveral ship channel, 55 loggerhead sea turtles were captured during the one-month study period (July-August 1992). Among the captured turtles there was a bimodal distribution of carapace lengths indicating that two distinct size classes of individuals were present (Figure 13).[6] The 13 individuals in the smaller group ranged in size from 49.6 cm to 74.8 cm, with a mean length of 60.4 cm (S.D. = 7.5). The mean length of the 42 larger animals was 90.4 cm (S.D. = 4.6) with a range in size of 82.8 cm to 101.1 cm. The mean weight for the 31 turtles which were captured and had transmitters attached was 99.9 kg (Figure 14).[6] It is likely that the smaller group represented the subadults which are residents of the area, while the larger turtles were probably transient adults from nearby nesting areas. This bimodal distribution and the range in sizes among the captured loggerheads was nearly identical to that reported by Henwood (1987), although his study reported that subadults predominated during July. Among the turtles that were selected to be used for the telemetry study, all but two individuals were from the larger adult group (Figure 15).[6]

Turtle movements

Of the 31 turtles that were outfitted with transmitters and released immediately back into the channel, 23 individuals were located again after intervals of greater than 24 hours (Figures 16 - 20).[6] Turtles had a mean rate of movement of 0.11 km/h (S.D. = 0.07, range 0.005 to 0.254). Caution should be used in interpreting these results as they were calculated from point to point locations recorded sometimes days apart and therefore may not reflect the actual distances traveled by the turtles. Fifteen of these turtles were recontacted more than once, and the intervals between first and last contact ranged from 26.6 to 293.3 hours. Although the plots of their movements (grouped according to monitoring periods) do not represent continuously monitored tracks, they provide information about habitat usage and horizontal movements within and around the channel area. Most turtles remained in the vicinity of the channel for up to several days after release. Upon subsequent contact, nearly half (48 percent) of the recontacted animals were found within 3 km of their initial release site; only three (13 percent) were located greater than 10 km away (Table 3).[6] Even if it is assumed that the six turtles (19 percent) that were never recontacted left the area, this represents a very large rate of retention in the Canaveral area.

Since contacts with turtles were not continuous, it was not possible to quantify the percentage of time spent in the channel for a single turtle. Nevertheless, with such a large sample size of individuals, the data indicate that turtles spend very little time within the channel boundaries over the next several days after release. This observed post-capture behavior could explain why, historically, turtles rarely have been recaptured during the same trawl survey within the channel. During the

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[6] Refers to tables, figures, or appendices in Standora et al. (1993a), not reproduced here.

nontargeted trawling periods in our study, no turtles were recaptured. Such a pattern may suggest that turtles are distributed throughout the entire Cape Canaveral area and that there is not a specific preference for the channel itself. This would make it very unlikely to recapture an individual in the same spot. Alternatively, the turtles may be exhibiting avoidance behavior as a result of being dragged up by the trawler. If they do respond to the disturbance of initial capture, however, they do not exhibit any extreme reaction, since most remain in the immediate area after release.

Distribution in the water column

Diving in turtles is an extremely important behavioral characteristic which influences the ability to census populations and to implement viable management plans. As a result of telemetrically monitoring the dive patterns of sea turtles at Cape Canaveral, it was possible to record how the turtles' time is partitioned with respect to position in the water column. By dividing the day into 4-hour segments, it was also possible to detect variations in diving behavior within the diurnal cycle. In all, 23 individual turtles were monitored over a 2-hour activity period (Table 4).[6] Three of these individuals were also monitored in a subsequent period. Since turtle #X1028 appeared to have emerged from the water to nest during one of the early morning readings (0000 to 0400), its first monitoring session was excluded from analysis. Thus, in each of the five time segments that were selected (between 0800 and 0400 hours the next day), monitoring was conducted on an equal sample size of five individual turtles.

Because of the study design, which called for such a high number of individuals, the resulting activity data represent the largest sample size of individual dive profiles ever collected for sea turtles (Appendix A, Figures 21- 45).[6] A wide array of behaviors was observed among 25 dive profiles of the 23 different turtles. Although, during 22 of the 2-hour profiles, the turtles dove to the bottom at least once (Table 5),[1] patterns of diving and surfacing, number of dives, and proportions of time spent at various levels varied greatly among individuals. In 13 separate profiles, turtles were observed to remain on the bottom for continuous periods of 10 minutes or greater. Three of these turtles spent more than 75 percent of their time on the bottom (Figures 24, 27, 42);[6] the only recorded vertical activity of two of these individuals was to shuttle to and from the surface to breathe. The three turtles that did not dive to the bottom spent most of their time at depths between approximately 2 and 8 m (Figures 21, 26, 31).[6] Although water depths during all profiles were greater than 10 m, the tendency to remain at such intermediate depths was pronounced in 8 other dive profiles (Figures 22, 23, 29, 30, 34, 36, 37, 40).[6] In many of these instances it appeared as if the turtles detected a layer or interface in the middle of the water column. Even after brief excursions to the surface or bottom, they would return to the intermediate depth where they had been previously stationed (Figures 22, 29 - 31, 34, 40).[6]

During the two-hour monitoring periods, some turtles shuttled to the surface as many as nine or ten times, although the majority surfaced four or fewer times (Table 6).[6] The variability in surfacing among individuals reflected observed differences in their activity levels. Turtles that came to the surface less often were typically less active, establishing themselves at constant depths for longer periods of time. For comparison of vertical activity, an index was devised which represented the total number of times a turtle moved more than 3 m vertically during the 2-hour monitoring period. This index had mean values ranging from 7.8 to 12.2 for the late A.M. and early P.M. time periods, respectively. The rates of ascent ranged from 1.3 to 13.6 m/min while the rates of descent ranged from 2.8 to 14.0 m/min.

Monitoring the frequency of surfacing of several individuals in an area can provide a reliable indicator of overall turtle activity. A very important observation that was detected from the monitoring of so many turtles was the small amount of time that turtles were at the surface. Only two turtles remained at the surface for a continuous period of more than three minutes; the longest time at the surface was 8 min. and 45 sec. (Figure 24).[6] These minimal surface times can have important implications on estimating population sizes, especially from aerial surveys.

Each of the five time periods in which the turtles were monitored were represented by an equal sample size of turtles. By combining all observations in each time period we were able to determine percentages of time spent at different levels in the water column throughout the day (Appendix B, Figures 46 - 53).[6] A common feature observed at all times of the day was that in each of the time periods, turtles spent greater than 25 percent of their time in the bottom third of the water column (Figure 46).[6] In the time periods spanning from Early A.M. (0000-0400) to Mid P.M. (1600-2000), the percentage of bottom times ranged from 25.7 to 37.6. The highest values were seen during the Late P.M. hours of 2000-2400, when turtles remain in the bottom zone for the majority of their time (57.6 percent). Four of the five turtles monitored in the Late P.M. exhibited prolonged intervals where, apparently, they remained stationary on the bottom (Figures 41 - 45).[6] Unlike the bottom third of the water column, turtles can occupy the mid depths simply by moving through this section. Such transient movements add to the total percentage of time spent at mid-water and can unduly influence perceptions of turtle activities. Nevertheless, turtles were observed to occupy the middle third most often during the Early P.M. (1200-1600). The fact that the majority of their time during this period was spent at mid-water, was demonstrated by three of the five turtles that appeared to be actively choosing this zone (Figures 31, 32, 34, 35, 37).[6] The lowest percentages observed during the Late P.M. were almost exclusively a result of brief transits through this zone by turtles shuttling to and from the bottom.

As was previously illustrated in the dive profiles, turtles spent very little time at the surface. This resulted in low percentages of time spent in the upper third of the water column for all animals (Figure 48).[6] There were two primary behaviors which influence the percentages of readings in the upper water column. Each time the turtle breathes, it must pass through this zone on the way up and on the way down. It was also noted among many dive profiles, although turtles were technically in the upper third of the water column, they were hovering very near the interface of the mid-zone.

When diving behavior was analyzed with respect to each different period (Table 7),[6] it was noted that nearly equal amounts of time were spent by turtles at all three levels of the water column during Early AM (Figure 49),[6] Late AM (Figure 50),[6] and Middle PM (Figure 52).[6] In contrast, turtles spent the majority of their time in the mid-water during Early PM (Figure 51),[6] and at the bottom in Late PM (Figure 53).[6]

Because of the high variability in individual turtle behaviors, the extreme readings (highest and lowest) for each time period were eliminated prior to statistical analysis. There was no significant difference between times spent in the upper third of the water column during the five time periods of the day ($n = 15$, $p = 0.42$). The relationship between time period of the day and time spent in the middle of the water column approaches statistical significance ($n = 15$, $p = 0.11$). The turtles spent more time in the middle third of the water column during the early PM time period than during any other time period. The turtles spent the least amount of time in the middle third of the water column during the late PM time period. A Tukey test showed the turtle depths between these two time periods to be different with $p = 0.07$. Of considerable importance to the Army Corps is the amount of time the turtles spent in the bottom third of the water column as these would be the animals most impacted by dredging operations. The turtles spent more time in the bottom third of the water column during the late PM period than during any other time period ($p = 0.09$).

This analysis of turtle behavior with respect to position in the water column has demonstrated that turtles within the channel area exhibit distinct diurnal patterns. An understanding of these general patterns can be applied directly to the use of trawling as a censusing and impact mitigation tool, and has important implications for dredging operations. The observed results from this study suggest that trawling during the Late PM period may increase the probability of capturing turtles. Therefore, we suggest there may be less of an impact on the turtle population if dredging activities were conducted during the other time periods.

Thermal ecology

Water temperatures ranged from 19.1° to 30.7 °C with the steepest thermal gradient occurring at depths of 6-12 meters depending on location. Thermal gradients in the water column may influence the vertical distribution of the turtles (Figures 54 - 61).[6] Three turtles (1020, 1028, 2772) (Figures 54 - 56)[6] spent major portions of their monitoring sessions at intermediate depths (i.e., not at the surface nor on the bottom). Although these individuals were monitored on different days and at different depths, they were located in water temperatures of 26-27 °C.

A slight increase in depth would have placed these animals below the thermocline in water temperatures several degrees cooler. Although other factors such as light intensity and food availability may influence their vertical distribution, temperature is very likely to have a strong influence on their behavior. Water and body temperatures of 25-30° C are frequently reported as important in the lives of sea turtles (Bell and Richardson 1978; Morreale et al. 1982; Mrosovsky 1980; O'Hara 1980; Spotila and Standora 1985; Standora and Spotila 1985).

Pinpoint trawling efficiency

Artificial targets were used in 21 trials to assess trawler efficiency. Initially, a standard turtle censusing net was employed to retrieve the targets from the bottom. After two of the first three trials were unsuccessful, it was determined that the net had insufficient weight to continuously drag along the bottom (Table 8).[6] By adding chain to the lead line, the net dragged more firmly and the improved performance was noted immediately by vast increases in the retrieval of bottom sediments and sessile, benthic invertebrates. Concurrent with this design change, there was an increase in the efficiency of retrieval of artificial targets. In six of the next seven trials, targets were easily captured.

During these earlier trials, underwater observations (using SCUBA gear) indicated that the weighted targets settled deeper into soft, silty sediments than in harder, sandy substrates. It was suspected, therefore, that differences in bottom type could also influence catchability by affecting net performance. This was supported in a second set of trials in which only the heavier net was used over different bottom types (Table 9).[6] In three separate trawling trials over a soft bottom, a target was retrieved only once, whereas targets were captured in seven of eight passes on hard substrates.

Since differences in net configuration affected trawling efficiency in the artificial target study, it was important to assess the influence of such design modifications on the capture of live turtles. Thus, 34 separate trawler tows were conducted in the ship channel, using two different net configurations simultaneously. The standard lighter rigging was towed along the port side, while the heavier net was used along the starboard. As was observed with the artificial targets, there was a considerable improvement in the effectiveness of trawling using the weighted net. This improved trawler efficiency was evident in three ways. First, of the 51 individual turtles that were captured using the dual net technique, more than three times as many were captured by the weighted, starboard net than by the port net (Table 10).[6] Second, the starboard net also had a significantly higher frequency of capture than the port net ($t = -4.74$, $df = 33$, $P < 0.0001$) with 24 of 34 trials (71 percent) resulting in at least one turtle being captured, while using the lighter net, only 11 of these trials resulted in captures. Third, in 13 separate tows, the weighted net caught two or more turtles, whereas only 1 tow by the standard net resulted in a multiple capture.

The results from these trawling studies on both artificial targets and live turtles clearly demonstrate the importance of net design on catchability. They also help to explain the mechanics of bottom trawling, and provide us with some insight into turtle behavior within the channel. In the first study, it was known that the weighted targets were stationary and resting lightly on the bottom. Because of this, it was not surprising that making the net heavier enhanced its performance. This was not a given, however, for live turtles which can be anywhere within the water column. While it is usually assumed that trawl nets of this design capture sedentary turtles, there has been only circumstantial evidence to support this. Once it was demonstrated that our nets were dragging firmly along the bottom, and there was a significant increase in capturers with the heavier net, we concluded that the turtles we were capturing were resting among the bottom sediments.

Despite the success of these trawling studies in the improvement of catchability, they do not account for turtle behavior. It is never possible to assess the influence of behavior on catchability when trawling is conducted during normal censusing surveys. However, in this study, we had the unique opportunity to monitor several turtles using telemetric techniques during pinpoint trawling trials. One such monitored turtle that was sedentary on the bottom was successfully retrieved using the heavier net design (Figure 62).[6] However, several turtles exhibited what could only be described as avoidance behavior to the approaching trawl net (Figures 63 - 65).[6] A second turtle was also resting on the bottom at the beginning of the trawler pass (Figure 63).[6] As the trawler approached, the turtle began swimming along the bottom and, as the net moved towards the turtle's location, the turtle rose up in the water column and evaded the net. Two other turtles were in midwater at the beginning of each trawling pass, (Figure 64 and 65)[6], and as the trawler approached, both turtles began swimming vigorously and quickly changed positions in the water column. The most startling example of evasive behavior occurred when a monitored turtle was captured in the trawler net but escaped, leaving its transmitter entangled in the net.

These observations suggest that turtle behavior strongly influences the efficiency of trawling. However, it is not possible to know whether these types of behavior are prevalent among all turtles or only those individuals which have had recent interactions with trawlers. A longer term study resulting in more data on turtle/trawler interactions would have important implications for collecting turtles as a means of estimating turtle populations and as a possible technique to mitigate negative impacts.

Summary[5]

In summary, the results of this study have important implications both for censusing turtles and for dredging impacts and mitigation. By monitoring turtle movements, it was shown that, while turtles were not confined to the channel itself, most utilize a relative localized area. Turtles also exhibited distinct diurnal patterns in diving behavior. The greatest amounts of time spent resting on the bottom occurred during the nighttime hours. Positions in the water column appear to be influenced by temperature, although other factors such as food availability and light intensity should also be considered. Time spent on the surface by these turtles during the summer was minimal, and therefore has strong implications for aerial survey data. Without aerial survey correction factors the population estimates would severely underestimate the true numbers present. Trawling is an effective method for collecting turtles but the limitations imposed by net design, substrate type and turtle behavior must be taken into account.

Although the data collected during this study provide new insights into turtle behavior, it must be realized that there are limitations to the application of data obtained during only one season. We do not expect that these data, which were collected primarily on one adult group of turtles, and over a relatively short time span, will necessarily directly apply to turtles of different size and age groups that are known to inhabit the channel area during different seasons. For a more complete understanding of turtle dredging interactions additional data should be collected on different size classes of turtles and during different seasons.

Diving Behavior, Daily Movements, and Homing of Loggerhead Turtles (*Caretta caretta*) at Cape Canaveral, Florida, March and April 1993

Introduction[7]

(Compiler's note: repetitive background material has not been duplicated here.)

To alleviate such negative impacts at Cape Canaveral, a better understanding is needed of the behavior of loggerhead turtles in the area, especially with respect to their interactions with dredging operations. More specifically, it is essential to study turtle movements and diving behavior because of their direct relevance to dredging operations and the mitigation of its impacts. Standora et al. (1993a) found that during the summer season, loggerheads exhibited distinct diurnal diving patterns with individuals spending most of their time on the bottom during the Late P.M. time period (20:00-24:00). Information such as this is crucial in devising a proper management plan and for making recommendations for the time of day when dredging will have the least impact on turtles. It was also noted in this study, however, that diving patterns among different seasons also must be studied to make a more complete assessment of potential dredging impacts.

Likewise, it is important to analyze the movements of turtles on a seasonal basis. Behavioral research during the summer of 1992 (Standora et al. 1993a) indicated that movements of adult female loggerheads were relatively localized, with occasional excursions to nearby nesting areas. It was further noted that most of the turtles that were monitored utilized the general area of the shipping channel rather than remaining specifically within the confines of the channel. Because of the change in population structure throughout the year, it is likely that these observed movements apply to that particular group of adult females during the summer months. Previous research has demonstrated large variations in the turtle population structure during the different seasons at Cape Canaveral, FL (Henwood 1987). During March and early April, the population mainly is composed of juveniles. The population structure shifts toward adult males and then toward adult females during April and May respectively. Henwood (1987) proposed that juveniles overwinter in the Cape Canaveral area and then travel to the nutrient rich northern waters to feed. After this time, they are replaced by incoming males and then females. Hence, there

[7] This section of Chapter 4 was reproduced verbatim from Standora, E. A., Eberle, M. D., Edbauer, J. M., Ryder, T. S., Williams, K. L., Morreale, S. J., and Bolten, A. B. (1993b), "Diving behavior, daily movements, and homing of loggerhead turtles (*Caretta caretta*) at Cape Canaveral, Florida, March and April 1993," Buffalo State College, Buffalo, NY; Cornell University, Ithaca, NY; University of Florida, Gainesville, FL. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

is probably some time when each group remains resident, but there is apparently a high degree of mobility by individuals among seasons.

Given the apparently high residency rates of turtles in certain seasons, relocation was considered to be another possible technique to mitigate the effect of dredging on the turtle populations. The process of dredging requires two to four weeks to complete. If turtles could be effectively removed from the area during that time, negative interactions would be greatly minimized. Kemmerer, Timko, and Burkett (1983) conducted a preliminary relocation study in which 10 turtles were displaced 8 km to the south of the Cape Canaveral channel. Out of this group, eight turtles returned within thirteen days (mean = 7 days). Thus the potential for the success of this type of displacement activity exists. It remains to be seen, however, whether these techniques are more or less successful during high residency periods or during times of high mobility. Moreover, the effects of displacement of turtles to different locations and to different distances from the dredge site are unknown.

The present study focused primarily upon sea turtle biology with respect to horizontal movement of turtles within the Canaveral area during early spring, and to their vertical movement within the water column. A second goal was to determine the effect of relocation on turtles that were captured and released. Included in this study was an analysis of direction and distance of displacement to determine if specific activities were more effective in keeping relocated turtles from returning to the site during short-term dredging operations. Specific objectives of the spring project were to:

a. Use biotelemetric methods to determine daily patterns of channel usage by the turtles, and compare these with patterns of usage outside the channel.

b. Monitor the diurnal diving patterns of turtles to determine the relative amount of time spent at different depths in the water column.

c. Determine the amount of time loggerheads spend at the surface. This will be essential in calculating correction factors for aerial surveys.

d. Evaluate the relocation of sea turtles from the channel area as a means to mitigate, or perhaps eliminate, dredging mortalities.

Summary[7]

Combined results from this study, which was conducted during spring 1993, and our earlier study of summer 1992 (Standora et al. 1993a) provided important information about the behavior, movements, and habitat usage of loggerhead turtles in the Cape Canaveral area. Comparisons of turtles between the two seasons revealed major differences in the patterns of vertical distribution within the water column. In the spring study, turtles spent greater amounts of time in the bottom third of the water column than they did in the summer. They also spent considerably less time at the surface during spring.

In addition to apparent seasonal differences, there were significant differences in behavior between size classes within the spring season. Adult males were more active at the surface than juveniles as was demonstrated by significantly greater number of excursions to the surface by this size class. Adult males also exhibited a greater tendency toward residency in the channel area than did the juvenile turtles. These behavioral differences were evident in the direction of movement, net distance moved, and rate of travel for most turtles. Such behavioral differences may be explained by the coincidence of this study with the start of the mating season for loggerheads in the area. At this time there is an influx of adult males followed later by adult females, which became more abundant throughout the summer. Thus, the differences in turtle behavior observed both between and within the seasons may reflect intrinsic differences among age classes such as reproductive condition.

These findings have important implications for developing strategies to minimize dredging impacts. Dredging conducted in the spring is more likely to have adverse effects on turtles than during summer (although both may be ill-advised) because of the increased time spent on the bottom. Additionally, because turtles spend less time at the surface, if turtle censusing is conducted by aerial surveys, spring surveys will tend to more greatly underestimate population numbers. For any aerial survey data time-sensitive correction factors, both seasonal and diurnal, need to be applied to increase the accuracy of population estimates.

A proposed management tool to mitigate or eliminate dredging impacts in channels is relocation of turtles prior to operations. Our studies have demonstrated that this method must be evaluated with respect to two factors; (1) efficiency of the turtle capture method, and (2) successful removal and translocation of animals to other sites. Results from the summer 1992 study showed that trawling as a method for collecting turtles is useful, but is affected by such factors as bottom substrate, net configuration, seasonal influences, and turtle avoidance behavior. The relocation study conducted in spring of 1993 showed that this method is similarly useful but has attendant limitations. More than half of the turtles that were relocated returned to the general channel area. We were able to generate a model with moderate predictive ability for turtles transported to locations south of the channel. Of the turtles that did return from the south, the farther a juvenile turtle was transported from the channel, the longer it took to return. Superimposed on this trend were apparent differences between turtles released north and south of the channel and between age classes. Although it is unclear what the effect of body size or reproductive state may have on a turtle propensity to return, it is possible that mating adults may be apt to return more quickly once relocated.

This study was conducted during the spring at Cape Canaveral, FL; therefore, any interpretations of the results or conclusions about observed turtle behaviors should be limited to this specific season and location. Several earlier studies in the Canaveral area demonstrated that there are significant changes in abundances and population structure of sea turtles throughout the year. Our research, both in the summer and spring, has further indicated that these seasonal changes directly result in different behavioral and activity patterns among turtles. It is our suggestion that any management strategies should account for such major seasonal differences. Although relocation appeared to be potentially effective, the use of this method as a mitigation technique for dredging is not recommended during the spring season. From our studies we have concluded that relocation can be confounded by several factors. The most important and overriding influence on the efficiency of relocation is seasonality. It is reasonable from a biological standpoint that relocation would be more effective if conducted in a season where the population is stable, with no immigration of new turtles into the area, and during a time when movements and activity levels of individuals are minimal. In order to determine the most effective time in which methods such as relocation should be employed, we feel that it is imperative to undertake similar studies during all seasons. As a matter of priority, in light of our observations on turtle behavior, we would strongly recommend that such a study be conducted in the Canaveral channel during the winter season.

Behavior of Loggerhead Sea Turtles in St. Simons Sound, Georgia

Introduction[8]

The United States Army Corp of Engineers (COE) is responsible for keeping the navigable channels of the intracoastal waterway at nominal depths by dredging. During the spring of 1991 it became apparent that dredging operations in the south-east U.S. were killing sea turtles, listed as endangered or threatened on the endangered species act.

Knowledge of the diving activity and local vertical and horizontal movements may be useful for devising a strategy to decrease the numbers of turtles killed by the dredges. Telemetry systems have become refined in the past 10 years and many studies have utilized the technique to measure the activities of sea turtles (Keinath 1991). We utilized sonic and radio telemetry to determine the movements and diving activities of loggerhead turtles (*Caretta caretta*) in Saint Simons Sound, GA.

Materials and methods[8]

Between 10 and 22 June 1991 five loggerhead sea turtles (*Caretta caretta*), which were captured by a shrimp trawler, were fitted with combination radio and sonic transmitters. Each transmitter had a distinct frequency so individual turtles could be identified. Radio signals can be detected at distances of 1 - 6 km, while sonic range is usually less than 2 km. Since radio waves do not travel through sea water, signals were only received when the transmitter's antenna was out of water. Thus, radio signals were used for long range location of turtles and for determination of exact surface duration. Since sonic signals can be monitored continuously,

[8] This section of Chapter 4 was reproduced verbatim from Keinath, J. A., Barnard, D. E., and Musick, J. A. (1992), "Behavior of loggerhead sea turtles in St. Simons Sound, Georgia," Virginia Institute of Marine Science, College of William and Mary, Gloucester, Point, VA. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

turtles could be located within 100 m, and locations recorded from on-vessel loran or a satellite positioning system. The inter-pulse interval of the sonic transmitters varied with pressure (depth) so vertical movement of turtles within the water column could be monitored.

The sonic portion of the transmitter was calibrated by lowering the transmitter to depth in 3 meter intervals and recording the interpulse period. A 4 mm hole was drilled through the rear marginal scute and bone of each turtle, and the buoyant transmitters were attached with plastic cable ties to a lanyard short enough so the turtle could not bite the transmitter or antenna. Magnesium links which corrode in seawater, were used so transmitters would eventually release from the turtles.

Turtles were released near the mouth of St. Simons Sound. Time and duration of surfacing and diving were determined from the presence or absence of radio signals. An interpulse timer was connected to a directional sonic receiver, and interpulse period was recorded at the commencement of a dive, until the interpulse period became stable (the turtle stayed at a certain depth). Interpulse period was thereafter recorded at various times, until the interpulse period started to show the turtle was moving vertically. We then attempted to record the interpulse period at a rapid rate.

Turtle positions were estimated from sightings from the support vessel and from direction and strength of the sonic signal. Surface and dive durations were calculated from the radio data, and dive profiles were derived from the sonic data. Because of the great number of dives recorded, 'long' dives (> 2000 sec) and dives near the mean of dives measured with radiotelemetry (250 - 500 sec), which had sufficient data, were selected for graphing.

Results and discussion[8]

Summary data on the five turtles instrumented are presented in Table 1.[9] Turtle 1 was tracked for 4 hours on the day it was released. No contact was made on the next day, but contact was made on the two subsequent days. Turtle 2 was tracked for four consecutive days. Turtle 3 was released in the late afternoon, and was tracked the next day. No further contact was made despite two days of searching. Turtle 4 was tracked for a few minutes after release, but efforts to locate the turtle later in the day and the two subsequent days failed. Turtle 5 was tracked for four days, commencing with the day after release. This data suggests some turtles are resident in the area. The loss of contact with 3 and 4 could be due to failure of the transmitters or emigration from the area, and the extent of longer range movements would be more efficiently studied with satellite telemetry.

Positions of all the turtles are shown in Figure 1,[9] and the positions of individual turtles are presented in Figures 2 - 6.[9] Each datapoint from Figures 2 - 6[9] is characterized in Tables 2 - 6,[9] along with direction of movement of the turtles and the tide at the time of the observation. As in Chesapeake Bay (Byles 1988), the turtles preferred to stay in the channels (> 6 m), moving with the current, probably feeding.

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[9] Refers to tables or figures in Keinath, Barnard, and Musick (1992), not reproduced here.

Radio telemetry data showed the turtles spent very little time at the surface (Figure 7),[9] with the majority of surfacing events under 10 sec. The majority of dives were also very short (Figure 8),[9] but dive profiles measured with sonic telemetry (below) showed that dives to the bottom usually took approximately 60 seconds. Thus these short "dives" measured with radios were most likely shallow dives and should be considered surface events. The duration of surface and dive activities, as measured by radiotelemetry, is shown in Table 7,[9] summarized by turtle and time of day. Much more time was spent submerged than at the surface, and there seemed to be no difference between the morning and afternoon. Turtle 5, the only turtle for which there was data during dark, spent more time both submerged and at the surface during dark compared with light periods, perhaps sleeping.

Selected dive profiles are shown in Figures 9 - 18.[9] Although the channels in Figures 1 - 6[9] are delineated by 6 m isobaths, the dredged channel was 10 m deep minimum (from hydrographic survey charts of the area after dredging, supplied by the COE), and the majority of dives (Figures 1 - 6)[9] were most likely to the bottom. Descent and ascent rates were rapid, with dives to the bottom taking 40 - 60 sec, and surfacings taking 20 - 60 sec. It is interesting to note that in some cases surfacing events were measured by the sonics, but not the radios. This suggests that the surfacing data measured with radios overestimates the duration submerged and underestimates the amount of time spent at the surface and number of dives.

Summary[8]

At least some of the loggerhead turtles in St. Simons Sound were residents for up to 5 days during June 1991. The turtles spent the majority of time at the bottom of channels, drifting with currents, probably foraging. The use of channels as opposed to adjacent widespread shallow habitats was marked. Future studies should address the conflicts of surfacing events measured with sonic and radio telemetry. Since many of the dives measured with radio telemetry were under 60 sec, these should be considered surfacing events. The differences between surface and submergence times collected with radios should be compared with the same data but with dives less than 60 sec considered as surface time.

Behavior of Loggerhead Sea Turtles in Savannah, Georgia, and Charleston, South Carolina, Shipping Channels

Results[10]

A total of 31 loggerhead turtles were telemetered in Savannah, GA and Charleston, SC in 1993. Carapace lengths ranged from 50 - 95 cm (Figure 1,[11] Tables 1 - 4).[11] Two turtles were studied in the spring in Savannah, ten were studied in the spring in Charleston, nine were studied in the autumn in Charleston (one was recaptured and re-equipped), and ten were studied in the autumn in Savannah (Tables 1 - 8).[11]

Water temperatures

Surface water temperature in Savannah at the start of the spring project was 15.8 C, and bottom (>15 m) temperature was 12.5 C. At the end of the spring project, surface temperature was 18.3 C and bottom (15 m) temperature was 17.0 C. Surface water in Charleston at the start of the spring project was 23.8 C, and bottom (15 m) temperature was 19.0 C. At the end of the spring project, surface temperature was 25.5 C and bottom (>10 m) temperature was 23.2 C. Surface water temperature in Charleston at the start of the autumn project was 27.7 C, and bottom (>15 m) temperature was 27.8 C. At the end of the autumn project, surface temperature was 22.1 C and bottom (>10 m) was 22.3 C. Surface water temperature in Savannah at the start of the autumn project was 24.9 C, and bottom (>10 m) temperature was 23.4 C. At the end of the autumn project, surface temperature was 15.6 C and bottom (>5 m) temperature was 16.2 C.

Movements

(Compiler's note: detailed descriptions of movements of 30 turtles have not been reproduced here.)

Discussion[10]

Water temperature and turtle captures

The water temperature in Savannah during the spring project was below that usually accepted as the lower limit (15 C) where wild turtles are found (Keinath

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[10] This section of Chapter 4 was reproduced verbatim from Keinath, J. A., Barnard, D. E., and Musick, J. A. (1995), "Behavior of loggerhead sea turtles in Savannah, Georgia, and Charleston, South Carolina, shipping channels," Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

[11] Refers to tables or figures in Keinath, Barnard, and Musick (1995), not reproduced here.

1993), and the scarcity of turtles off Savannah in the spring reflects this. However, temperatures during the subsequent three projects were above 15 C, and turtles appeared to be abundant. Turtle behavior in cool water (basking at the surface, see below) also may have contributed to the minimal capture rate at Savannah (the trawl net only captured turtles near the bottom).

Movements

Of the 30 turtles tracked (Table 9),[11] six spent more than 10% of the time within channels (QQZ327 - 51%, SSB705 - 71%, SSB759 - 16%, SSB763 - 35%, SSB776 - 30%, SSB780 - 18 %). These results are consistent with studies done in Cape Canaveral in spring, summer, and autumn (Nelson and Shafer 1996; Standora et al. 1993a, 1993b) where few turtles stayed within channels. A study in St. Simons Sound, GA during the early summer (Keinath, Barnard, and Musick 1992) showed that some turtles exited the area, but some stayed well within the channels. However, turtles tracked in Chesapeake Bay usually stayed in the channels of tributaries of the Bay (Byles 1988). It is probable that many of the turtles off the southeast coast, especially in the spring and autumn, are migrating through the area to reach oversummering and overwintering areas (Keinath 1993), but turtles in Chesapeake Bay were summer residents which occupied well defined ranges (Byles 1988).

Diving behavior

Diving behavior was variable within, as well as between turtles (Table 10).[11] All turtles spent more overall time per dive cycle submerged than at the surface. This behavior is consistent with other studies along the east coat of the United States (Byles 1988; Keinath 1986, 1993; Keinath, Barnard, and Musick 1992; Nelson and Shafer 1996; Renaud and Carpenter 1994; Standora et al. 1993a, 1993b). Turtles tracked in the spring in both sites spent more time at the surface and less time submerged per dive cycle, as opposed to the autumn tracks. This behavior was probably due to cool water temperatures, with turtles basking at the surface and making short dives to forage. Other studies found most turtles spent more time both submerged and at the surface at night as compared to day, whereas we had a number of turtles which showed varied behavior between day and night.

The two turtles tracked in Savannah in the spring had large surface times, and did not stay at the bottom for long periods. These behaviors were probably due to the cool water temperatures, especially at the bottom. These turtles were most likely basking to absorb heat, and then making short forays to the bottom to feed. Similar behavior has been observed off Virginia when a strong thermocline was present (Keinath and Musick, unpublished data).

Of the remaining turtles tracked off Charleston and Savannah, all but two turtles spent the majority of the time at the bottom, as is consistent with other studies (Byles 1988; Keinath, Barnard, and Musick 1992; Nelson and Shafer 1996; Renaud and Carpenter, 1994; Standora et al. 1993a, 1993b). The two exceptions (QQZ310, Charleston, spring; SSB701, Charleston, autumn) were turtles that stayed near the surface for the entire monitoring period. These turtles did not appear to have been injured in the trawling process, however trawling may have affected the diving behavior of the turtles since water temperatures were not cool enough to deter turtles from foraging at the bottom. A loggerhead captured by trawl off North Carolina appeared to have excess gas in the intestines that prevented the animal from diving normally until about four days after capture (Musick, unpublished data).

Summary[10]

Turtles captured in shipping channels rarely remained within the channels after release. Most either went offshore into deeper water, traveled to shallow water adjacent to the channels, or vacated the area. Turtles appear to avoid water temperatures below 15 C. At temperatures near 15 C turtles spend more time at the surface, probably basking, and make short forays to the bottom. Except in very few instances turtles spent little time within the water column - only when ascending or descending. In water temperatures over approximately 19 C, turtles spend the majority of the time at the bottom, probably foraging for benthic prey.

Subadult Loggerhead Behavior in Kings Bay, Georgia, USA

Methods[12]

This study was conducted in the Fernandina Harbor entrance channel (Kings Bay) located on the southeastern Atlantic coast on the boundary line of the states of Florida and Georgia. Turtles were captured by conducting repetitive 15-30 minute (total time) tows in the channel. The trawler was fitted with two 60 foot trawling nets constructed from 8 inch mesh (stretch). All captured turtles were identified, measured, and tagged on each front flipper with a NMFS inconel tag. Trovan Passive Integrated Transponder (PIT) tag was injected subcutaneously in the wrist area of the right front flipper. Measurements were taken according to protocol detailed in Pritchard et al. (1983). At a minimum, straight line length, straight line width, tail length, and weight were taken. Turtles were released back into the channel near the point of capture as soon as possible following measurement and tagging. Captured turtles were instrumented with both radio and sonic transmitters for biotelemetry studies. The radio and sonic tags were embedded in syntactic foam for flotation and attached to a tether. The tether with an erodible link and breakaway link were attached to the posterior marginal scute of the turtle. The vertical position of the turtle in the water column was recorded through the use of depth sensitive sonic transmitters.

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[12] This section of Chapter 4 was reproduced verbatim from Nelson, D. A. (1993), "Subadult loggerhead behavior in Kings Bay, Georgia, USA," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

Telemetry studies were conducted continuously for approximately 30 days during the spring, summer, and fall seasons. 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 variance (ANOVA) with alpha set at 0.05. All time intervals were measured in seconds. Raw data were first transformed prior to analysis. Surface and bottom interval data were transformed using the log(x + 1) 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 SPSS for Windows version 6.1.

Results and discussion[12]

The percent of time spent on the bottom for spring was less than for summer or fall (Figure 1).[13] Percent of time spent at mid-water depths and at the surface was greater in the spring than in the summer or fall. The percent of time spent at mid-depth primarily reflects ascent and descent time, although turtles monitored during spring spent a higher percent of time at mid-depths than during other seasons.

The 24 hour day was divided into 6 each 4 hour time groups beginning at 00:01 and ending at 24:00 (Figure 2).[13] Bottom time was largest from 20:01 to 04:00 (night) and significantly less from 08:00 to 16:00 ($p \leq 0.05$) (day). Dawn (04:01-08:00) and Dusk (16:01-20:00) had mean bottom times intermediate between day and night.

Diving patterns varied widely among individual turtles. Mean bottom time for all turtles combined was 1557.1 $\pm$ 71.5 seconds (n = 844, mean, $\pm$ SE). Mean surface interval was 169.8 $\pm$ 14.0 seconds (n = 1150, mean, $\pm$ SE). Mean bottom time was significantly greater in fall (3258.6 sec, SE = 216.7, n = 222) than in the spring (983.0 sec, SE = 143.4, n = 101) and summer (943.1 sec, SE = 30.3, n = 521) ($p \leq 0.05$) (Figure 3).[13] Mean surface time was significantly greater in the spring (510 sec, SE = 98.4, n = 131) than in the fall (203.9 sec, SE = 25.7, n = 271) and summer (97.8 sec, SE = 6.7, n = 6.7) ($p \leq 0.05$) (Figure 4).[13] Mean surface time in the fall was significantly greater than mean surface time in summer.

Additional analyses are being conducted, but preliminary results suggest that if the dredging season must be expanded outside the winter season, spring is when turtlers spend less time on bottom thus less susceptible to entrainment.

[13] Refers to tables or figures in Nelson (1993), not reproduced herein.

5 Acoustic-Detection Investigations

Introduction

The purpose of this research task was to investigate the feasibility of using acoustical methods for remote detection and identification of turtles. No published literature existed on this technique at the initiation of the STRP. Exploratory concepts were based on fundamental acoustical ideas and experience with acoustic detection of other marine animals (fish locators). Specific objectives of this research were to identify the biological and acoustical issues involved in acoustic detection of sea turtles and to identify approaches that warranted additional investigations.

Acoustic measurements were obtained from live loggerhead turtles during large-scale field tests at Belle Chasse, LA. SubSea International provided a dive tank, crane, and assistance with data collection. Loggerhead turtles were provided on loan from the Aquarium of the Americas, New Orleans, LA; Indianapolis Zoo, Indianapolis, IN; Toledo Zoo, Toledo, OH; Columbus Zoo, Powell, OH; Virginia Institute of Marine Science, Gloucester Point, VA; and the Gulfarium, Fort Walton Beach, FL. Limuli Lab, Cape May Courthouse, NJ, donated horseshoe crabs used in tests to discriminate between sea turtles and horseshoe crabs. The Aquarium of the Americas also provided housing and care for the turtles and crabs, and services of the Aquarium of the Americas volunteer diver program.

The acoustic-detection investigations were conducted by Kasul and Dickerson (1993). Appropriate sections of that document pertaining to acoustic detection are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the study are given in the original document.

Feasibility of Sampling Sea Turtles in Coastal Waterways with Sonar

Introduction[14]

(Compiler's note: repetitive background material has not been duplicated here.)

The purpose of this paper is to explore the feasibility of using acoustical methods to remotely detect and identify sea turtles. Since no published information exists on the acoustic detection of turtles, we draw on fundamental acoustical ideas and on experiences with acoustic detection of other marine animals, particularly fishes. The objectives of this paper are to identify the biological and acoustical issues involved in acoustic detection of sea turtles and to identify approaches that may warrant additional investigation. We also present the results of some acoustic measurements collected from loggerhead sea turtles. These provide a starting point for empirically examining the acoustic characteristics of sea turtles.

(Compiler's note: acknowledgment of research associates has not been duplicated here.)

Information needs[14]

A reliable remote sensing survey method must be able to consistently detect sea turtles in their natural environment, and with very high accuracy, it must be able to distinguish sea turtles from other objects in the sea. The dual requirements of detection and identification create two different sets of demands on the remote sensing method.

Sea turtles are large compared to many marine organisms that are sampled acoustically, so detecting one that has been ensonified in a sonar beam should not challenge virtually any available sonar technology, at least not when the turtle is in open water and clear of other echo producing objects. The challenges of sea turtle detection involve acoustical limitations associated with detecting them on the seabed or at the surface and the practical limitations of sampling for rare objects in a large waterbody. Both of these are minor challenges compared to the challenges associated with distinguishing detections of sea turtles from those of other underwater acoustic scatterers.

Many objects in the sea are detectable on sonar. Fish may be especially numerous but there are also many other marine animals and nonliving acoustic scatterers in the water column and on the seabed that are detectable to sonar. In a typical sonar survey in coastal waters these may produce hundreds of detections per survey

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[14] This section of Chapter 5 was reproduced verbatim from Kasul, R. L. and Dickerson, D. D. (1993), "Feasibility of sampling sea turtles in coastal waterways with sonar," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

hour. The primary challenge associated with sonar surveys is to accurately and reliably distinguish sea turtles from all other acoustic scatterers. The method must have a very low misclassification rate. To be useful, it should not frequently identify a turtle as some other target. Perhaps more importantly, it should seldom misclassify one of the many animals and objects in the sea as a turtle. Because of the large number of sonar scatterers that can be encountered during a sonar survey, false positives occurring even a fraction of one percent of the time can create the false impression of a large turtle population. Consequently, the primary challenge in remote sensing for sea turtles is in developing a very reliable turtle identification method.

Maximum dorsal aspect target strength of loggerhead sea turtles and horseshoe crabs[14]

Introduction

Target strength is used to establish echo amplitude criteria for target identification and for setting minimum and maximum threshold amplitudes for rejecting non-target echoes. It is often the one echo characteristic that is widely obtained for many types of sonar targets. As a result it is often the basis for comparing echo reflecting characteristics of different types of scatterers, especially among biological targets. In addition a knowledge of the target strength of objects of interest is essential to the effective design and operation of an active sonar system for use with that particular object.

The target strength of an object is a measure of the object's inherent ability to reflect sound. Because it is a large target composed of some quite reflective materials, we expect the target strength of sea turtles to be large compared to many other acoustic scatterers that occur in coastal marine waters. As a result, target strength can be useful in helping to isolate and identify turtles detected in sonar surveys.

These data were collected to document the dorsal aspect target strengths of loggerhead sea turtles found in coastal shipping channels, to document dorsal aspect target strengths of the horseshoe crab that occur with turtles, and to determine the relationship between target strength and carapace length of turtles and horseshoe crabs. Finally, these data are used to explore how well target strength may discriminate sea turtles and other known acoustic scatterers.

Methods

Echo returns were collected from 6 live loggerhead sea turtles that ranged in size from approximately 30 to 85 cm straight carapace length (*SCL*) and from 5 horseshoe crabs (4 alive and 1 recently moribund) that varied from 16 to 30 cm *SCL* (Table 2).[15] The turtles originated from Atlantic coast stocks in Florida and Virginia. They were obtained on loan from zoos, aquaria, and research facilities in

[15] Refers to tables or figures in Kasul and Dickerson (1993), not reproduced here.

several states. The horseshoe crabs were obtained from the Atlantic coast in Virginia and Florida.

The acoustic data were collected from 1-4 September 1992 in a 9.1 m deep by 15.2 m diameter cylindrical steel dive tank contributed by SubSea International, Belle Chasse, Louisiana. Specimens were moved to the study site as needed from temporary holding facilities located a few miles away at the Aquarium of the Americas, New Orleans LA. On arrival at the dive tank, turtles were fitted with a sparse nylon body harness attached with four 4-m long nylon monofilament tethers. They were then placed into a cargo box and lifted into the tank with an industrial crane for a variable acclimation period. Horseshoe crabs were treated similarly except they were wrapped in nylon monofilament netting with monofilament tethers and they required no acclimation in the tank.

Data were collected from one animal at a time. Four divers, each controlling the free end of a tether, positioned the animal over the center of the transmit beam at a depth of approximately 8 m. Animals were ensonified while loosely restrained in this manner. The tethers allowed divers to control the animals movements while maintaining their own body positions outside the main lobe of the transmit beam. By controlling the turtles in this manner the diver's contribution to echoes from the turtles was negligible. Data from the 5 largest turtles were collected on two dives each of 4-6 minutes duration. Data from the smallest turtle were limited to one dive of 3 ½ minutes. Approximately 8-10 minutes of data from a single dive were collected from each crab.

Acoustic data were obtained with a calibrated Biosonics Model 102 Echo-sounder matched to a dual-beam transducer with 10/22 degree beamwidths associated with the transmit/receive and receive channels, respectively. The transducer was supported in the center of the tank just below the water surface and aimed downward toward a marker on the bottom that identified the exact center of the transmit beam. Animals were ensonified in freshwater at a rate of 2-5 pings per second using a source level from 209 to 219 dB || µPa re 1 m and a 0.5 millisecond pulse length. At the receiver, a 40log(R) Time Varied Gain and constant system gain were applied to echo signals. The signal was also bandpass filtered to a 5 kHz bandwidth around a 120 kHz center frequency and recorded on digital tape.

The maximum target strength of each animal was calculated from the highest amplitude echo with the sonar equation

$$TS = V_n - SL - G_1 + RG$$

where

TS = maximum target strength in decibels

V_n = narrow beam echo amplitude

SL = projector source level

G_l = receiving sensitivity at 1 m

RG = receiver gain during data collection

Calculated target strengths for two of the turtles were increased by 1.5 dB and those for all crabs were increased by 2.1 dB to compensate for apparent increases in the rate of sound attenuation associated with plankton growth in the dive tank on the last two days of data collection. Adjustment values were estimated from changes in the observed target strength of a calibration sphere over the course of the data collection period. Decreases in the estimated target strength of the sphere coincided with visible decreases in water clarity resulting from increased phytoplankton levels that followed dechlorination of the water prior to the start of data collection.

Results and discussion

The maximum dorsal aspect target strengths of six loggerhead turtles measuring 30 to 85.5 cm *SCL* varied from -18.9 to -9.9 dB. Acoustic size increased linearly with turtle body size in a manner consistent with the backscattering relationship $\sigma_{bs} = A\,\zeta_{bs}$. In target strength form, the relationship between dorsal aspect target strength in dB and turtle carapace length *SCL* in cm was established by linear regression as

$$LOG_{10}(\text{Length } SCL) = 2.404 + 0.046(TS)$$

with an associated R^2 of 0.95. This relationship suggests a useful way to predict the length of loggerhead turtles from target strength measurements as is often done for fishes (Love 1971).

The target strengths of five horseshoe crabs measuring 18.5 to 28 cm *SCL* varied from -26.7 to -19.6 dB. The relationship between target strength and carapace length *SCL* was estimated to be

$$LOG_{10}(\text{Length } SCL) = 2.316 + 0.038(TS)$$

with a R^2 of 0.88.

A plot of the relationships between target strength and carapace length (Figure 1)[15] suggests that for the same length *SCL*, loggerhead turtles are approximately 2 dB larger than horseshoe crabs. The larger target strength of turtles is consistent with the larger surface area projection associated with the greater width of the turtle (Table 2).[15] Large interior air cavities present in the lungs of the turtles but absent from the crabs may also contribute to the differences in target strength between the two species.

The estimated relationship between target strength and carapace length indicates the 45 to 110 cm loggerheads that are found in coastal shipping channels have dorsal aspect target strengths ranging from approximately -16 to -8 dB. The most commonly found sizes from 50 to 75 cm *SCL* would have corresponding target strengths from approximately -15 to -11.5 dB. Horseshoe crabs not exceeding 35 cm carapace length *SCL* are expected to have dorsal aspect target strengths not exceeding about -20 dB. Therefore, target strength may usefully aid discrimination of loggerhead turtles and horseshoe crabs.

Fishes are among the most numerous acoustic targets in coastal waters. Love (1971) estimated that for 120 kHz ensonification, fish length in cm can be predicted from maximum dorsal aspect target strength by

$$LOG_{10}(\text{Standard Length}) = 3.344 + 0.052(TS).$$

From this equation, fish varying in length from 10 to 100 cm have associated dorsal aspect target strengths of about -47 to -28 dB. Fishes without air bladders have expected target strengths that are 10 to 15 dB lower than these values (Foote 1980). Except perhaps for very large jewfish, few bottom fishes would be expected to have target strengths approaching those of subadult loggerheads. As a result, most fish can probably be distinguished from sea turtles based on echo amplitude measurements.

Summary and conclusions[14]

Loggerhead, Kemp's ridley, and green sea turtles are the species most likely to be found in trawl surveys of harbors and shipping channels. Loggerheads are by far the most numerous. They are typically found in sizes from 45 to 110 cm SCL, but they are most abundant in sizes from 55 to 75 cm SCL. Sea turtles collected from shipping channels that are approximately 30 to 45 cm SCL are most likely to be Kemp's ridleys.

Sonar-based sampling of these species and sizes of sea turtles in harbors and coastal shipping channels requires methods for both target detection and identification. The technical and practical requirements of these two functions are different, therefore feasible sampling approaches may require several types of information obtained by more than one sensing technique.

Detection of sea turtles does not appear to be acoustically challenging in a channel environment where the water column is unobstructed by aquatic vegetation and there is reasonably distinct water-seabed interface. But two detection needs must be addressed. First, the method must be able to detect turtles on the seabed, where in the summer months, they may spend 80 percent of their time. Also, since sea turtles may be present in low density, a detection method with a wide search area in water 4-10 m deep is advantageous. High-resolution sector-scanning sonars designed for use in shallow water may address the most important detection needs.

The success of a remote sensing method for turtles will depend mainly on the reliability of target identification. Very reliable target classification and identification methods are needed to distinguish sea turtles from a large number of other acoustic scatterers found in coastal waterways. In the water column, fish can be extremely abundant. On the seabed, demersal animals and various forms of debris will occur with turtles. Of particular interest are the horseshoe crabs that loggerhead turtles are found with and feed upon extensively. Horseshoe crabs occur in the same areas and habitats as loggerheads, and are similar in body shape and overlap in size with sea turtles. Horseshoe crabs may indicate the presence of sea turtles, but the two must also be distinguishable from one another.

Unlike marine targets such as zooplankton and fishes where extensive data exist, no previous acoustic data have been reported for sea turtles. Consequently, there is no body of empirical knowledge to help direct efforts at turtle classification. To develop this capability, there is a need both for basic acoustic backscattering data on turtles and for applied efforts on likely approaches to acoustic target identification. A number of approaches used singly or in combination may provide reliable identification data. Some methods appear promising but may require a long time for development of concepts and hardware. Other methods use existing approaches but their merits for this application have yet to be demonstrated. While other methods exist, at least four approaches to sea turtle identification seem to warrant additional investigation.

One approach exploits the dependence of target strength on sonar transmission frequency to produce spectral signatures that are characteristic of different aquatic animals. Encouraging results have been obtained with fishes, but the method is still experimental and requires additional development and verification.

A second approach applies high resolution sonar imaging to obtain recognizable sonar pictures. Industrial and military applications of sonar imaging are used for target identification. The availability of commercial and specialized instrumentation for imaging may allow for rapid implementation provided that target identification can be made with a reasonably high degree of certainty.

A third approach that may assist sea turtle identification involves observing the behavior of targets tracked inside of the acoustic detection beam. Sonars that cover a large area with high resolution (make) it possible to track targets inside the beam over time. Since benthic-feeding turtles spend most of their time on the bottom and since they surface regularly to breathe, there are behavioral expectations that can be used to help distinguish turtles from other targets.

Finally, the acoustic characteristics of echoes detected in a sonar search may also assist in target identification. Target strength, pulse shape, and pulse elongation have all contributed to successful identification of certain targets. Since target strength is often widely obtained for many type of sonar targets, it is a particularly valuable characteristic for screening and initial separation of objects, and in some cases, for target identification. A knowledge of target strength is also needed for the proper design and operation of the sonar detection system.

As part of this study, we experimentally determined the acoustic target strength of loggerhead turtles in sizes commonly found in coastal shipping channels. The data indicate that the dorsal aspect target strength of loggerhead turtles 45 to 110 cm *SCL* varies approximately from -16 to -8 dB with 120 kHz ensonification. These values are considerably larger than the dorsal aspect target strengths of nearly all fishes expected in shallow coastal waterways. We also found that the target strength of loggerhead turtles are about 2 dB larger than the target strength of horseshoe crabs having the same carapace length. Since horseshoe crabs seldom exceed 35 cm *SCL*, their maximum target strength is at least 4 dB lower than the smallest loggerhead turtles that are typically found in coastal channels.

Variations in the target strengths of both loggerhead turtles and horseshoe crabs were associated with variations in turtle size. Regression equations describing this relationship suggest that physical size can be estimated from target strength measurements.

These data suggest that loggerhead turtles in sizes typically found in coastal waterways can be acoustically separated from most other aquatic animals on the basis of echo amplitude. Amplitude-based criteria are probably not adequate as a sole means of sea turtle identification, but they may be used effectively in conjunction with additional identification criteria to provide acceptably accurate turtle identification.

6 Bioacoustic Studies

Introduction

The Sea Turtle Research Program (STRP) was a multifaceted research project designed to eliminate adverse impacts to turtles by hopper dredging. The research included trawling, telemetry, draghead modifications, acoustic detection, and acoustic-dispersal feasibility studies. Prior to developing techniques for acoustic dispersal of sea turtles, it was necessary to ascertain the auditory responses of turtles to sound stimuli. Just 20 years ago, it was believed that sea turtles could not hear at all. In order to repel sea turtles using sound, the source intensity, frequency range, and frequency modulation that stimulates the turtle's acoustic receptors had to be determined.

While all of the research program facets had primary emphasis on sea turtles, simultaneous other investigations were necessary on certain marine mammals during the bioacoustic studies. Any deterrent techniques developed to repel sea turtles must also be assessed to determine any detrimental effects on other marine animals in the vicinity. The West Indian manatee is a marine mammal of primary concern because it travels the same nearshore coastal waters as sea turtles and may be susceptible to sound-pressure levels necessary for repelling turtles.

As part of the bioacoustic studies, auditory-evoked potentials of the loggerhead sea turtle were investigated by Moein (1994). An evaluation of the response of loggerhead sea turtles to a fixed sound source was conducted by Lenhardt et al. (1994). An auditory assessment of the West Indian manatee was performed by Gerstein (1994a). Appropriate sections of those documents pertaining to bioacoustics of sea turtles and manatees are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the studies are given in the original documents.

Auditory Evoked Potentials of the Loggerhead Sea Turtle (*Caretta caretta*)

Abstract[16]

Repulsion from hopper dredges using auditory stimuli is one frequently proposed solution for reducing incidental mortalities of sea turtles. However, before this tactic can be assessed, research must first be performed on the auditory mechanism of sea turtles, an area underdeveloped in the literature. In this study, threshold for response to stimuli and the effects of stimuli and white noise on the threshold were determined for the loggerhead sea turtle, *Caretta caretta*.

Thirty-five juvenile loggerhead turtles caught in the Chesapeake Bay were used in this study. A computer capable of delivering stimuli and receiving bioelectric activity via electrodes implanted in the loggerhead sea turtle was used. Either a low frequency broadband click or tone bursts (250, 500, 750 or 1000 Hz) were delivered by a bone vibrator to the turtle's tympanum. Intensity and frequency of stimulus was manipulated for the threshold experiment. Rate of stimulus presentation and intensity of white noise were manipulated for the rate and masking experiments, respectively.

The maximum sensitivity was in the low frequency region of at least 250 to 1000 Hz with a maximum sensitivity at 250 Hz of -24.4 dB re: 1 gravity unit. The broadband click produced clear auditory response with a mean threshold of -10.8 dB re: 1 gravity unit and 8.5 dB re: 1 dynes/cm^2. In the rate experiment, interpeak latencies for peak I and peak V were significantly dependent on rate. In the masking experiment, signal to noise ratios ranged from -3.5 to -8.5 dB ($x = -5.2 \pm 2.4$).

The broadband click stimuli elicited synchronous neural activity of the hair cells and was determined to be the most efficient stimulus to use when recording threshold from the loggerhead sea turtle. An increase in the stimulus rate resulted in the disruption of neural synchrony and thus interpeak latencies increased with rate of stimulus. Finally, loggerheads appear to be able to resolve the stimulus through a high level of white noise. These techniques of auditory evoked potentials may be utilized in two fields of applied research; (a) the development of an acoustic repelling device, and (b) the identification of diseases of the brain of sea turtles.

Introduction[16]

(Compiler's note: background material pertaining to auditory evoked potential has not been reproduced here.)

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[16] This section of Chapter 6 was reproduced verbatim from Moein, S. E. (1994), "Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*)," thesis presented to the faculty of the School of Marine Science, College of William and Mary, Gloucester Point, VA, in partial fulfillment of the requirements for the Degree of Masters of Arts. Research funded by U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

The objectives of this project were threefold; (a) collect auditory evoked potentials from loggerhead sea turtles to determine threshold of response for both tone bursts and click stimuli, (b) test the stimulus rate as presented to the loggerhead for its effect on the I-V interpeak conduction time, and (c) test white noise for its ability to mask the stimulus and render the stimulus inaudible. These goals were achieved by laying out a methodology for collecting evoked potentials from sea turtles.

Discussion[16]

Threshold

The recording of the auditory evoked potentials for tones became very difficult due to the inability of attaining discernible and repeatable responses and only data from six turtles could be recorded. However, the click, a composite of all of the individual tones tested, produced consistently clear responses. This lack of agreement among the tone and click data is thought to be a result of the nature of the stimuli as well as the recording techniques used to attain responses. The responses recorded in this project are reflections of the synchronous discharge of neural fibers found at the base of the hair cells. Hair cells are the sensory receptor cells responsible for converting the motion of the basilar membrane into an electric signal which is then received by the auditory nerve (Yost & Nielsen 1977). Each hair cell contains a filter and thus the cell is tuned selectively to a narrow band of frequencies (Crawford and Fettiplace 1980; Fettiplace and Crawford 1980). A transient stimulus, such as the broadband click, initially stimulates the basal end of the cochlea, the site of synchronous activity of neural fibers. The low frequency tone burst, however, appears to stimulate the apical end of the cochlea and thus elicits an asynchronous response of the neurons. If this is the case, and the techniques for auditory evoked potentials record the synchrony of the neural discharge, then the efficiency of the click over the tone burst is apparent.

Another possible problem in recording tone burst data could be related to the volume of the neural response. This problem becomes evident when examining the placement of the electrodes. The loggerhead skull is composed of many layers of thick bone. By stimulating a small portion of the hair cell population with the tone bursts (only those hair cells tuned to the central frequency of the tone), it is possible that the resulting electrical signals were not strong enough in all cases to travel through the bone to the electrodes. Yet by stimulating a larger set of hair cells with the broadband click (a composite of five frequencies), I was able to collect a clear peak V that was trackable in nearly every turtle tested. Due to the loggerheads' protected status, however, I was unable to place the electrodes anywhere but unintrusively on top of the skull.

The frequency range of response found in this project can be compared to a study by Ridgeway et al. (1969) in which they examined the threshold levels of the green sea turtle. Ridgeway et al. tested tones on the green sea turtle from 30 to 700 Hz and found the maximum sensitivity to fall between the 300-500 Hz frequency range. I found similar results with the tone burst data. Using a variety of stimuli, the maximum sensitivity fell between 250-1000 Hz. The computer was unable to test below 250 Hz so I am unable to speculate on the low end of the loggerhead's sensitivity. However, I was able to test up to 8 kHz and found that over 1000 Hz the sensitivity fell off drastically.

Comparing the sound pressure data from the green sea turtle (Ridgeway et al. 1969) to loggerhead sea turtles, a larger discrepancy is found. Ridgeway et al. (1969), using tones, found the sound pressure in dynes/cm^2 to range from -5 to -35 dB for the 100-700 Hz range. I could only record the sound pressure level successfully for the click, a stimuli which encompassed approximately the same frequency range, and found the mean threshold to be 8.5 dB re: 1 dyne/cm^2. This dissimilarity of results can possibly be explained by a difference in recording techniques. Ridgeway collected cochlear potentials with electrodes surgically inserted into the paralymphic spaces. This technique would allow for greater detection by the electrodes. This disparity of results could also be explained by a dissimilarity between species. However, I do not believe that recordings using sound pressure levels in air as a reference are appropriate when collecting data from sea turtles. I ran this calibration in the laboratory so that my results could be compared to the limited published research on turtle hearing sensitivity. However, there is convincing research which strongly suggests that sea turtle auditory perception is through bone rather than air conduction. The tympanum appears to be a poor aerial receptor, and displacement of the columella was not significantly changed by the removal of the tympanum (Moffat and Capranica 1978). Furthermore, except for females nesting on the beach and green sea turtles basking in the Pacific, sea turtles spend the majority of their time underwater (Keinath and Musick 1993) and thus it would be unlikely that the sea turtle would have a developed and functional air conduction hearing mechanism. The bones of the shell and skull, much denser than sea water, could serve as a receptor for vibrations in underwater sound fields (Lenhardt et al. 1983). In this scenario the tympanum is displaced outward as a mechanism for the release of the columella rather than inward as an air conductive sound receptor. Consequently, the use of vibratory stimuli, placing a vibrator against the turtle skull and relaying stimuli through the bone, is a more appropriate technique and likely to result in a more accurate measure of the sensitivity of the sea turtle hearing mechanism. Ideally, recording of auditory evoked potentials in an underwater environment large enough to eliminate the harmonics due to reflection of sound would result in thresholds more representative of the turtle's true hearing ability.

Loggerheads' ability to detect low frequency sound has been theorized to be involved in natal beach homing behavior (Dodd 1988). Tagging data reveals that adult females repeatedly return to the same nesting beach, and possibly the same beach from which they hatched. Furthermore, it has been recorded that surf waves have a signature sound distinct to each beach (Bowen et al. 1993). The sounds of the beach may be distinct enough to serve as a cue for loggerheads when nesting. However, this theory implies that the turtle is able to discriminate between frequencies, a feature of sea turtle hearing that has not yet been investigated.

Repetition rate

Auditory evoked potentials reflect synchronous electrical activity and thus, as found in the threshold section of this study, clicks represent the best stimulus for evoking the synchronized response. Of all of the peaks (Jewett bumps) found in these recordings, I was most interested in peak I and peak V. Latencies of these peaks are a convenient and useful measurement for evaluating auditory evoked potentials. Absolute latencies are variable depending on a number of factors, including temperature and stimuli intensity. However the interpeak latencies, the time between the firing of two peaks, is a consistent and reliable response among individuals.

The direct dependency of latency on rate reflects the reduction in efficacy of the stimulus with an increase in click rate to activate a synchronous progression of the signal down the auditory pathway. After the neuron discharges, it remains in a refractory period, a period of no activity. This refractory period limits the number of times the neuron can discharge in a second. With an increasingly high rate of the stimulus, the neurons were unable to respond in a synchronized fashion and thus the signal required a longer period of time to activate the path.

An application for the interpeak latencies could be the identification of brain lesions. In the medical field, auditory evoked potentials have been used extensively in human diagnostic techniques to identify brainstem disorders and lesions (Markand 1994). In patients who show no clinical symptoms, auditory evoked potentials have been capable of detecting lesions of the brainstem in one third of the cases. A common abnormality observed is the prolongation of the interpeak latency of peaks I and V.

This same diagnostic technique may be applicable to sea turtles. Recently, a new disease of the brain of loggerheads has been identified as Giant Cell Meningoencephalitis (GME) (George, Wolke, and Keinath, in press). GME has been identified by necropsies performed on loggerheads who exhibited signs of central nervous system disorders: lethargy, inactivity, and uncoordinated movement. The lesions were found in the regions of the medulla, optic lobe, and cerebellum. This disease goes undetected until symptoms are severe (George, Wolke, and Keinath, in press). However, it may be possible to test clinically for this brain lesion in loggerheads before the lesion becomes symptomatic. From the rate experiment we know that the interpeak latencies are convenient to measure and consistently increase with the rate of the stimulus. By developing a baseline for conduction time for peaks I and V in normal turtles, abnormalities in the interpeak latencies may allow researchers to examine the occurrence and possible treatments for GME brain disease.

Masking experiment

Signal detection for marine species can be masked by the often high level of background noise found in the oceans. Ambient noise in the oceans can arise from a number of sources, including surface waves, seismic activity, shipping, and biological activity. The frequency range of ambient noise is often localized in the low frequency end of the spectrum (Hawkins and Myrberg 1983), the range at which loggerheads hear. Thus it is possible that ambient noise actually designates the limit at which loggerheads can detect an acoustic signal.

This masking experiment investigated the limits at which the loggerhead can distinguish a signal through ambient noise by examining the point at which the noise disrupts the synchrony of the neural response. The white noise used in the study was composed of a similar spectrum as that found in the click. Masking is most effective in concealing a signal which contains the same frequencies and thus this scenario was constructed to produce the highest level of masking.

These results, a signal to noise ratio of -5.2 dB re: 1 gravity unit, may prove to be misleading. The click stimulus is a broadband spectrum of energy as is the white noise. The difference between the two, however, is that white noise is steady with all possible frequencies represented equally (Gelfand 1990) while the click, when activated by the bone vibrator, has a transient character. This transience, an abrupt on and off sound, can cause the vibrator to resonate around a single frequency (Green 1976). Consequently, the overall click decibel levels, as calculated by the accelerometer, may be an underestimate of the actual amount of intensity at a particular frequency, the resonant frequency.

Even with this apparent exaggeration of the signal to noise ratio, these results do confirm that the loggerhead has the ability to distinguish a signal through ambient noise, possibly at a relatively high level of noise. An adaptation of the hearing mechanism to reduce interference from noise would certainly be advantageous for the sea turtle. Due to the high and variable level of ambient noise centered around the low frequency range in the oceans, signal detection would only be possible if the sea turtle were able to discriminate sound through an elevated level of noise.

Conclusions

This study represents one of the first steps in understanding the loggerhead's hearing mechanism. The methodology for collecting auditory evoked potentials from loggerhead sea turtles was developed and threshold levels were measured. Auditory responses for loggerheads were most sensitive from at least 250 to 1000 Hz. Secondly, the latencies of peak I and peak V were dependent on the rate and thus the interpeak latency increased with the increase in stimulus rate. Finally, loggerhead sea turtles appear to be able to distinguish signals through a relatively high level of ambient noise.

At present, evoked potential methods may be utilized in two fields of applied research; (a) in the development of repelling devices, and (b) in the identification of diseases. To return to the initial catalyst of this study, repelling devices are being developed to repel turtles away from areas where human activities place them in danger. The conclusions of this research can certainly define the frequencies and intensity for a possible repelling device. Moreover, the methods of evoked potentials laid out by this project can be used as a tool to protect the sea turtle during the development of repelling devices. Researchers have an obligation to conduct their studies unintrusively and to insure that damage is not being caused to the species they are trying to protect. By examining the threshold levels of an individual before and after testing a potential repelling device, the researcher can take precautions to avoid damage to the turtle's hearing mechanism. These methods may also prove beneficial to the further identification of brain diseases, such as Giant Cell Meningoencephalitis. If able to detect GME before the onset of symptoms, it might be possible to record the progression of the disease as well as test possible drugs as curative agents.

There are, however, many questions about sea turtle hearing yet to answer. Does the threshold to vibratory stimulus change when the turtle is submerged? The first step is to perform electrophysiological trials in a tank, one which is large enough to prevent the reflection of low frequencies. The second question which arises from this research is whether the loggerhead uses hearing in nature and why. Is the loggerhead ear a useless vestige or does hearing play a role in the turtle's life history? The use of hearing by sea turtles can be investigated by performing underwater localization experiments to examine whether sea turtles can be conditioned to sound stimuli. Finally, do all sea turtles hear by similar methods, specifically bone conduction? How does the leatherback, a species which has exchanged its hard shell for a leathery one, hear? All of these questions may be answerable in the very near future.

Evaluation of the Response of Loggerhead Sea Turtles (*Caretta caretta*) to a Fixed Sound Source

Introduction[17]

(Compiler's note: repetitive background material has not been duplicated here.)

The Army Corps of Engineers (COE) has proposed to use a fixed sound source acoustic stimuli to repel sea turtles from hopper dredges. Sound stimulation may produce behavioral responses in sea turtles but it is unknown if a response is repeatable and produces the desired effect, repulsion of turtles from a sound source. The purpose of this study was to document behavior to acoustic stimulation of unrestrained sea turtles swimming in a net in the York river and a tank.

[17] This section of Chapter 6 was reproduced verbatim from Lenhardt, M. L., Moein, S. E., Musick, J. A., and Barnard, D. E. (1994), "Evaluation of the response of loggerhead sea turtles (*Caretta caretta*) to a fixed sound source," Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

Materials and methods[17]

Net study

A net enclosure (approximately 18 m × 61 m × 3.6 m, 3.8 cm bar) was erected in the York River, VA to contain the turtles. The enclosure was stratified into two equal sections; near and far (Figure 1).[18] The USN J15 sound projector was suspended in the net at one end and was calibrated both by the laboratory (USN Orlando Underwater Reference Laboratory) prior to being shipped to the Virginia Institute of Marine Science and by the use of a F-37 USN hydrophone. By placing this calibrated hydrophone one meter from the source, output frequencies were confirmed. The output from the hydrophone was fed through a grounding circuit to a real time spectral analyzer for spectra calibration. Even order harmonics were recorded within the net.

Tonal stimuli were generated by the sound projector. Tone bursts of 250, 500, and 750 Hz were used. Rise and fall times were 30 cycles for the 500 and 750 tone bursts and 15 cycles for the 250 Hz tone burst. Tonal burst duration was approximately 120 ms at a repetition rate of 1.1 per second for five minutes. Interstimulus intervals were fifteen minutes.

Five loggerhead turtles were tested (Table 1).[18] This procedure was previously reported by Moein et al. (1994). A float was attached to the posterior end of the carapace of each turtle with a 3 m line so position could be monitored. For each test, a single loggerhead was placed in the enclosure and allowed to acclimate for one hour prior to exposure to stimuli. Relative movements were recorded for each turtle swimming in the net by observing the position of the float. Float position was taken in fifteen second intervals during the five minute trials.

Behavior after the initial firing of the horn was categorized into two types. If the turtle entered the zone adjacent to the sound source the response was termed an approach. If the turtle entered the zone opposite the sound source the response was termed an avoidance. The amount of time in each trial the turtle stayed in the sections of the net were also categorized. If the turtle stayed in a zone for at least 2.5 minutes (i.e., half of the trial or more), the response was either a sustained approach or sustained avoidance. However, if the turtle exhibited behavior of swimming from one end of the net and then back again repeatedly, this was considered non-directed swimming response. Response to the stimulus was analyzed using the nonparametric Cochran's Q test (Zar 1984).

Tank study

A large outdoor tank (6.9 m × 4.6 m × 1.3 m) in Gloucester Point, VA was used to contain the turtles (Figure 2).[18] The tank was divided into three sections; near, mid, and far from the source. The USN J15 sound projector was suspended in the

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[18] Refers to tables or figures in Lenhardt et al. (1994), not reproduced here.

tank at one end and was calibrated as in the net study. Harmonics were found to be present in the tank at octave intervals. When the hydrophone was placed in the far end of the tank (opposite the projector), the transmission loss from the projector to the far end was approximately 5 dB in the low frequencies examined (100-300 Hz) and approximately 2.5 dB for the remaining frequencies examined (400-2000 Hz). Thus when the sound pressure level was 178 dB at the source, the pressure was 173-175.5 dB at the far end of the tank. This tank was too small in reference to the wavelengths to produce pure tonal stimuli without amplitude changes (standing waves), distortions, and reflections (harmonics and subharmonics). However, because the water was clear, the tank study was utilized to directly observe any reaction to sound.

Five loggerhead turtles were tested (Table 2)[18] five separate times with at least two days between each test. Tone burst, noise bursts, and frequency sweeps (linear frequency modulation) stimuli were generated by the sound projector. A filtering system was used to keep the tank water clear and a video camera was mounted on scaffolding opposite the sound projector to record the turtle's reactions. Moreover, a concealed observer was used to monitor the turtle's behavior to the projector. For each test, a single loggerhead was placed in the tank and allowed to acclimate for at least half an hour prior to exposure to stimuli. Turtles were exposed to three different stimuli (250 Hz, 500 Hz, and white noise) in separate presentations with two replicates for each type of stimulus (six trials), with fifteen minutes of no stimulus between each trial. The order of presentation of the three stimuli was selected randomly prior to each test. Turtles were observed prior to, and post acoustic stimulation for the presence of startle responses or instant rapid movement of flippers upon sound presentation.

Auditory brainstem evoked response testing was performed in both the net and tank studies prior to testing to obtain a baseline auditory threshold and subsequent to testing to determine if hearing damage had occurred. The procedure was the same as described in Moein et al. (1994). Briefly, three needle electrodes were placed in the top of the head with a ground in the neck. Bioelectric energy was amplified, filtered, and digitally averaged. Electroencephalographic (EEG) energy was timed locked to the activation of a vibrator mounted on the ear, and summed by the computer. Using clicks delivered into the vibrator, the threshold of the physiological response of the ear was determined by gradually attenuating the vibrational energy. The lowest intensity that produced a repeatable neural response was the threshold. One animal used in the net study had an abnormal evoked response (QQM656/QQM657). Total deafness was unlikely since the latency landmarks were present but reduced in amplitude, nonetheless partial deafness could not be excluded.

Results[17]

Net study

In thirty sound trials in the net study, turtles initially moved toward the sound source (approach response) 13 times and away from the sound source (avoidance response) 17 times. The Cochran's Q test found no significant difference between avoidance and approach responses for the three tone burst stimuli. Moreover, non-directed swimming occurred 83.3 percent of the time.

Tank study

Of the 175 trials performed in the tank, startle responses were observed 14 times. It did not appear that any specific stimuli produced this startle response.

Evoked potential testing, carried out at the completion of testing for each animal, revealed no change in threshold or evoked waveform morphology. The one turtle with a reduced amplitude evoked responses prior to testing exhibited the same response post-test. Thus, there was no damage to the hearing mechanisms of the turtles due to testing.

Discussion[17]

The key concepts in applying the usefulness of this method to reduce turtle mortality during dredging operations are repeatable directional swimming responses by turtles. Neither directionality nor repeatability were observed with sound in the net or tank. Turtles showed no significant approach or avoidance behavior. Each turtle always continued in the direction it was headed when the sound projector was activated.

It can be speculated that the responses exhibited by the turtles could be a result of the confined nature of both the net and the tank. The next step should be to use telemetry to track turtles' behavioral response to a sound source in situ. Until unrestrained animal behavior is observed when approached by a moving sound emitter, any assessment of acoustic turtle repellants will be inconclusive.

Auditory Assessment of the West Indian Manatee (*Trichechus manatus*): Potential Impacts of Low Frequency Activities on Manatee Acoustic Behavior and Communication

Statement of the problem[19]

The U.S. Army Corps of Engineers (WES) is conducting a multifaceted research program to predict potential impacts on endangered and threatened sea turtle populations prior to dredging and to develop potential management strategies to minimize the effects of dredging on sea turtles. The program includes trawl sampling, telemetry studies, hydroacoustic studies and investigations into potential deterrent techniques to ward off sea turtles. Although all of these facets have primary emphasis on sea turtles, simultaneous investigations are necessary on certain marine mammals during the deterrent techniques studies. Any deterrent techniques developed for sea turtles must be assessed for the effects on the marine mammals occurring in the same locations. The West Indian manatee is an endangered marine mammal of primary concern. To evaluate potential effects of deterrents and hopper dredges on manatee hearing and behavior, this basic hearing study was conducted.

Physiological test on average evoked potentials (Bullock, Domning, and Best 1980; Bullock, O'Shea, and McClune 1982) and morphological calibrations (Walls 1967; Kaiser and Schoropfer 1970; Johnson et al. 1988) have given us valuable insight into the species' potential. However, prior to this study no empirical data was available on the manatees' ability to detect sound and absolute frequencies underwater. The research was designed to comprehensively measure the hearing abilities of manatees. Experiments were conducted to measure

a. The absolute underwater hearing potential of manatees in a quiet environment.

b. The effects of background noise on the manatees hearing thresholds.

c. How well the manatee can localize sound underwater.

Presented here is the first audiogram for any of the Sirenian species. It is the most definitive measurement of manatee hearing available. Numerous underwater audiograms and sensitivity experiments have been conducted on aquatic mammals (Johnson 1967, 1968; Mohl 1968; Hall and Johnson 1972; Jacobs and Hall 1972; Schusterman, Balleiet, and Nixon 1972; Terhune and Ronald 1972, 1975a, 1975b; Moore 1975; Moore and Au 1975; Moore and Schusterman 1978; Schusterman and Moore 1978; Aubrey, Thomas, and Kastelein 1988; Thomas et al. 1988; Thomas

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[19] This section of Chapter 6 was reproduced verbatim from Gerstein, E. R. (1994a), "Auditory assessment of the West Indian manatee (*Trichechus manatus*): Potential impacts of low frequency activities on manatee acoustic behavior and communication," Department of Biological Sciences, Florida Atlantic University, Boca Raton, FL. Final contract report to U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

et al. 1990). To facilitate cross-species comparisons, this study has been carefully designed to be consistent with the tolerances and specific criteria set forth in the literature.

Subjects[19]

The provisions of U.S. Fish and Wildlife Service Endangered Species Permit PRT-761873 allowed for a maximum of two manatees to be trained and tested for this research. The two subjects (Stormy and Dundee) are captive born, young adult, male manatees. Stormy is 9 and Dundee is 8 years old. They are in good health and have never been treated with ototoxic medications. Both subjects, being captive born, are well adapted to captivity. Though the sample size is small, many of the underwater audiograms published on other marine mammals have been single animal studies. Information derived from these one subject studies have been universally accepted in subsequent published comparative hearing studies. The use of two animals essentially doubles the typical sample size utilized in comparable studies conducted on various cetaceans and seals. The rationale for two animals is to obtain some comparative data between subjects. The benefits of using these particular animals are threefold. First, they are housed at the same facility, so training and subsequent data collection were accomplished in a consistent and controlled environment. Secondly, both animals were captive born, negating any concern that environmental noise may have damaged or prejudiced the animals' response to these acoustic tests. Finally, the two animals are of the same sex, approximate age and weight (1,000 lbs).

Though no sex related hearing differences have been documented in mammals, it was still advantageous to have as few variables as possible for the subsequent comparisons between subjects.

Facilities[19]

The research was conducted at The Lowry Park Zoo, Tampa, FL. The Zoo provided a secured underwater viewing area with a research work area where all the necessary controlling electronics were housed. This research lab has two 3′ x 10′ underwater viewing windows as well as interior conduits for electro-acoustical cabling. The Lowry Park Zoo manatee exhibit (LPZ) is a new multi-pool exhibit and rehabilitation facility, which currently houses five male manatees. It consists of two large irregular shaped exhibit pools.

The primary test tank for Experiments 1 & 2 was the main 130,000 gallon exhibit pool. This pool has eight large underwater viewing panels and an irregular surface and bottom contour with rocks, ledges, and logs. The two exhibit pools range from four to ten feet in depth. Long channels connect the two exhibit pools with 3 twenty-foot diameter, 20,000 gallon holding pools in the back area. One of these back pools was used both to train the animals for the pure tone audiogram, and was also used at a later date to conduct Experiment 3 - the directional sensitivity test. (See Figure 1.)[20]

With the assistance of the Naval Research Laboratory, Underwater Sound Reference Detachment (USRD), the underwater acoustics were surveyed to insure that ambient acoustic conditions were suitable for the threshold tests. Skimmers, return line, and drains were turned off prior to and during actual testing to maintain consistent low ambient sound pressure levels. The pools proved to be within the tolerances necessary to conduct all the acoustic tests with sound pressure levels @ 20 dB sea state zero at 1 Hz -50 kHz. (See Figure 2.)[20]

Procedures

Experiment 1[19]

A forced two-choice paradigm was used. The test required an equal demonstrative action by the manatees to clearly indicate a choice (to push the no-tone paddle took as much effort as to push the tone paddle). Using an unambiguous paddle presentation also facilitated a shorter discrimination training period (Gerstein, Patton, and Tavolga 1987; Gerstein 1994b).

The experiment was a double-blind presentation of randomized tone and no-tone trials. Computer generated modified Gellerman series lists (Gellerman 1933) selected the chance ordered sequence of trials. The experimenter working with and reinforcing the subject was unaware of the on-off sequence presented. During testing, the paddles were unmanned to insure against inadvertent cuing. When pushed with sufficient force, the subject's choice was recorded on the computer. To safeguard against motivational artifacts, a system of warm-up and cool-down trials were accepted as a useful criteria check on the animal's performance. Both warm-up and cool-down trials were characterized by using an amplitude of 15 dB above the animal's known or estimated threshold for a given frequency. Additionally, these warm-up and cool-down trials were an indicator of the animal's accuracy and/or motivational state. If during a warm-up trial the subject was less than 80 percent accurate in paddle selections (behavioral baseline for performance), then the session was used as a training trial and not counted as data. If the subject scored less than 80 percent during cool-off trials, then the session would not be considered accurate, and was discarded. Once a session began and the animal passed the warm-up trials, each successive signal was attenuated in 2 dB steps until the first incorrect response ("miss") was noted during a signal-on trial. Once a "miss" was made, the sound pressure level was increased in 2 dB steps until the animal responded correctly, or had a "hit". The successive signals were then decreased in 2 dB increments until the animal once again responded incorrectly. This procedure is an up-down staircase psychometric method (Robinson and Watson 1973). The turning points from miss to hit and hit to miss are termed reversals. Sessions ranged from 40 to 86 trials to achieve 5 reversals. A minimum 10 reversals were averaged to calculate the threshold limits for each frequency. The order of frequencies tested was at random. One

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[20] Refers to tables or figures in Gerstein (1994a), not reproduced here.

test subject (Stormy) was tested on 19 frequencies (.015, .05, .1, .2, .4, .5, .8, 1.6, 3, 6, 10, 12, 16, 18, 20, 26, 32, 38, and 46 kHz). Both test subjects (Stormy and Dundee) were tested on 8 frequencies (.5, 1.6, 3, 6, 12, 18, 26, and 38 kHz). A total of 7,962 test trials were run.

Experiment 2[19]

The same general procedures applied to the masked threshold experiment as in Experiment 1. This test measured one test subject's (Stormy) hearing thresholds against a noise background. This test was necessary for determining the measured effects that different levels of noise had on the subject's absolute hearing. During this test, background masking levels were played at different spectral level in a 1/3 octave bandwidth around the center frequency of the pure tone stimulus. Effective masking noise levels were 68 to 88 dB *re*:1μPa. Six frequencies were tested at the different masking levels (.5, 1.6, 3, 6, 12, and 18 kHz). A total of 1178 trials were run.

Experiment 3[19]

This test was conducted in the back pool with one test subject (Stormy). A hand signal from the experimenter to Stormy initiated the start of each trial. Following the hand signal, the subject was trained to station his head in the PVC hoop located in the center of an array of 4 transducers. The transducer locations were rotated to lessen the possibility of any particular speaker being identified by its unique spectral content or relative intensity. Tones were emitted at 30 dB above Stormy's measured signal thresholds. He was trained to leave the station hoop upon hearing a tone and press the speaker where the tone originated. Detections were scored incorrect or correct, and time stamped into the computer log.

Short and extended repetitions of 100 msec pulses, centered around the target frequency were used to measure the manatee's ability to localize brief, complex sounds. The subject's ability to localize as a function of signal frequency and pulse duration was tested for five different frequencies (.5, 1.6, 3, 6, and 12 kHz). The pulse train duration selected for each respective frequency was .2 and .5 seconds. Signals consisted of 100 msec pulses of 100 Hz bandwidth noise centered around the test frequency. Short, five-repetition pulse trains produced .2 sec signals. These short .2 sec signals insured a reliable way to measure the manatees' ability to localize sound without the aid of tracking or head scanning movements (not enough time for Stormy to react and begin scanning). The .5 sec duration of the extended pulse train consisted of 25 repetitions and provided just enough time for the manatee to make a quick scan. Left and right sided detectability were tested at 45 and 95 deg angles from the animal's central midline. A minimum of 20 trials were run for each frequency in each condition at each angle and side. A total of 1,137 trials were run.

Summary discussion[19]

While the sample size is arguably small, the definitive results of this comprehensive hearing study remain our best estimate of what manatees are capable of hearing. Discussions and recommendations presented which make inferences about typical manatee hearing should be viewed cautiously and are offered in the spirit of discovery. As new sensory information and propagation measurements unfold, these conclusions may be affected, and provide additional recommendations for research and conservation initiatives.

The measured manatee audiogram demonstrates that in quiet conditions @ 20 dB sea state zero, manatees have a hearing range of 500 Hz to 38 kHz. The manatee's most sensitive region of hearing is 10 to 20 kHz. In this region, amplitude levels as low as 50 dB $re{:}1\mu Pa$. are detectable. Below 1.6 kHz manatee hearing sensitivity falls off rapidly (20 dB per octave). In near field projections at very high energy levels (111 dB $re{:}1\mu Pa$.) one manatee was able to detect infrasonic signals of 15 Hz, possibly through air resonance or tactile sensations. The manatee's ability to effectively hear very low and infrasonic frequencies suggests that they do not rely on communication cues at these frequencies. In support of this, no infrasonic or low frequency vocalizations were recorded. However, the manatees' high frequency sensitivity may be utilized in intraspecific communication and underwater orientation, as manatee vocalizations have harmonic banding above 18 kHz.

The masked threshold tests demonstrated critical signal to noise ratios from 14 to 26 dB $re 1\mu Pa$ with standard deviations of < 3 dB, indicating that background noise significantly raised the hearing thresholds of the animal. In moderate noise conditions @ sea state 2 (noise level of an inland spring), the manatee would require a minimum of a 15 dB increase in order to hear 3 kHz, and a 29 dB increase at 500 Hz. In intracoastal corridors sea state levels can reach 4 & 7, and could require as much as a 50 dB increase for boat related frequencies. Masked threshold probes suggest that manatees are consistent with other mammals in their ability to better detect pulsed signals than continuous signals from background noise. Boat noise is characterized as broadband noise with limited frequency or amplitude fluctuation. As the manatee requires significantly more energy behind a pulsed signal to detect it from the background, it is not unreasonable to infer that even greater energy would be required for the manatee to detect the continuous broadband noise of an approaching boat from the background.

Directional sensitivity tests demonstrated that the manatee was relatively poor at locating sound sources below 3 kHz. The animal could not utilize phase detection cues. The manatee demonstrated increased localization performance at higher frequencies, and required repetitive pulsed signal trains to localize sounds. The manatee was less effective at localizing short pulses and required more time to scan the sound field before localizing a sound source. Dolphins and other mammals are much more effective at localizing signals than Stormy.

A further complication is the Lloyd mirror effect in shallow water acoustic propagation. Wavelength inversion and canceling at the surface make locating low frequency point sources very difficult. The manatees' limited low frequency hearing sensitivity, high signal to noise detection ratios, and poor underwater localization abilities for lower frequencies, suggest that they would have trouble trying to detect or locate approaching vessels from a safe distance. The low frequency sound of vessels (1 Hz - 2 kHz) is probably indistinguishable from background noise in moderate noise environments. Though manatees may be able to detect some of the 3 - 4 kHz signals which boats can produce, in moderate noise conditions the boats would have to be very close before signal strengths would be detectable above background. The manatee's reliance on intensity difference cues for localizing sound, and its need to scan suggest that they would require more time to react to an approaching boat as well. Perhaps the repeated chirps of manatee vocalizations centered at 5 kHz with harmonics above 18 kHz reflects the animal's adaptation to a shallow water environment, where low frequency noise cannot propagate effectively. Pulsed vocalizations with their fundamental frequency and associated banding may be providing the manatee the detection and localization cues it needs to communicate and find individuals. There is little conjecture that the majority of low frequency bandwidth noise produced by most commercial and recreational vessels is effectively masked by moderate to high background levels in the Intracoastal Waterway. Limitations of the manatee's ability to hear and localize low frequency sound render it vulnerable to repeated collisions with watercraft.

Conclusions specific to project questions[19]

a. Manatees are not sensitive to low frequency mechanical noise of hopper dredging or the proposed acoustical deterrents being designed to ward off sea turtles. Only in near field projections could manatees be able to detect blast signals at sound pressure levels approximating 110 dB $re{:}1\mu Pa$ @ one meter distances. Furthermore, in moderately noisy environments signals would need to be >130 DB before manatees would be able to detect deterrents or ship operations.

b. Recorded manatee vocalization and measured hearing ranges indicate that low frequency noise associated with dredging and sea turtle deterrents would not interfere or compete with intraspecific communication.

c. There are no measurable acoustic effects of low frequency noise (5 - 500 Hz) produced by Army Corps of Engineers hopper dredges on manatee hearing thresholds. Frequencies from 1 - 2000 Hz are subject to Lloyd mirror effects in shallow areas where manatees would be at risk. The majority of noise produced by dredges and deterrents would be dispersed and canceled. Manatee hearing thresholds at these frequencies would be unaffected.

d. Manatees cannot accurately detect the low frequency sounds produced by hopper dredges and associated Army Corps vessels traveling in manatee inhabited waters and are at risk of collision with these vessels.

e. Stormy and Dundee were not attracted, dispersed, or measurably affected by controlled simulated deterrent noise projections. Manatees may not be able to detect these signals from less than one meter distances.

f. Manatees will habituate to continuous wave background noise.

7 Acoustic-Dispersal Evaluations

Introduction

Seismic-energy sources have been widely and safely used by the petroleum exploration industry in offshore environments for more than three decades. Their development came about as an alternative to explosives, which were known to be harmful to aquatic life. Recent studies have indicated that seismic sources are not harmful to marine life except at extremely close distances (Frick and Ng 1990). Use of seismic sources to disperse sea turtles from water intake structures for power plants was proven feasible in 1983 (O'Hara and Wilcox 1983).

As part of acoustic-dispersal evaluations, the characterization of a seismic air gun acoustic-dispersal technique was performed by Zawila (1994a). An evaluation of seismic sources for repelling sea turtles from hopper dredges was conducted by Moein et al. (1994). An analysis of seismic air gun signature attenuation in the open ocean was conducted by Zawila (1994b) off Fort Pierce, FL. Appropriate sections of these documents pertaining to acoustic-dispersal evaluations are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the studies are given in the original documents.

Characterization of a Seismic Air Gun Acoustic Dispersal Technique at the Virginia Institute of Marine Science Sea Turtle Test Site

Background[21]

(Compiler's note: repetitive background material has not been duplicated here.)

Personnel of the Geotechnical Laboratory (GL) USAE Waterways Experiment Station (WES), along with three other WES laboratories, investigated potential solutions for the problem. One approach selected for further study was to safely disperse endangered sea turtles away from areas of dredging activity. This approach is based on development of a dispersal system composed of a specially designed turtle deflector shield and seismic "scaring" device.

Seismic energy sources have been widely and safely used by the petroleum exploration industry in offshore environments for more than three decades. Their development came about as an alternative to explosives which were known to be harmful to aquatic life. Recent studies have indicated that seismic sources are not harmful to marine life except at extremely close distances (Frick and Ng 1990; Linton et al. (1985); Greenlaw 1986; Chelminski (undated); Bowles (undated); Chamberlain (undated); and NMFS 1984 (Cape Canaveral sea turtle survey and air gun experiment)). Use of seismic sources to disperse marine life and in particular sea turtles from dangerous areas such as water intake structures for power plants was proven feasible in 1983 when tests were conducted at the Florida Power and Light Company's St. Lucie Facility (O'Hara and Wilcox 1983).

This research report addresses these objectives; (1) develop an acoustic attenuation and absorption prototype model for the Virginia Institute of Marine Science test site, (2) characterize seismic sources used in study of sea turtle behavioral responses, and (3) collect data that can be used to develop a safe, effective method of utilizing seismic sources to repel sea turtles from dangerous areas.

Procedure[21]

The controlled sea turtle behavior reaction experiment was conducted on 28 June - 17 July 1993 off of the old ferry pier at the Virginia Institute of Marine Science in Gloucester Point, VA. A pen of netting approximately 60 by 240 feet was installed just off the end of the ferry pier. The depth of water around the pier ranged from 10 to 15 feet. The seismic sources, a Bolt Technology Par 2800 Air Gun and Water/Air 2800 Combo Gun were placed four feet underwater at opposite ends of the net. The 2800 Air Gun was positioned downstream and the 2800 Combo Gun operating

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[21] This section of Chapter 7 was reproduced verbatim from Zawila, J. S. (1994a), "Characterization of a seismic air gun acoustic dispersal technique at the Virginia Institute of Marine Science sea turtle test site," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

in the air mode was positioned upstream. The closest distance a sea turtle could approach the seismic guns was five feet. See Figure 1[22] for the schematic layout of the pen and air gun configuration.

Eleven endangered loggerhead (*Caretta caretta*) sea turtles were tested to characterize their behavioral response to seismic gun signatures. One sea turtle at a time was placed within the net and allowed to acclimate to the environment for one hour before testing. A coin toss determined the seismic gun discharge order. The testing procedure started with one gun set at the lowest air input pressure discharging for 5 minutes at a 5 seconds repetition rate. As the test progressed, the acoustic signature of the seismic gun was recorded and the sea turtle behavioral response was monitored. After 5 minutes the gun would cease discharging for 10 minutes to allow the sea turtle to rest before the next trial initiated. For the next trial, the other seismic gun would discharge at its lowest air input pressure for 5 minutes at a 5 second repetition rate. This procedure would be followed two more times at medium and high air input pressure levels for a total of 6 trials. The low, intermediate, and high air input pressures during the sea turtle trial tests for the combo and air guns are 1,000, 1,500, and 2,000 psi and 800, 1,000, and 1,200 psi respectively. After the six trials were completed for the sea turtle, it was removed from the pen and examined for any hearing or physical impairment while another sea turtle was placed into the pen to be tested using the same procedure. After a few days rest, seven of the eleven sea turtles were retested using the same procedure.

The acoustic signatures from the seismic guns were recorded on a Rapid Systems R1200 Digital Oscilloscope and its spectral content analyzed by utilizing a Rapid Systems R3 Fast Fourier Transform (FFT) software program. A calibrated Innovative Transducers Inc. Model RF-1 omnidirectional hydrophone, which has a sensitivity of -189 decibels relative to one microPascal (db re 1 μPa) between 10 to 20,000 hertz, was positioned in the center of the net on the south end during the sea turtle behavior reaction tests. After the sea turtle tests were completed, acoustic signatures from the seismic guns were recorded at various positions within the net to develop an attenuation model. This allowed an accurate calibration of the transmission loss model for the shallow water environment at the Virginia Institute of Marine Science test site.

The Bolt Technology Par 2800 Air Gun operates by pressurizing air into a small chamber volume (20 cubic inches) to a high pressure level, typically 1.000-2,000 psi. An electric current is then applied to the air gun which opens side ports that release pressurized air into the underwater environment thereby causing an acoustic sound from the pressure differential. Then the ports are closed before water can enter the chamber and pressurized air reenters the chamber ready to be discharged another time. The Bolt Technology Par 2800 Combo Gun is an air/water gun combination that can operate either as a water or air gun. When it is operated in its air gun mode, as during the sea turtle tests at the Virginia Institute of Marine Science, it functions exactly as the Bolt Technology Par 2800 Air Gun described above. In its water gun mode, the chamber (100 cubic inches) is

[22] Refers to tables, figures, equations, or appendix in Zawila (1994a), not reproduced here.

pressurized with air to 1,000-2,000 psi. A current is then applied which opens side ports for the surrounding water to enter the chamber and expels the pressurized air through a hose to the surface. Then pressurized air enters the chamber and expels the water from it, thereby leaving an air pocket ready to be discharged again. The difference between the air and water guns is that the air gun is an explosive type of energy, it expels pressurized air into the underwater environment, whereas the water gun is a more intense implosive energy, it expels air to the surface causing a void for water to enter the chamber and implode. The Bolt Technology Par 2800 Air Gun and 2800 Combo Gun (water mode) discharge at peak pressure levels of 226 db re 1 μPa and 229 db re 1 μPa, respectively. The spectral energy is concentrated between 20 to 100 hertz and varies from 194 db re 1 μPa for the air gun to 197 db re 1 μPa for the combo gun (water mode). When the combo gun is utilized in the air mode, the peak pressure level and spectral content are similar to the 2800 Air Gun. Figures 2 and 3 provide typical acoustic and spectral signatures for both seismic guns.[22]

Sea turtle trial tests[21]

During the sea turtle trial tests, data was recorded of the acoustic signatures from the seismic guns by the calibrated hydrophone that was positioned equidistant (40 yards) from both ends of the net where the seismic guns were situated. During each sea turtle test up to six different trials were conducted - both seismic guns discharging at three different air input pressures. For each trial, four acoustic signals were averaged together into a record and three records were collected per trial for a total of 12 acoustic signatures per trial. The data from the sea turtle trial tests was analyzed with the R3 FFT spectrum analyzer and examined for intensity levels at the peak pressure time history wave and 125, 250, 500, and 1,000 hertz. The data was cross-referenced between different turtle tests to determine the average acoustic signature of the seismic gun for a set air input pressure. The data for the sea turtle tests is located in Appendix 3[1] and the average and range of sound pressure levels of the seismic guns at each air input pressure are shown in Figures 7 and 8.[22] As shown in Figure 7,[22] the sound pressure levels ranged the most at 800 psi and the least at 1,200 psi because the lower air input pressure may not discharge the air gun at an even amplitude due to the mechanics of the gun. Figure 8[22] demonstrates the range of sound pressure levels of the combo gun has the most variability at 125 and 1,000 hertz for all air input pressures. This data shows that the source was repeatable and provided a consistent stimulus throughout the tests.

The average sound pressure level during the sea turtle tests decreased as the frequency increased, therefore 125 hertz was the most intense frequency and 1,000 hertz was the least intense. The average sound pressure levels of the air and combo guns at all air input pressures during the sea turtle trial tests are shown in Table 2.[22] Note that these sound pressure levels were recorded 40 yards from the source.

From Table 2,[22] the average sound pressure levels from the seismic guns are similar at the low, intermediate, and high air input pressures (i.e., the sound pressure levels of the air gun at 800 psi is similar to the combo gun at 1000 psi). A spreading and attenuation model was developed based upon the average sound pressure level 40 yards from the source and the spherical spreading attenuation (Equation 3)[22] characteristics of the shallow water net environment at the Virginia Institute of Marine Science. This transmission loss model is shown in Figures 9 - 14[22] for the combo and air guns at each air input pressure. The data for these figures is shown in Appendix 4.[22]

Based upon the source level characteristics of the seismic guns, the spherical spreading attenuation environment at the Virginia Institute of Marine Science, and the estimated hearing thresholds of the sea turtles, a sea turtle 'scare response' model can be calculated. The source levels of the seismic guns and attenuation characteristics at the Virginia Institute of Marine Science are known and presented graphically in Figures 9 - 14.[22] Assuming that the sea turtles respond to the seismic guns at a peak pressure level of 170 db re 1 μPa, they would be affected by the peak pressure wave at a distance of 100 yards for the combo gun operating at 1,000 psi as shown in Figure 9.[22] Note that the dashed line represents the estimated sea turtle acoustic threshold within the pen of netting at the Virginia Institute of Marine Science. Assuming the upper threshold limit is 20 db re 1 μPa above the hearing threshold, or 190 db re 1 μPa for sea turtles, then the sea turtles would have been exposed to high sound pressure levels of approximately 200 db re 1 μPa if they were within 5 yards of the combo gun operating at 1,000 psi. Note that the sea turtle acoustic and upper limit thresholds are estimates based upon research conducted on land turtles. Therefore by knowing the acoustic and upper limit thresholds of sea turtles or the distance at which sea turtles detected/responded to the seismic source, the other can be solved for by coregistering the data with Figures 9 - 14.[22] For example, in Figure 9[22] if sea turtles responded to a peak pressure wave of 180 db re 1 μPa, then the corresponding response distance is 25 yards. During these tests, the acoustic source provided a stimulus that was above the hearing threshold of the sea turtles throughout the netted environment and below the upper limit at a distance of 15 feet from the source.

Conclusions[21]

The impact on endangered sea turtles by developing and utilizing preventive equipment and methods within the hopper dredging environment has only started to be realized. A controlled test at the Virginia Institute of Marine Science in Gloucester Point, VA was conducted to determine the behavioral reaction of sea turtles to seismic signatures. Time histories and spectral characteristics that were collected at the Virginia Institute of Marine Science test site concluded that the shallow water environment could be represented as a spherical transmission loss model. Knowledge of the attenuation characteristics and source levels aided in characterizing sea turtle responses to the seismic signatures. Assuming a sea turtle acoustic threshold of 170 db re 1 μPa and an upper limit of 190 db re 1 μPa, the acoustic source and its operational parameters provided a consistent stimulus that was above the acoustic threshold throughout the netted enclosure and below the upper limit beyond 15 feet.

In conclusion, this test was successful in achieving the objectives of developing a spreading and attenuation prototype model and aiding in delineating sea turtle behavioral responses to seismic disturbances. More testing is urgently needed to determine sea turtle reactions in an uncontrolled environment because the net may have affected the reactions of the sea turtles.

Evaluation of Seismic Sources for Repelling Sea Turtles from Hopper Dredges

Introduction[23]

(Compiler's note: repetitive background material has not been duplicated here.)

The Army Corps of Engineers has proposed to use pneumatic energy sources in the form of air guns to produce acoustic stimuli to repel sea turtles from hopper dredges. In the course of the air gun testing, parameters such as distance of the turtle from the air gun, chamber pressures, and firing rates were recorded. These data were subsequently used to assess the safety in utilizing this method to disperse sea turtles. Furthermore, the behavior of the sea turtles was evaluated before and during discharge to evaluate effectiveness of the air gun in repelling sea turtles.

Materials and methods[23]

A net enclosure (approximately 18 m × 61 m × 3.6 m, 3.8 cm bar) was erected in the York River, VA to contain the turtles. The enclosure was stratified into two equal sections; near and far (Figure 1).[24] Air guns, provided by the Army Corps of Engineers (COE) were positioned at each end of the net, and the two guns were calibrated to create equal seismic and auditory output. A hydrophone was positioned equidistant from the air guns to monitor the output.

Ten loggerhead turtles were tested (Table 1),[24] and seven of these were retested for a total of seventeen tests. A float was attached to the posterior end of the carapace of each turtle with a 3 m line so position could be monitored. For each test, a single loggerhead was placed in the enclosure and allowed to acclimate for one hour prior to exposure to stimuli.

Air guns were initially discharged only when the turtles were near the center of the net so that there would be equal distance for movement toward or away from the sources. Three different decibel levels (175, 177, 179) were utilized twice each,

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[23] This section of Chapter 7 was reproduced verbatim from Moein, S. E, Musick, J. A., Keinath, J. A., Barnard, D. E., Lenhardt, M. L., and George, R. (1994), "Evaluation of seismic sources for repelling sea turtles from hopper dredges," Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA. Final contract report to U.S. Army Engineer Waterways Experiment Station. (Not all sections of that report have been reproduced herein.)

[24] Refers to tables, figures, or appendixes in Moein et al. (1994), not reproduced here.

resulting in six trials per test. A coin toss determined which air gun was to be used first. The air gun was discharged at 175 dB every 5-6 seconds for 5 minutes, followed by at least 10 minutes of no emission. The other air gun was then discharged at the same decibel level for 5 minutes. After at least 10 minutes of no emission, the decibel level was increased to 177 dB and one of the air guns, randomly determined by a coin toss, was discharged for 5 minutes. After at least 10 minutes of no emission the other gun was discharged at the same decibel level for 5 minutes. This sequence of events continued until the turtle was exposed to six trials; the first two trials at 175 dB, the third and fourth at 177 dB, and the fifth and sixth at 179 dB.

Position and direction of movement of the turtle within the net was recorded every 15 seconds. The number of positions in the near and far sections during each trial were tallied. Turtles were separated into two groups; the first time tested vs. the second time tested. Due to problems with either the upkeep of the air guns or unforeseen weather, not all the turtles were subjected to six trials.

The data were used to compare the mean amount of time each turtle spent in the section of the net away from each of the two air guns in order to infer whether differences existed between the air guns. A nonparametric two-sample t-test, the Wilcoxon paired sample test, was used (Zar 1984).

Secondly, the observed response of each turtle to the emission of the air gun (observed number of positions in the section of net away from the gun) was compared to the expected (equal amount of time spent in both sections of the net) using the Wilcoxon test as a test of goodness-of-fit (Siegel and Castellan 1988). Only the first trial data for each exposure were examined to determine the turtle's reaction on first encountering the air gun.

The possibility of habituation of the turtle to the stimulus over time was examined. The number of positions each turtle spent in the section of net away from the stimulus for each trial was analyzed using the nonparametric Friedman's test (Zar 1984). Only data from those turtles which completed six full trials in a test were examined.

The amount of time for the turtle to respond to the initial firing of the stimulus ("response time") as well as the time taken to turn away from the stimulus ("turn time") were calculated for those turtles who were initially moving toward the stimulus prior to firing the air gun. The response time was defined as any perceived increase in speed of the turtle irrespective of direction. Turn time was the time from the first firing of the air gun until the turtle changed direction away from the air gun. Response time and turn time data were computed for the first three trials of those turtles in the first exposure group. Averages were computed for both response and turn times for each turtle. The same data were compiled for the distances from the air gun at which the turtle responded ("response distance") and turned ("turn distance") after the stimulus (Figures 2 - 4).[24]

In order to monitor the health and to determine the effects of exposure to air guns on the experimental animals, blood was drawn prior to and within 24 hrs after each test and analyzed by a veterinarian for several standard parameters

(Appendix I).[24] Furthermore, the hearing threshold levels were determined for each turtle before, within 24 hours after each test, and approximately 14 days later using an auditory evoked potentials computer, the Nicolet Spirit Portable (Appendix II).[24]

Results[23]

The Wilcoxon paired sample test found no significance between reaction to the two air guns. This unbiased response was seen in both first exposure (T_+ and $T_- > T_{0.05(2),10}$) and second exposure (T_+ and $T_- > T_{0.05(2),7}$).

The goodness-of-fit analysis found significant differences in the observed vs. expected for the first trial of the first exposure group ($T_- < T_{0.05(2),10}$). However, the observed number of positions away from the gun in the first trial of the second exposure group was not significantly different than expected (T_+ and $T_- > T_{0.05(2),7}$).

The Friedman analysis to examine for habituation effect found significant differences among the trials ($X^2 > X^2_{0.05,5}$) in the first exposure group (Figure 5).[24] However, in the second exposure group, significant differences among the turtles were not found ($X^2 < X^2_{0.05,5}$) (Figure 6).[24]

The mean response time was 39.5 s (range 5-135 s); mean turn time was 49.4 s (range 5-150 s). Moreover, the average response distance was 20.8 m (range 1.5-37.8 m) while the average turn distance was 15.0 m (range 1.5-34.8 m) (Table 2).[24]

Discussion[23]

The first task was to test whether a significant difference existed in the response of the turtle to each of the two air guns. Once establishing that response to these air guns was not statistically different, analysis of behavior was continued by combining data from the two air guns.

On first exposure to the air guns (trial one), naive turtles occupied a significantly higher number of positions in the far section of net than expected by chance. This suggests an avoidance response to the air gun emissions. However, in the second exposure, no difference in observed and expected response was seen. This response suggests that the turtles are habituating to the stimuli.

To pursue the idea of habituation, the response of each turtle in all the trials of each exposure group was analyzed. In the first exposure group, number of positions in the sections of the net were not the same for each trial. Turtles avoided the air gun in the first three trials, but did not avoid emissions in trials 4-6 (Figure 5).[24] The second exposure group did not avoid the emissions throughout all six trials (Figure 6).[24] This suggests that turtles are habituating to the stimuli after approximately three exposures, and do not lose this habituation over days of no exposure.

Do the turtles have enough time to avoid a dredge with an air gun on the draghead emitting emissions every 5 sec? Dredges operate at speeds up to 5 knots (or

2.57 ms^{-1}). Mean response time was 39.5 s and in this time the dredge would be 101.5 m away. However, turtles probably would not respond at that distance. The average response and turn distances were 20.8 m and 15.0 m, respectively. A dredge traveling at 2.57 ms^{-1} would cover 13 m in the 5 s between emissions from the air gun. Using 15.0 m as a conservative distance at which turtles will respond to first encounters with a dredge, it appears the turtles would avoid the dredge.

However, a turtle subsequently encountering a dredge may or may not avoid the dredge. These preliminary results need to be further explored to see how turtles would react under field conditions. If a turtle begins to respond to the emissions of the air gun 23.7 m away from the approaching dredge and continues to respond 23.7 m after the dredge passes, the turtle will be exposed to 4 emissions from the air gun. A possible experimental design to address the question of habituation under normal dredge conditions in the field would be to expose the turtle to 4 emissions, allow the turtle to rest for several days and then expose the turtle to 4 more emissions. Ultimately, the final phase of this study should be to use telemetry to track turtles' behavioral response to air gun emissions in the field.

Analysis of a Seismic Air Gun Acoustic Dispersal Technique at the Fort Pierce Sea Turtle Trial Site

Background[25]

(Compiler's note: repetitive background material has not been duplicated here.)

The objective of this research is to (1) determine the feasibility of using the seismic air guns on hopper dredges, (2) characterize the acoustic source signatures during both dredging and non-dredging shallow water environment tests, and (3) develop an attenuation and absorption prototype model.

Procedure[25]

The acoustic dispersal tests were conducted on 1-7 June 1993 at a 240-ft by 1000-ft site 5 miles east of the Ft. Pierce, FL ship channel. The seismic sources, a Bolt Technology Par 2800 Air Gun and Water/Air 2800 Combo Gun were placed on the port drag arm of the United States Corps of Engineers (USCE) hopper dredge McFarland. Assuming a drag head depth of 48 feet, the air gun was positioned 21 ft from the sea bottom and 36 feet up the drag arm from the drag head. The water gun was positioned 10 feet from the sea bottom and 23 feet up the drag arm. See Figure 1[26] for the schematic air layout. Operation of the seismic guns in the dredging

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[25] This section of Chapter 7 was reproduced verbatim from Zawila, J. S. (1994b), "Analysis of a seismic air gun acoustic dispersal technique at the Fort Pierce sea turtle trial site," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

[26] Refers to tables or figures in Zawila (1994b), not reproduced here.

environment was successful. The seismic guns were not physically damaged nor operationally hindered by the McFarland and the McFarland operated effectively without impairment or damage caused by the seismic guns.

Data was recorded on a Rapid Systems R1200 Digital Oscilloscope utilizing a Rapid Systems R3 FFT Spectrum Analyzer version 2 software program. A calibrated Innovative Transducers Inc. Model RF-1 omnidirectional hydrophone, which has a sensitivity of -189 db re 1 μPa between 10 to 20,000 hertz, was positioned on the McFarland's launch at a depth of 45 feet and was used to collect acoustic data. The data sets that were collected are (a) the background noise level of the shallow water environment, (b) the noise level during dredging activity without the seismic guns operating, (c) the noise level during dredging activity with the seismic guns operating, and (d) the noise level of the seismic guns while the McFarland was idle.

When data was collected of the background noise level, the launch was anchored between 50-160 yards starboard of the McFarland. During dredging operations the launch was anchored at one end of the test site while the McFarland approached the launch from the other end of the test site. This produced a data set of distances ranging from 160 to 420 yards. When the McFarland was idle and the seismic guns were operating, the launch collected acoustical signatures at approximately 100, 500, 1,000, 2,500, and 5,000 feet aft of the McFarland. These distances are approximate because the launch was not anchored and did drift during each seismic discharge. The distance between the McFarland and launch was computed by using a radar distance measuring system on the McFarland, which has an accuracy of 15 ft. During the tests, the seismic guns were discharged simultaneously at input pressures of 1,000, 1,500 and 2,000 pounds per square inch (psi).

Spectral analysis of the source signatures was conducted by using a fast fourier transform hanning filter upon the individual time histories supplied as a part of the R3 software program. The R3 program only allowed spectral analysis of the complete time history and not of specific components of the time history. Therefore, to analyze the individual air and water gun signatures, the R3 time histories' binary data formats were converted to an ASCII readable format to utilize a Programmable Interactive Toolbox for Seismological Analysis (PITSA) program. Thereby the individual air gun and water gun spectral characterization could be incorporated into the progressive attenuation and absorption prototype model. Note that when referring to spectral amplitudes, the frequencies are not exact but vary within a range. For example, 125 hertz is ± 25 hertz, 250 hertz is ± 50 hertz, 500 hertz is ± 100 hertz, and 1,000 hertz is ± 200 hertz.

Results[25]

Acoustic data was collected of the seismic sources at the Ft. Pierce site during dredging and non-dredging activity. When the dredge McFarland was idle (non-dredging activity), the launch was anchored 100, 500, 1,000, 2,500, and 5,000 feet aft of the McFarland to collect seismic gun source characterization time histories. This data was then compared to data collected when the seismic guns were operating during dredging activity. Also frequency distributions with respect to distance and input pressure were analyzed for both the air/combo gun combination and for their individual frequency components to help derive a typical shallow water dredging environment acoustic model.

Air guns discharging, McFarland idling

At 1,000 psi air input pressure, the transmission of the spectral signature with distance of both guns is shown in Figure 12.[26] A least squares logarithmic fit was extrapolated to calculate what the source level would be for selected frequencies if both guns fired simultaneously. The most intense frequency signal is at 125 hertz, which is approximately the seismic guns' expected spectral energy output. After that in decreasing order of intensity is 250, 500, and 1,000 hertz. The rate of attenuation from highest to lowest for the spectral frequencies is 125, 250, 500, and 1,000 hertz. Similar trends of the most intense spectral energy and attenuation rates were observed for the seismic guns operating at 1,500 and 2,000 psi air input pressures (Figures 13 and 14).[26]

Spectral transmission of the peak pressure level is illustrated in Figures 15, 16, and 17[26] for input pressures of 1,000, 1,500, and 2,000 psi. A least squares logarithmic fit was extrapolated from the data and derived that the water gun has a source level ranging between 232-234 db re 1 μPa. The source level of the air gun computed by the least squares extrapolation was higher than expected. Therefore data points were inserted at a distance of 1 yard to derive a more accurate source level. With the padded data, the source level of the air gun ranged from 223 to 231 db re 1 μPa.

Analysis of the frequency amplitudes of both seismic guns operating simultaneously, concludes that the spectral amplitudes did increase when the air input pressure increased. The amplitudes of all frequencies increased by 4-6 db re 1 μPa when the air input pressure increased from 1,000 to 1,500 psi. When the air input pressure increased to 2,000 psi, the frequency amplitudes increased slightly, 1 or 2 db re 1 μPa, or decreased slightly 1 db re 1 μPa. This may indicate that the seismic gun combination tends to reach its maximum spectral intensity at an air input pressure of 1,500 psi. Table 2[26] summarizes the data that is plotted in Figures 12 through 17.[26] The data in Table 2[26] was calculated by averaging the amplitudes of all of the acoustic signatures. Note that only the farthest positions (1,000, 2,500, 5,000 ft) from the dredge were used in this analysis because an estimated 50 foot variable distance caused by the drifting launch at 1,000 feet (950-1,050) would not affect the amplitude signatures as much as closer distances (500 feet and less from the dredge).

Comparing the attenuation of the signals with respect to distance from the dredge, the lower frequencies (125, 250 Hz) are attenuated at a faster rate than the higher frequencies (500, 100 Hz). The reason for the higher rate of attenuation of the low frequencies is because the low frequencies produce wavelengths that are too long to propagate through the shallow water environment. As the water depth becomes more shallow, long wavelengths/low frequencies cannot effectively propagate through the medium because the wavelengths become larger than the medium, thereby causing the long wavelengths to attenuate rapidly. To determine what the cutoff frequency is for the rapid attenuation rate, the velocity of a propagating wave equals its wavelength times frequency.

$$V = \lambda * f \tag{5}$$

Assuming $V = 5000$ feet/second and the maximum wavelength equals the medium thickness or water depth (50 feet), then

$$f = (5000 \text{ ft/sec}) / 50 \text{ ft} = 100 \text{ hertz}$$

Therefore frequencies equal to or below 100 hertz will attenuate rapidly. As the water depth becomes more shallow (40 feet), then higher frequencies will attenuate - 125 hertz and below.

By placing a logarithmic least squares fit to the peak pressure level and spectral data to determine the source level of the respective gun, a comparison of collected data versus theoretical models can be analyzed. The source levels for each data point were calculated by the spherical and shallow water transmission loss models. Those source levels were then averaged for each model and compared to the least squares extrapolated source levels. Figure 18[26] compares the source levels calculated by the least squares logarithmic fit method, the spherical transmission loss model, and the shallow water transmission loss model for the peak pressure level data of the combo gun at 1,000 psi (data from Figure 15).[26] The peak pressure level of the water gun (Figures 15 -17)[26] fits well with a shallow water transmission loss model at all air input levels even though the data is moderately scattered. The peak pressure level of the air gun (Figures 15 - 17)[26] could not be accurately determined because the data was padded. Therefore the source levels of the air gun estimated by Bolt Technology will be used for source level comparisons. Examining the spectral amplitudes (Figures 12 - 14)[26] shows that at low frequencies (125 hertz and less), a spherical spreading loss model is most representative of the data whereas at high frequencies, the shallow water transmission loss model is more representative of the data. These conclusions were based upon source levels calculated by (1) extrapolating a least squares line fit through the data, (2) the spherical transmission loss model, and (3) the shallow water transmission loss model.

Each time history source record was split into its individual air and water gun components to examine their spectral contents separately. The spectral amplitudes were calculated by applying a fourier transform hanning filter to each time history record.

The data for the spectral amplitudes of the air gun at input pressures of 1,000, 1,500, and 2,000 psi are graphed in Figures 19, 20, and 21.[26] These graphs demonstrate that the most intense energy is around 125 hertz, which is expected for the air gun. In decreasing order of spectral energy is 250, 500, and 1,000 hertz. The fastest rate of attenuation is at 125 hertz whereas the other frequencies attenuate relatively at the same rate. Initially, there is more energy in the 125 hertz band at close distances, but beyond 1,000 feet there is more energy around 250 hertz. A possible reason for the 250 hertz energy at far distances is that the shallow water environment causes the longer wavelengths/shorter frequencies (i.e., 125 hertz) to attenuate more rapidly or even possibly shift into a shorter wavelength/higher frequency (250 hertz).

The data for the spectral amplitudes of the water gun at input pressures of 1,000, 1,500, and 2,000 psi are illustrated in Figures 22, 23, and 24.[26] These graphs are similar to the air gun spectral amplitude characterization in that the most intense energy is around 125 hertz which is expected for the water gun. The spectral energies and attenuation rate decrease as frequency increases.

Since most of the far field data of the seismic guns is near the hydrophone's resolution limit (123 db re 1 μPa), source level calculations extrapolated from the data may not be accurate. This was observed with the water gun spectral signatures. Source levels calculated by extrapolating best-fit logarithmic lines to the data produced extremely high source levels for the low frequencies and low source levels for the high frequencies. Therefore due to hydrophone's resolution limit, the individual air and water gun data is valid only for its present spatial relationship to the dredge and should not be used to extrapolate an individual source level for the air or water gun. The problem of the hydrophone resolution limit was not observed on the spectral images when both the air and water gun signatures were fourier transformed together.

Analysis of the spectral amplitudes of the air and water gun signatures at each input pressure, concluded an increase of 3-5 db re 1 μPa for the water gun when the air input pressure increased from 1,000 to 1,500 psi. Increasing to 2,000 psi tended to increase the spectral amplitudes by 1-3 db re 1 μPa. The air gun spectral amplitudes increased by 1-2 db re 1 μPa when the air pressure input increased from 1,000 to 1,500 psi. Increasing to 2,000 psi caused an increase of 1-3 db re 1 μPa in the spectral amplitudes. At 2,500 feet and beyond, specific spectral signatures of the air gun were below the hydrophone's resolution limit. Table 3[26] summarizes the data that is plotted in Figures 19 - 24.[26] The data in Table 3[26] was derived by averaging the amplitudes of all of the acoustic signatures.

Air guns discharging, McFarland dredging

Another set of tests were conducted at the Ft. Pierce site to determine the interaction between the seismic guns and the McFarland under dredging conditions. This was conducted by anchoring the launch at one end of the test site and having the McFarland approach it from the other end of the test site. The seismic guns were operated at 1,000, 1,500, and 2,000 psi at a twenty second interval for a variety of distances ranging between 160-420 yards from the McFarland. The number of passes the McFarland made at 1,000, 1,500, 2,000 psi are 1, 1, and 2, respectively.

The data for the spectral characterization of the seismic guns operating at 1,000, 1,500, and 2,000 psi under dredging conditions are graphed in Figures 25, 26, and 27.[26] These graphs demonstrate that the most intense energy is around 125 hertz beyond 30 yards from the McFarland. The sound pressure decreases as frequency increases. The spectral attenuation rates vary depending on the air input pressure, but overall the 125 hertz range attenuates the slowest and the higher frequencies attenuate more rapidly. This is the exact reverse case when compared to the spectral characterizations of the seismic guns during non-dredging activity. Because the data was clustered in a small range of distances (150-450 yards), attenuation rates and extrapolated source levels are not as accurate as the data during non-dredging activity. The attenuation rates and extrapolated source levels are very sensitive to variations within the data. This is observed in Figures 25 - 27[26] where the source level for 125 hertz is lower than expected. If the data was collected at a larger interval of distances, then an accurate source level could be extrapolated from the data.

The spatial transmission of the peak pressure levels demonstrated a more rapid attenuation rate for the air gun than the water gun at 1500 and 2000 psi input pressures (Figures 28, 29, and 30).[26] The source level of the air gun cannot be estimated by the least squares method because additional data had to be inserted to pad the source level to an accurate level as estimated by Bolt Technology. Possible reasons for needing to pad the data are the low sample size and the small range of clustered data.

Due to the varying distance for each pass the McFarland made, only the source levels extrapolated from the data can be used for comparison analysis. Extrapolating source levels from the spectral signatures and peak pressure levels provide an opportunity to compare against theoretical models. Each data point was examined closely to see whether it could be produced by the spherical transmission loss model or the shallow water transmission loss model.

The peak pressure level of the combo gun with a least-squares logarithmic fit follows a normal transmission loss model at 1,000 psi and the shallow transmission loss model at 1,500 and 2,000 psi. The extrapolated source levels of the air gun by using the lease squares logarithmic fit at 125 hertz are below the theoretical levels for both the spherical and shallow water transmission loss models. Therefore the source levels calculated by Bolt Technology will be used in comparison analysis. The extrapolated source level for 125 hertz actually decreased as the air input pressure increased from 1,000 to 1,500 to 2,000 psi. The data at 250 hertz followed a spherical transmission loss model at low air input pressures (1,000 psi) to a shallow transmission loss model at high air input pressures (2,000 psi). The source level at 250 hertz was equal at 1,000 and 1,500 psi but decreased at 2,000 psi. There was more energy at 250 hertz than 125 hertz because of the acoustic noise around 250 hertz that the McFarland produced when dredging. At higher frequencies, the least squares method followed more closely to the shallow water transmission loss model at all air input pressures. Also, the extrapolated source levels increased as the air input pressure increased. This information is summarized below in Table 4[26] and derived from Figures 25 - 30.[26]

Due to the varying distance for each pass the McFarland made, only the extrapolated source levels in Table 4[26] can be used to compare to the seismic guns' source characterization during non-dredging activity. Figures 31 - 33[26] graphically compare the source levels derived by the spherical transmission loss, shallow water transmission loss, and least squares model. The source levels during non-dredging activity computed by spherical transmission loss, shallow water transmission loss, and least squares data fit are tabulated below in Table 5.[26] Figures 34 - 36[26] illustrate the source levels during non-dredging activity.

Comparing Tables 4 and 5[26] and Figures 31 - 37[26] and disregarding the least squares method because more data is needed shows that noticeable differences occur between dredging and non-dredging activity. At 125 hertz, the source levels during dredging operation increased 6 db re 1 μPa at 1,000 and 1,500 psi and 3 db re 1 μPa at 2000 psi for both transmission loss models over non-dredging activity. At 250 hertz the air gun source levels increased 1-3 db re 1 μPa at 1,000 and 2,000 psi, but remained equal at 1,500 psi to the non-dredging source levels. At 500 and 1,000 hertz, the source levels during dredging activity decreased 2-5 db re 1 μPa from the source levels during non-dredging conditions. A possible explanation for the increase of the source levels at low frequencies and the decrease at high frequencies is the McFarland is transmitting wavefronts during dredging operation that coincide with the low frequencies, otherwise known as constructive interference, but inversely coincident with the high frequencies thereby causing destructive interference. The 6 db re 1 μPa increase does correspond with data collected of the McFarland during dredging and non-dredging activity when the seismic guns were not operating. Table 6[1] summarizes the difference in pressure levels between dredging and non-dredging activity.

Prototype model[25]

The objective of this project was to determine if seismic guns could effectively operate within a dredging environment to disperse endangered sea turtles from such environments. The collection of data from the Ft. Pierce test has produced a prototype model for the acoustical source characterization parameters. The source level of the air/water gun combination is estimated depending upon the air input pressure, dredging mode, and transmission loss model. Tables 4 and 5[26] provide the estimated source level if given the parameters. Also Figures 37 - 42[26] illustrate how the seismic signature amplitudes change with respect to distance and frequency during dredging and non-dredging operations.

Another indirect objective of this project, but the overall Sea Turtle Acoustic Dispersal System objective, is to determine at what distance will a sea turtle disperse from an area of an incoming dredge. Assuming a turtle will disperse if the acoustic level reaches 180 db re 1 μPa at 250 hertz, then the dredge during dredging operation (source level = 188 db re 1 μPa) will disperse the sea turtle when the dredge is on top of the sea turtle. This is too late. If the same turtle is subjected to the seismic guns (source level = 200 db re 1 μPa at 250 hertz) at 1,000 psi, the sea turtle will disperse at a distance of 10 yards if it is scared only by the spectral wave characteristics. The same turtle will experience the peak pressure level (source level = 230 dB re 1 μPa) of the seismic guns. If the turtle will disperse at 190 dB re 1 μPa for the peak pressure level, it will disperse at 100 yards from the dredge. Knowing that the dredge moves 5-7 knots = 2.5-3.5 yards per second and assuming the sea turtle needs 15 seconds to move from the path of the dredge, then the safety dispersal zone is 37.5 to 52.5 yards (2.5 yards per second x 15 seconds = 37.5 yards, 3.5 yards per second x 15 seconds = 52.5 yards).

If the sea turtle is only affected by the spectral amplitude (scare distance = 10 yards), then more intense input pressures and/or more seismic guns are needed. If the sea turtle is affected by the peak pressure level instead (scare distance = 100 yards), then this configuration is sufficient to disperse sea turtles from dredging areas. As it can be seen by the sample calculations, more study on sea turtle behavior is urgently needed to determine how effective seismic air guns are in dredging environments.

Conclusions[25]

Development and utilization of preventive equipment and methodologies within a hopper dredging environment has started to determine the impact on endangered sea turtles of utilizing this equipment. A test in Ft. Pierce, FL was conducted to analyze spectral characterization of utilizing seismic guns as a potential "scare" device to be used in conjunction with a deflector shield during dredging operations.

Time histories and spectral characterization were collected at a variety of air input pressures and ranges to derive an acoustic shallow water prototype model for dredging and non-dredging activity. During dredging activity, the McFarland's source level increases by 6 db re 1 μPa at 250 hertz over non-dredging operations. During seismic gun operation when the McFarland was idle, the spectral source characterization concludes that most of the seismic energy was focused in the low frequencies and that these frequencies attenuated more rapidly than the high frequencies. During dredging activity and seismic gun operation, the spectral amplitudes compared to the non-dredging seismic gun amplitudes increased at the low frequencies and decreased at the high frequencies because the dredging activity caused constructive interference at the low frequencies and destructive interference at the high frequencies.

In summary, this test was successful in that the source and spectral characterization of the seismic guns formulated an initial prototype dredging condition environmental model. More testing is urgently needed to determine what the source/spectral characterization would be within other actual dredging environments, such as a shipping channel, and to determine the sea turtle behavioral response to the seismic guns.

8 Dredging-Equipment Development and Evaluation

Introduction

The slow-moving and nearly silent dragheads that make contact with bottom sediments during hopper-dredging operations pose a potential threat to endangered sea turtles in certain areas. Concern over the welfare of the sea turtles resulted in a USACE research effort centered at WES to develop, field test, and evaluate a full-scale prototype deflector draghead capable of moving aside any sea turtle that might be in the path of an oncoming hopper-dredge draghead. The rigid-deflector draghead was field tested aboard the Corps hopper dredge *McFarland* during June 1993 off Fort Pierce, FL. Prototype performance of the new draghead was based on its ability to deflect model (mock) turtles constructed specifically for the field tests, and on the dredge's production rate. Comparative data were collected with a conventional hopper-dredge draghead both with and without the currently-used chain deflector. The rigid-deflector draghead was evaluated in Canaveral Harbor entrance channel during September 1993 under actual production dredging operations.

The rigid deflector for the hopper dredge draghead was designed by the Corps' Marine Design Center (MDC), located in the Philadelphia District. The MDC is the marine plant design center for the Corps of Engineers. Originally established in 1908 as the Marine Design Division, the MDC has played a major role in the development of hopper-dredge plants and the advancement of technology pertinent to hopper dredging and disposal. The MDC provides design for new technology for the existing Corps fleet. Contract specifications for the prototype rigid deflector were developed by the MDC, in cooperation with the Jacksonville District and WES. Fabrication of the prototype rigid deflector, and its successful installation on the draghead of the hopper dredge *McFarland*, were under the direct supervision of the MDC.

Field testing of the rigid-deflector draghead, and comparative evaluation of that draghead with a chain-deflector draghead and an unmodified draghead in a model (mock) turtle field were performed by Banks and Alexander (1994). Subsequently, an evaluation of the rigid-deflector draghead during actual dredging operations at Canaveral Harbor entrance channel was reported by Nelson and Shafer (1996). Appropriate sections of those documents pertaining to field testing and evaluation of the rigid-deflector draghead are reproduced herein verbatim (with spelling corrections where necessary), with no interpretation of the authors' intent. Complete details of the studies are given in the original documents.

Development and Evaluation of a Sea Turtle-Deflecting Hopper Dredge Draghead

Objective[27]

The objective of this report is to summarize the design and model evaluations and to describe in detail the prototype performance of a new turtle-deflecting hopper dredge draghead. Prototype performance of the new draghead was based on its ability to deflect model turtles constructed specifically for the field trials, and on its production rate. Comparative data were collected with a conventional hopper dredge draghead both with and without the currently used chain deflector.

Prototype rigid deflector draghead construction[27]

A cooperative effort between U.S. Army Corps of Engineers Marine Design Center, Philadelphia District, Jacksonville District, and WES resulted in contract specifications for the prototype draghead construction. The prototype was built by NORSHIPCO in Norfolk, VA. Like the model rigid deflector, the prototype was a modified California draghead with a radically redesigned V-shaped heel pad. Figure 3 (Figure 6 in Banks and Alexander 1994) shows the prototype rigid deflector draghead.

The rigid deflector prototype was constructed for the Corps of Engineers hopper dredge *McFarland*. The *McFarland* is operated by the Philadelphia District and works along the Eastern United States coastline. Design specifications for the prototype draghead were based on an operating depth of 48 to 52 ft and available on-deck ship clearances. The *McFarland*'s draghead saddle design and available area on deck for the new V-front draghead did not significantly impact the model-to-prototype design goals. (This may, however, be a concern for other hopper dredges.) The design operating depth was selected for prototype testing. Other operating depths would require modifying the V-shaped heel pad angle.

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[27] This section of Chapter 8 was reproduced verbatim from Banks, G. E., and Alexander, M. P. (1994), "Development and evaluation of a sea turtle-deflecting hopper dredge draghead," Miscellaneous Paper HL-94-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

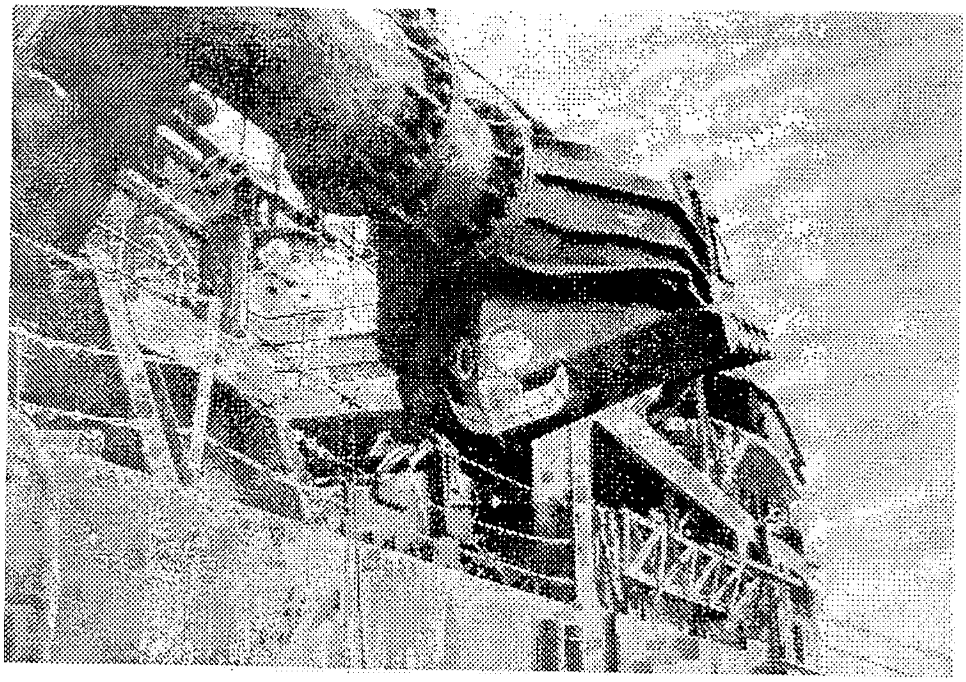

Figure 3. Prototype rigid deflector draghead installed on *McFarland's* port dragarm (after Banks and Alexander (1994))

Field test goals[27]

The rigid deflector draghead tests were designed to thoroughly evaluate the effectiveness of the rigid deflector draghead. Two general test goals were addressed:

a. Visual Observation of Effectiveness. Draghead positioning on the bottom required visual observations. Guidelines for using the new draghead were determined using underwater cameras. Visual observations were also used to determine the draghead effectiveness at deflecting model turtles.

b. Comparative Performance of Dragheads. This task included evaluating the model (mock) turtle-deflecting ability of the standard California draghead with and without the chain deflector. Testing the chain deflector allowed a prototype scale evaluation of existing technique deflecting capability. Prior to the STRP, only model evaluations had validated the chain deflector capability. A base condition was obtained using the standard California draghead without the chain deflector. The *McFarland* is outfitted with production meters, and comparative production data were also collected and considered a critical performance element to evaluate the rigid deflector.

Model (mock) sea turtle construction[27]

Prototype-scale model (mock) turtle construction presented a unique engineering task for the prototype draghead tests. The model (mock) turtles used in the draghead test facility for the model draghead were of comparatively simple construction and reusable. Regulations prevented the use of plastics and related products that would not be compatible or degrade quickly at an ocean test site. Determining what type of material could be constructed to a size, shape, and weight similar to a live turtle specimen and how it could be mass produced at a reasonable cost for a large-scale field effort was a formidable task.

Sea turtles are not perfectly circular in planform, but a circular model (mock) turtle was considered sufficient for testing purposes. Representative turtle diameters were found to be around 22 in., and model (mock) turtle appendages were not considered necessary. The center portion of the model (mock) turtle body was planned to be around 6 in. thick, tapering to a 2- to 3-in. thickness around the perimeter so that a natural-looking shell model (mock) would result. Figure 7[28] shows a schematic of the model (mock) turtle form constructed at WES. A center hole was included to facilitate handling and placement.

WES Geotechnical Laboratory personnel provided an air-entrained concrete mix design that would match the submerged weight of a live turtle having the average dimensions discussed above. The model (mock) turtles were cast at WES using the air-entrained, low-strength concrete mix. A model (mock) turtle made of concrete (cement, sand, water, and air) was an acceptable material that could remain in an offshore dredged material disposal site following testing. Figure 8[28] shows a single model (mock) turtle, and Figure 9[28] shows the loaded models (mocks) on their way to the field test site.

Field test site[27]

Several candidate field sites were considered as the hopper dredge *McFarland* was dispatched to the Jacksonville District for dredging assignments. Desirable site conditions included good water clarity for underwater observations, smooth bottom topography, low bottom current velocities (so that the model (mock) turtles would remain in position), and a location without protected mammal or fisheries resources. Since dredging operations at Fort Pierce, FL, were planned for July 1993, the Fort Pierce offshore disposal site was selected for field testing. The disposal site bottom was relatively flat, ranging from 48 to 52 ft deep. Water clarity was expected to be good, and little current was expected. The site was relatively free of marine life, and a small boat was arranged to continuously patrol the vicinity for right whale or sea turtle activity.

Two areas within the disposal site were delineated for testing, the sea trial site and the model (mock) turtle grid (Figure 10).[28] The model (mock) turtle grid was arranged into five rows of 60 model (mock) turtles each. Rows were 240 ft long and spaced 250 ft apart to form a rectangular grid. The separate sea trial testing area was necessary to determine proper operating conditions prior to evaluating performance of the new draghead in the model (mock) turtle grid.

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[28] Refers to tables, figures, or appendixes in Banks and Alexander (1994), not reproduced here.

Model (mock) turtle deployment[27]

Field test activity began with a contract to a local Fort Pierce, FL, area salvage company for diver placement of the model (mock) turtle grid. A Jacksonville District/WES team worked with the contractor providing Differential Global Positioning System grid layout. Each model (mock) turtle grid row end point was located with the Jacksonville District global positioning satellite unit and marked with anchored buoys. A hard-hat diver (contractor) secured a line on the bottom from one grid cross-section row end point to the other cross-section end point. The line was marked on 4-ft centers so that 60 model (mock) turtles could be positioned on each row. The model (mock) turtles were sent to the bottom diver from a work barge (Figure 12).[28] A line was secured from the barge to the row end anchors. The line was passed through the center hole in each model (mock) from the barge as it was cast overboard. The submerged weight of the models (mocks) was 4 to 5 lb, and they gently sank down the surface-to-bottom line to the bottom diver. The barge was positioned and anchored over each of the five cross-section rows to complete model (mock) turtle placement. The marked ropes used for bottom positioning were removed as each row of model (mock) placement was completed.

Field performance descriptors[27]

To evaluate draghead performance in the model (mock) turtle grid, several terms were applied to describe models affected by the draghead. An "encounter" was regarded as a model (mock) turtle in the oncoming draghead path that was relocated in some way by the draghead. Encounters were further described as "deflected," "damaged," or "entrained." Deflected model (mock) turtles were pushed to the side of the oncoming draghead and buffered from any dangerous impact by the sand riffle ahead of the deflector. Damage was defined to be noticeable chips, breaks, or scratches to the models. Entrained models (mocks) were taken in with the dredged slurry and deposited in the hopper. The entrained models (mocks) were fragmented as they passed through the draghead grate and dredge pump, and therefore were comparable with a live specimen mortality.

Rigid deflector performance in the model (mock) turtle grid[27]

Multiple tracklines through the model (mock) turtle grid provided a total of 39 encounters with model turtles. Most of the encounters were successful deflections. (Table 1[28] provides a tabulation of the rigid deflector test results in the model (mock) turtle grid.) Two model (mock) turtles were entrained in the draghead suction when the draghead lost contact with the bottom as it moved over a depression. The two entrained models (mocks) were in a noticeable depression; and on this particular test run, the crew was advised to follow their normal draghead positioning procedure and ignore (for comparative test purposes) the hard-on-bottom, straight-pipe condition. This case of model (mock) turtle entrainment points out that design operation procedures should be followed for maximum deflecting capability. Also, there may be times when a sea turtle may be located in a depression similar to where the two models (mocks) were so that it would be entrained if the swell compensation system did not react fast enough to keep the dragline hard on bottom.

In addition to deflecting capability, what effect, if any, that the V-shaped lead draghead edge would have on vessel steering and maintaining course along a dredged trackline was unknown prior to the prototype rigid deflector tests. The ship captain, however, reported somewhat easier steering with the V-shaped prototype than conventional dragheads. The V-shape apparently reduces drag forces encountered with conventional draghead shapes. It is significant that the new design did not adversely impact maneuverability.

Chain deflector performance[27]

Prior to the STRP tests, no prototype chain deflector tests using underwater video had been done. Following the rigid deflector draghead tests, the video equipment and instrumentation package were switched to the starboard dragarm where a standard California draghead was outfitted with a chain deflector. The sea trial site was used for video observation of the chain deflector during normal dredging operations. It was noted that the lead edge of the deflector was not sliding on the bottom as it should. The forward support cable (Figure 3)[28] had to be lengthened to allow the deflector to make contact with the bottom. Otherwise, the chain deflector would have been ineffective. Also notable was a much less prominent sand riffle pushed ahead of the chain deflector bottom bars (when proper adjustment was achieved), implying an increased possibility for damage to a turtle. Optimum operating procedures for the standard California draghead with chain deflectors was determined to be the same as for the rigid deflector; a straight-pipe, hard-on-bottom operation.

Dredged tracklines through the model (mock) turtle grid resulted in 34 model (mock) turtle encounters. Four model (mock) turtles slid under the deflector and were entrained with dredged material. One other model (mock) turtle was damaged. Of the four entrained (mock) turtles, one of these was initially pinned under the forward support cable on the front of the chain deflector before it slid under.

Standard California draghead performance[27]

The final draghead field test evaluated a standard California draghead without any turtle deflecting modifications. This provided a statistical base condition with which the rigid deflector and chain deflector effectiveness could be compared. The chain deflector was removed from the starboard draghead leaving the conventional California draghead without any sea turtle-deflecting mechanism.

To be statistically compatible with the rigid deflector prototype and chain deflector tests, the standard California tests were conducted with the same straight drag-pipe and hard-on-bottom draghead operation. The standard California draghead encountered 28 model (mock) turtles during test runs. Fourteen of these were entrained with dredged material. Another 14 were deflected, but 9 of these were damaged as they were deflected.

Model (mock) deflection and production comparison[27]

Table 1[28] summarizes the number of model (mock) turtle encounters, deflections, and damages for the prototype draghead field tests. These results are believed to be conservative when considering a live turtle. A live turtle would naturally swim away from immediate danger, and the turtle's effort could be expected to reduce, at least, the number of damages.

The rigid deflector successfully deflected 95 percent of the model (mock) turtles it encountered. The chain deflector was comparatively effective, deflecting 85 percent of the models (mocks) it encountered. The standard California draghead only successfully deflected 18 percent of the models (mocks) that it encountered. Table 1[28] shows that a significant increase in draghead-deflecting capability can be realized using either the rigid deflector draghead or chain deflectors on conventional dragheads. Qualifying deflecting capability with the specified operating procedures and adjustments previously discussed is important.

Hopper dredging is expensive, and a deflector draghead that reduced standard production rates would be a costly drawback for possible future deflector draghead requirements on hopper dredges. The *McFarland*'s production metering system was used to calculate volumes of material for each dredged line through the model (mock) turtle grid. Table 1[28] shows averaged production values for the three draghead tests. The rigid deflector prototype production rates are comparable with the conventional California draghead production. (Appendix A[28] provides additional production evaluation details.)

Conclusions[27]

A new rigid sea turtle deflector hopper dredge draghead was constructed and field tested. The rigid deflector prototype proved most successful at deflecting model (mock) sea turtles by comparison with a standard California draghead with and without the currently used flexible chain deflector mechanism. Under specified operating conditions while dredging, the rigid deflector draghead was easiest to maintain position along dredge tracklines. The rigid deflector draghead also resulted in comparable (slightly higher) dredged material production rates than did the conventional draghead. However, effective turtle deflection requires following the operating and adjustment procedures described in this report. The prototype-scaled model (mock) turtle field test is believed to be a reliable indicator of how the new draghead will deflect real turtles.

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

Purpose and objectives[29]

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 (a) determine sea turtle presence and relative abundance in Canaveral Harbor entrance channel, (b) determine the percentage of time the turtles are on the bottom, and (c) assess the number of sea turtles entrained on the inflow screens during dredging with the rigid deflector draghead.

Approach[29]

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 unacceptable high rates of sea turtle entrainment and mortality. Documented turtle takes 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.

Dredge operation and monitoring[29]

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).

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[29] This section of Chapter 8 was reproduced verbatim from Nelson, D. A., and Shafer, D. J. (1996), "Effectiveness of a sea turtle-deflecting hopper dredge draghead in Port Canaveral entrance channel, Florida," Miscellaneous Paper D-96-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. (Not all sections of that report have been reproduced herein.)

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.

Results and discussion

Sea turtle abundance[29]

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),[30] 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).

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).[30] MFS contributed 12 additional loggerheads captured during Turtle Excluder Device (TED) tests in Canaveral Channel (Table 3).[30] 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[29]

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 injured. 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,

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[30] Refers to tables or figures in Nelson and Shafer (1996), not reproduced here.

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).[30] 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).[30] 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, 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.

Diving and submergence behavior[29]

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).[30] 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 from 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).[30] 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 middepth primarily reflects ascent and descent time, although one turtle (SSE647) was observed to spend nearly equal amounts of time on the bottom (47.3 percent) and at middepth (46.8 percent). On the 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 percent) on the surface (Nelson, Benigo, and Burkett 1987; Renaud and Carpenter 1994).

Diving patterns varied widely among individual turtles (Table 7).[30] Bottom time for individual turtles ranged from 12.4 to 52.6 min, with an average of 21.1 $\pm$ 1.0 (mean $\pm$ SE). Mean surface interval ranged from 0.7 to 2.3 min, with an average of 1.5 $\pm$ 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 $\pm$ 0.01 and 0.8 $\pm$ 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 $\pm$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 $\pm$ 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; Nelson, unpublished data, USACEWES).

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 difference 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.

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 min ± 0.9 (SE), $n = 55$) than during the day (mean = 1.2 ± 0.08 (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 et al. 1993a, 1993b; Nelson, Benigno, and Burkett 1987). Factors that may influence diving behavior include water temperature and 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 °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).

Turtle locations and movements[29]

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).[30] 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).[30] 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 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, SSE636, SSE647, SSE659, and SSE669) traveled more than 2 km from the channel during the monitoring period (Figure 11).[30] 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.

Summary and conclusions[29]

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 from 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 variations, 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.

9 Synopsis

Sea turtles are endangered or threatened, and are so listed and protected under the Endangered Species Act (ESA) of 1973 and subsequent amendments. The U.S. Army Corps of Engineers (USACE) has a congressional mandate for maintaining the navigability of entrance channels to harbors, seaports, and military facilities along the southeastern Atlantic coast of the United States by periodic dredging activities. Most of these channels are inhabited for at least part of the year by threatened or endangered sea turtles. A major concern is entrainment of sea turtles by hopper-dredge dragheads. Mortalities due to entrainment during hopper-dredging operations have been documented since 1980. The USACE maintenance-dredging operations comply with the ESA.

USACE districts were instructed by Headquarters (HQUSACE) in August 1991 to implement measures that would lead to reduced impacts on sea turtles. Those measures included avoidance and reduction of impact through dredging operation windows and equipment modification as well as improved techniques to measure and monitor incidental take. USACE districts were directed to expand research efforts on new draghead designs and operational controls to protect sea turtles in navigation channels. HQUSACE stated that significant field studies, well coordinated with the U.S. National Marine Fisheries Service (NMFS), should be conducted to better understand turtle behavior around ship channels.

The purpose of the Sea Turtle Research Program (STRP) was to minimize the risk to sea turtle populations in channels along the southeast Atlantic region of the United States from hopper-dredging activities. Achieving this goal would have the effect of widening dredging operation windows previously established by USACE and NMFS that restrict dredging to specific times in certain channels.

Sea Turtle Research Program (STRP)

A coordinated research program adequate to address the sea-turtle problem on a nationwide basis was developed by WES Coastal and Hydraulics Laboratory, Environmental Laboratory, Geotechnical Laboratory, and the U.S. Army Corps of Engineers South Atlantic Division. This Sea Turtle Research Program (STRP) was divided into two interrelated components; (a) a biological approach, and (b) an engineering approach. Each approach provided a series of products that served to reduce the effect of dredging operations on sea turtles (McNair 1992). The biological approach consisted of two distinct research tasks; (a) relative-abundance investigations, and (b) behavioral studies. The engineering approach consisted of four distinct research tasks; (a) acoustic-detection investigations, (b) bioacoustic studies, (c) acoustic-dispersal evaluations, and (d) dredging-equipment development and evaluation.

The 2-year STRP was authorized by HQUSACE and initiated by WES in November 1991. The six distinct research tasks of the STRP were conducted by, or contract studies were performed under technical oversight of WES principal investigators. Contractors to WES who contributed to the STRP included Buffalo State College, Buffalo, NY; Cornell University, Ithaca, NY; Okeanos Ocean Research Foundation, Inc., Hampton Bays, NY; Archie Carr Center for Sea Turtle Research, University of Florida, Gainesville, FL; Virginia Institute of Marine Science, College of William and Mary, Gloucester Point, VA; Manatee Research Center, Florida Atlantic University, Boca Raton, FL; Lowry Park Zoo, Tampa, FL; and J. O'Hara, Aiken, SC.

Biological approach

The biological approach employed spatial and temporal surveys and telemetry that provided statistical representations of data to establish meaningful indices of turtle abundance and behavioral patterns.

Relative-abundance investigations

The objective of the relative-abundance investigations was to determine indices of sea turtle abundance at six southeast Atlantic harbor entrance channels maintained by hopper dredges; (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL, (c) Brunswick Harbor ocean bar channel, GA, (d) Savannah Harbor ocean bar channel, GA, (e) Charleston Harbor entrance channel, SC, and (f) Morehead City Harbor entrance channel, NC. The study was accomplished through trawling the channels in a set pattern with standardized trawling equipment over a specified time period. As turtles were captured in the trawl, they were brought aboard the trawling vessel, examined, measured, tagged for identification, and released. Analysis included capture and recapture rates per unit time and per unit area of channel.

Behavioral studies

The objective of the behavioral studies was to monitor movement of sea turtles over time and distance with biotelemetry techniques in the vicinity of four southeast Atlantic harbor entrance channels maintained by hopper dredges; (a) Canaveral Harbor entrance channel, FL, (b) Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL, (c) Savannah Harbor ocean bar channel, GA, and

(d) Charleston Harbor entrance channel, SC. Biotelemetry is the process of attaching radio, sonic, and/or satellite transmitters to the shell of captured sea turtles and documenting their behavior through detailed observation. Highly-trained observers followed the instrumented turtles in survey boats equipped with sensitive receivers to record their behavior.

Engineering approach

The engineering approach made use of physical model studies, engineering and structural analyses, acoustics, and field demonstrations to develop hardware modifications that would make dredging operations safer for sea turtles. This approach consisted of two basically different kinds of investigations; (a) acoustic studies, and (b) dredging-equipment development and evaluation.

Acoustic-detection investigations

The objective was to evaluate acoustic-detection techniques for faster, more reliable, and quantitative sea-turtle surveys. The task was conducted to determine if the presence and numbers of turtles in channels can be assessed through hydro-acoustic means. Mine-detection and fish-locating technologies were pursued to determine hydro-acoustic signatures that might provide a discrimination of sea turtles submerged in a navigation channel.

Bioacoustic studies

The objectives of the bioacoustic studies were to determine acoustic thresholds, frequency range, and auditory behavior of sea turtles and manatees (mammals which occupy the same coastal waters as sea turtles, and may be impacted by sea turtle dispersal techniques). Controlled tests on live loggerhead sea turtles at the Virginia Institute of Marine Science, Gloucester Point, VA, established acoustic thresholds and frequency-range baseline information for sea-turtle acoustic-dispersal studies. Controlled tests on live West Indian manatees by the Manatee Research Center, Florida Atlantic University, Boca Raton, FL (tests conducted at Lowry Park Zoo, Tampa, FL), established acoustic thresholds and auditory behavior of manatees.

Acoustic-dispersal evaluations

The objective was to evaluate a safe acoustic technique for dispersing sea turtles from the vicinity of hopper-dredge dragheads. Air- and water-guns meeting turtle-response auditory-range requirements were field tested aboard the Corps hopper dredge *McFarland*; no sea turtles were present. Controlled tests using live sea turtles were conducted at the Virginia Institute of Marine Science; turtles responded with apparently no detrimental effects.

Dredging-equipment development and evaluation

The objective was to develop, field test, and evaluate an effective sea-turtle deflector for the Corps' California-style hopper-dredge draghead. Three draghead configurations were field tested; (a) California-style draghead unmodified, (b) California-style draghead with chain deflector, and (c) California-style draghead with rigid deflector. The California-style draghead with rigid deflector was evaluated under actual prototype dredging operations at Canaveral Harbor entrance channel.

STRP Research Synopsis Methodology

The following synopses of the research tasks conducted by the STRP were judiciously extracted from the verbatim sections previously reproduced in the body of this summary report. These extracts are a summation of major findings of the research, and are themselves essentially verbatim. They, again, contain no interpretation of the authors' intent as found in the original WES and contract reports referenced herein.

Relative-Abundance Evaluations

Assessment of sea-turtle abundance in six south Atlantic U.S. channels

As part of the biological studies by Dickerson et al. (1995), a total of 76 monthly trawling surveys were conducted for sea turtle relative abundance from June 1991 through March 1993 in the Canaveral Harbor entrance channel, FL (12 surveys), Fernandina Harbor St. Mary River entrance channel (Kings Bay), FL (14 surveys), Brunswick Harbor ocean bar channel, GA (9 surveys), Savannah Harbor ocean bar channel, GA (17 surveys), Charleston Harbor entrance channel, SC (11 surveys), and Morehead City Harbor entrance channel, NC (13 surveys). The objectives of these surveys were to evaluate species composition, population structure, and spatial and temporal (seasonal) distributions. Results of relocation efforts conducted during this time are also included in Dickerson et al. (1995).

A combined total of 645 loggerheads (*Caretta caretta*), 20 Kemp's ridley (*Lepidochelys kempi*), and 5 green turtles (*Chelonia mydas*) were captured. Loggerheads were consistently the most abundant species in all six channels. Kemp's ridley and green turtles did not appear to utilize the deeper dredged areas of the channels. Catch per unit effort was calculated as indices to compare spatial and temporal sea turtle abundance within and between the six channels. Juvenile loggerheads 50-70 cm in length were the predominant size classes in the five channels north of Canaveral Harbor. Very few adult loggerheads were present in the deeper dredged section of these channels. Both adult and juvenile loggerhead size classes utilized the deeper dredged section of Canaveral Harbor; however, differences in seasonal occurrence were seen.

For the five channels surveyed north of Canaveral Harbor, loggerhead (primarily juveniles) captures began in late spring (April, May), increased throughout summer (June, July, August), peaked in fall (September, October, November), then dramatically declined during winter (December, January, February). Peak month for loggerhead captures in these channels appeared to be October. In Canaveral Harbor, adults were primarily present during late spring through summer whereas peak occurrence for juveniles was midwinter (January).

Recaptures of sea turtles throughout this 21-month study suggest month-to-month and year-to-year site fidelity of some individuals. Recaptures of turtles tagged between multiple channels suggest channel utilization during migratory activities.

The success of relocation efforts is difficult to evaluate; however, relocation of turtles out of the dredging area may be most feasible when there are low densities of turtles.

For the five channels surveyed north of Canaveral Harbor, very few sea turtles were captured when water temperatures were at or below 16 °C. Although the lower critical temperature limits may be different for each species and size-class, temperatures below 16 °C may be used as a conservative indicator of time periods in these channels which have reduced sea turtle occurrence or activities. The relationship between sea turtle occurrence and water temperature was not seen at Canaveral Harbor as was shown in the other channels surveyed (Dickerson et al. 1995).

Assessment of sea turtle relative abundance in Port Canaveral Ship Channel, Florida

Bolten et al. (1993) conducted monthly surveys of the turtle populations in the Port Canaveral Ship Channel, FL, from March 1992 through February 1993. The objectives of those surveys were to evaluate species composition, size class frequencies, relative abundance, and seasonal and spatial distributions. In addition, baseline blood chemistry parameters were determined for loggerhead sea turtles (*Caretta caretta*).

The sea turtle populations in Port Canaveral Ship Channel are dominated by loggerheads. Although only one Kemp's ridley was captured during the survey year, other surveys have indicated that the Channel is important habitat for immature Kemp's ridley.

The size frequency of loggerhead captures in Port Canaveral Ship Channel has a strong bimodal distribution, suggesting that the two size classes may use the Channel habitat for different purposes, and that they may move in and out of the Channel at different times. The two classes were divided at 82.5 cm maximum straight carapace length, and designated as juveniles or adults. Juveniles occupy the channel year-round in relatively constant numbers and apparently use the channel as an area in which to rest and/or feed. Adults essentially move into the Channel during the breeding season, and females use the area as an inter-nesting habitat. The sharp increase in number of juvenile loggerheads in the Channel in January probably represents a group of juveniles migrating south away from cooler northern temperatures. The maximum CPUE found by Bolten et al. (1993) occurred in January, and the minimum CPUE occurred in September. Based on CPUE values, it appeared the relative abundance of loggerheads in Port Canaveral Ship Channel has declined between the time of Henwood (1987) (for surveys conducted in the Channel between 1978 and 1984) and the Bolten et al. (1993) study.

There was significant differential use of four stations in the Channel by loggerheads. Turtles were present in higher numbers in Stations B and C than in Station A, and only one turtle was captured in Station D. The distribution may be correlated with bottom type. Stations B, C, and D have softer substrates than Station A, and Station D does not have the steep-sided channel of the other Stations, which may provide shelter to the turtles or act to concentrate organisms on which the turtles feed.

Blood samples were collected from 168 loggerheads, and plasma samples were evaluated for 26 analytes. It is important to establish baseline values for blood chemistries to monitor physiological status of loggerhead populations.

In this study by Bolten et al. (1993), 22 of 26 analytes had a significant seasonal effect; only chloride, alkaline phosphatase, gamma-glutamly transferase, and total iron did not. There was a trend for values to increase in warmer months, except for urea nitrogen (BUN), which decreased in warmer months. Of the seven chemical parameters evaluated (glucose, sodium, potassium, chloride, magnesium, calcium, and urea), only chloride did not vary significantly by month. Concentrations of 22 of the 26 analytes are significantly related to body size in the loggerheads in this study.

Behavioral Studies

Assessment of sea turtle baseline behavior and trawling efficiency in Canaveral Channel, Florida

Objectives of this study by Standora et al. (1993a) in Canaveral Channel, FL, were to (a) use telemetry techniques to determine the normal pattern of usage of the channel and compare this to time spent outside the channel, and (b) telemetrically monitor vertical movements of turtles to determine the relative amounts of time spent in different portions of the water column.

As a result of trawl surveys within the confines of the Cape Canaveral ship channel, 55 loggerhead sea turtles were captured during the 1-month study period (July-August 1992). Among the captured turtles there was a bimodal distribution of carapace lengths indicating that two distinct size classes of individuals were present. The mean weight for the 31 turtles which were captured and had transmitters attached was 99.9 kg. It is likely that the smaller group represented the subadults which are residents of the area, while the larger turtles were probably transient adults from nearby nesting areas. Among the turtles that were selected to be used for the telemetry study, all but two individuals were from the larger adult group.

Of the 31 turtles that were outfitted with transmitters and released immediately back into the channel, 23 individuals were located again after intervals of greater than 24 hr. Most turtles remained in the vicinity of the channel for up to several days after release. Upon subsequent contact, nearly half (48 percent) of the recontacted animals were found within 3 km of their initial release site; only three (13 percent) were located greater than 10 km away. Since contacts with turtles were not continuous, it was not possible to quantify the percentage of time spent in the channel for a single turtle. Nevertheless, with such a large sample size of individuals, the data indicate that turtles spend very little time within the channel boundaries over the next several days after release. This observed post-capture behavior could explain why, historically, turtles rarely have been recaptured during the same trawl survey within the channel.

As determined by dive profiles, turtles spent very little time at the surface. This resulted in low percentages of time spent in the upper third of the water column for all animals. When diving behavior was analyzed with respect to each different period, it was noted that nearly equal amounts of time were spent by turtles at all three levels of the water column during Early AM, Late AM, and Middle PM. In contrast, turtles spent the majority of their time in the mid-water during Early PM, and at the bottom in Late PM. The observed results from this study suggest that trawling during the Late PM period may increase the probability of capturing turtles. Therefore, it was suggested by Standora et al. (1993a) there may be less of an impact on the turtle population if dredging activities were conducted during the other time periods.

Three turtles spent major portions of their monitoring sessions at intermediate depths (i.e., not at the surface nor on the bottom). Although these individuals were monitored on different days and at different depths, they were located in water temperatures of 26-27 °C. A slight increase in depth would have placed these animals below the thermocline in water temperatures several degrees cooler. Although other factors such as light intensity and food availability may influence their vertical distribution, temperature is very likely to have a strong influence on their behavior.

Artificial targets were used in 21 trials to assess trawler efficiency. Since differences in net configuration affected trawling efficiency in this artificial target study, it was important to assess the influence of such design modifications on the capture of live turtles. Thus, 34 separate trawler tows were conducted in the ship channel, using two different net configurations simultaneously. A standard lighter rigging was towed along the port side, while a heavier weighted net was used along the starboard. As was observed with the artificial targets, there was a considerable improvement in the effectiveness of trawling using the weighted net. The results from these trawling studies on both artificial targets and live turtles clearly demonstrate the importance of net design on catchability. Despite the success of these trawling studies in the improvement of catchability, they do not account for turtle behavior. It is never possible to assess the influence of behavior on catchability when trawling is conducted during normal censusing surveys. These observations suggest that turtle behavior strongly influences the efficiency of trawling.

Diving behavior, daily movements, and homing of loggerhead turtles (*Caretta caretta*) at Cape Canaveral, Florida, March and April 1993

This study by Standora et al. (1993b) focused primarily upon sea turtle biology with respect to horizontal movement of turtles within the Canaveral area during early spring, and to their vertical movement within the water column. A second goal was to determine the effect of relocation on turtles that were captured and released. Included in this study was an analysis of direction and distance of displacement to determine if specific activities were more effective in keeping relocated turtles from returning to the site during short-term dredging operations.

Combined results from this study, which was conducted during spring 1993, and an earlier study of summer 1992 (Standora et al. 1993a) provided important information about the behavior, movements, and habitat usage of loggerhead turtles in the Cape Canaveral area. Comparisons of turtles between the two seasons revealed major differences in the patterns of vertical distribution within the water column. In the spring study, turtles spent greater amounts of time in the bottom third of the water column than they did in the summer. They also spent considerably less time at the surface during spring.

In addition to apparent seasonal differences, there were significant differences in behavior between size classes within the spring season. The differences in turtle behavior observed both between and within the seasons may reflect intrinsic differences among age classes such as reproductive condition. These findings have important implications for developing strategies to minimize dredging impacts. Dredging conducted in the spring is more likely to have adverse effects on turtles than during summer (although both may be ill-advised) because of the increased time spent on the bottom. Additionally, because turtles spend less time at the surface, if turtle censusing is conducted by aerial surveys, spring surveys will tend to more greatly underestimate population numbers. For any aerial survey data, time-sensitive correction factors, both seasonal and diurnal, need to be applied to increase the accuracy of population estimates.

A proposed management tool to mitigate or eliminate dredging impacts in channels is relocation of turtles prior to operations. These studies by Standora et al. (1993a, 1993b) have demonstrated that this method must be evaluated with respect to two factors; (1) efficiency of the turtle capture method, and (2) successful removal and translocation of animals to other sites. Results from the summer 1992 study showed that trawling as a method for collecting turtles is useful, but is affected by such factors as bottom substrate, net configuration, seasonal influences, and turtle avoidance behavior. The relocation study conducted in spring of 1993 showed that this method is similarly useful but has attendant limitations. More than half of the turtles that were relocated returned to the general channel area. Although relocation appeared to be potentially effective, the use of this method as a mitigation technique for dredging is not recommended by Standora et al. (1993b) during the spring season.

This study by Standora et al. (1993b) was conducted during the spring at Cape Canaveral, FL; therefore, any interpretations of the results or conclusions about observed turtle behaviors should be limited to this specific season and location.

Behavior of loggerhead sea turtles in St. Simons Sound, Georgia

Keinath, Barnard, and Musick (1992) utilized sonic and radio telemetry to determine the movements and diving activities of loggerhead turtles (*Caretta caretta*) in St. Simons Sound, GA. Between 10-22 June 1991, five loggerhead sea turtles, which were captured by a shrimp trawler, were fitted with combination radio and sonic transmitters. The turtles were released near the mouth of St. Simons Sound. Time and duration of surfacing and diving were determined from the presence or absence of radio signals.

Radio telemetry data showed the turtles spent very little time at the surface, with the majority of surfacing events under 10 sec. The majority of dives were also very short, but dive profiles measured with sonic telemetry showed that dives to the bottom usually took approximately 60 sec. Thus these short "dives" measured with radios were most likely shallow dives and should be considered surface events. Much more time was spent submerged than at the surface, and there seemed to be no difference between the morning and afternoon. Descent and ascent rates were rapid, with dives to the bottom taking 40-60 sec, and surfacings taking 20-60 sec. In some cases surfacing events were measured by the sonics, but not the radios. This suggests that the surfacing data measured with radios overestimate the duration submerged and underestimate the amount of time spent at the surface and number of dives.

At least some of the loggerhead turtles in St. Simons Sound were residents for up to 5 days during June 1991 (Keinath, Barnard, and Musick 1992). The turtles spent the majority of time at the bottom of channels, drifting with currents, probably foraging. The use of channels as opposed to adjacent widespread shallow habitats was marked. Future studies should address the conflicts of surfacing events measured with sonic and radio telemetry. Since many of the dives measured with radio telemetry were under 60 sec, these should be considered surfacing events. The differences between surface and submergence times collected with radios should be compared with the same data, but with dives less than 60 sec considered as surface time.

Behavior of loggerhead sea turtles in Savannah, Georgia, and Charleston, South Carolina, Shipping Channels

Keinath, Barnard, and Musick (1995) telemetered 31 loggerhead turtles in Savannah, GA, and Charleston, SC, in 1993. Two turtles were studied in the spring in Savannah, ten were studied in the spring in Charleston, nine were studied in the autumn in Charleston (one was recaptured and re-equipped), and ten were studied in the autumn in Savannah.

The water temperature in Savannah during the spring project was below that usually accepted as the lower limit (15 °C) where wild turtles are found, and the scarcity of turtles off Savannah in the spring reflects this. However, temperatures during the subsequent three projects were above 15 °C, and turtles appeared to be abundant. Turtle behavior in cool water (basking at the surface) also may have contributed to the minimal capture rate at Savannah (the trawl net only captured turtles near the bottom). Of the 30 turtles tracked, 6 spent more than 10 percent of the time within channels. These results are consistent with studies done in Cape Canaveral in spring, summer, and autumn (Nelson and Shafer 1996; Standora et al. 1993a, 1993b) where few turtles stayed within channels.

Diving behavior was variable within, as well as between turtles. All turtles spent more overall time per dive cycle submerged than at the surface. Turtles tracked in the spring in both sites spent more time at the surface and less time submerged per dive cycle, as opposed to the autumn tracks. This behavior was probably due to cool water temperatures, with turtles basking at the surface and making short dives to forage. The two turtles tracked in Savannah in the spring had large surface times, and did not stay at the bottom for long periods. These behaviors were probably due to the cool water temperatures, especially at the bottom. Of the remaining turtles tracked off Charleston and Savannah, all but two turtles spent the majority of the time at the bottom, as is consistent with other studies. The two exceptions were turtles that stayed near the surface for the entire monitoring period.

According to this study by Keinath, Barnard, and Musick (1995), turtles captured in Savannah, GA, and Charleston, SC, shipping channels rarely remained within the channels after release. Most either went offshore into deeper water, traveled to shallow water adjacent to the channels, or vacated the area. Turtles appear to avoid water temperatures below 15 °C. At temperatures near 15 °C, turtles spend more time at the surface, probably basking, and make short forays to the bottom. Except in very few instances turtles spent little time within the water column - only when ascending or descending. In water temperatures over approximately 19 °C, turtles spend the majority of the time at the bottom, probably foraging for benthic prey.

Subadult loggerhead behavior in Kings Bay, Georgia

This study by Nelson (1995) was conducted in the Fernandina Harbor entrance channel (Kings Bay) located on the southeastern Atlantic coast on the boundary line of the states of Florida and Georgia. Turtles were captured by conducting repetitive 15- to 30-min (total time) tows in the channel. All captured turtles were identified, measured, and tagged. Captured turtles were instrumented with both radio and sonic transmitters for biotelemetry studies. The vertical position of the turtle in the water column was recorded through the use of depth-sensitive sonic transmitters. Telemetry studies were conducted continuously for approximately 30 days during the spring, summer, and fall seasons.

The percent of time spent on the bottom for spring was less than for summer or fall. Percent of time spent at mid-water depths and at the surface was greater in the spring than in the summer or fall. The percent of time spent at mid-depth primarily reflects ascent and descent time, although turtles monitored during spring spent a higher percent of time at mid-depths than during other seasons. The 24-hr day was divided into six 4-hr time groups beginning at 00:01 and ending at 24:00. Bottom time was largest from 20:01 to 04:00 (night) and significantly less from 08:00 to 16:00 ($p \leq 0.05$) (day). Dawn (04:01-08:00) and dusk (16:01-20:00) had mean bottom times intermediate between day and night.

Preliminary results suggest that if the dredging season must be expanded outside the winter season, spring is when turtles spend less time on the bottom, and are thus less susceptible to entrainment.

Acoustic-Detection Investigations

Feasibility of sampling sea turtles in coastal waterways with sonar

The purpose of this study by Kasul and Dickerson (1993) was to explore the feasibility of using acoustical methods to remotely detect and identify sea turtles. A reliable remote sensing survey method must be able to consistently detect sea turtles in their natural environment, and with very high accuracy, it must be able to distinguish sea turtles from other objects in the sea. The dual requirements of detection and identification create two different sets of demands on the remote sensing method.

Loggerhead, Kemp's ridley, and green sea turtles are the species most likely to be found in trawl surveys of harbors and shipping channels. Loggerheads are by far the most numerous. They are typically found in sizes from 45 to 110 cm SCL, but they are most abundant in sizes from 55 to 75 cm SCL. Sea turtles collected from shipping channels that are approximately 30 to 45 cm SCL are most likely to be Kemp's ridleys.

Two detection needs must be addressed. First, the method must be able to detect turtles on the seabed, where in the summer months, they may spend 80 percent of their time. Also, since sea turtles may be present in low density, a detection method with a wide search area in water 4-10 m deep is advantageous. High-resolution sector-scanning sonars designed for use in shallow water may address the most important detection needs.

On the seabed, demersal animals and various forms of debris will occur with turtles. Of particular interest are the horseshoe crabs that loggerhead turtles are found with and feed upon extensively. Horseshoe crabs occur in the same areas and habitats as loggerheads, and are similar in body shape and overlap in size with sea turtles. Horseshoe crabs may indicate the presence of sea turtles, but the two must also be distinguishable from one another.

At least four approaches to sea turtle identification seem to warrant additional investigation. (1) The first approach exploits the dependence of target strength on sonar transmission frequency to produce spectral signatures that are characteristic of different aquatic animals. (2) The second approach applies high-resolution sonar imaging to obtain recognizable sonar pictures. (3) The third approach involves observing the behavior of targets tracked inside of the acoustic detection beam. Since benthic-feeding turtles spend most of their time on the bottom and since they surface regularly to breathe, there are behavioral expectations that can be used to help distinguish turtles from other targets. (4) Finally, as a fourth approach, the acoustic characteristics of echoes detected in a sonar search may also assist in target identification. A knowledge of target strength is also needed for the proper design and operation of the sonar detection system.

Kasul and Dickerson (1993) experimentally determined the acoustic target strength of loggerhead turtles in sizes commonly found in coastal shipping channels. The data indicate that the dorsal aspect target strength of loggerhead turtles 45 to 110 cm SCL varies approximately from -16 to -8 dB with 120 kHz ensonification. These values are considerably larger than the dorsal aspect target strengths of nearly all fishes expected in shallow coastal waterways. Kasul and Dickerson (1993) also found that the target strength of loggerhead turtles is about 2 dB larger than the target strength of horseshoe crabs having the same carapace length. Since horseshoe crabs seldom exceed 35 cm SCL, their maximum target strength is at least 4 dB lower than the smallest loggerhead turtles that are typically found in coastal channels.

Variations in the target strengths of both loggerhead turtles and horseshoe crabs were associated with variations in turtle size. Regression equations describing this relationship suggest that physical size can be estimated from target strength measurements.

These data suggest that loggerhead turtles in sizes typically found in coastal waterways can be acoustically separated from most other aquatic animals on the basis of echo amplitude. Amplitude-based criteria are probably not adequate as a sole means of sea turtle identification, but they may be used effectively in conjunction with additional identification criteria to provide acceptably accurate turtle identification.

Bioacoustic Studies

Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*)

Repulsion from hopper dredges using auditory stimuli is one frequently proposed solution for reducing incidental mortalities of sea turtles. Before this tactic can be assessed, research must be performed on the auditory mechanism of sea turtles. In this study by Moein (1994), threshold for response to stimuli and the effects of stimuli and white noise on the threshold were determined for the loggerhead sea turtles (*Caretta caretta*). The objectives of this study were threefold; (a) collect auditory evoked potentials from loggerhead sea turtles to determine threshold of response for both tone bursts and click stimuli, (b) test the stimulus rate as presented to the loggerhead for its effect on the I-V interpeak conduction time, and (c) test white noise for its ability to mask the stimulus and render the stimulus inaudible. These goals were achieved by laying out a methodology for collecting evoked potentials from sea turtles.

Thirty-five juvenile loggerhead turtles caught in the Chesapeake Bay were used in this study. A computer capable of delivering stimuli and receiving bioelectric activity via electrodes implanted in the loggerhead sea turtle was used. Either a low-frequency broadband click or tone bursts (250, 500, 750, or 1,000 Hz) were delivered by a bone vibrator to the turtle's tympanum. Intensity and frequency of stimulus were manipulated for the threshold experiment. Rate of stimulus presentation and intensity of white noise were manipulated for the rate and masking experiments, respectively.

Maximum sensitivity was in the low-frequency region of at least 250 to 1,000 Hz with a maximum sensitivity at 250 Hz of -24.4 dB re: 1 gravity unit. The broadband click produced clear auditory response with a mean threshold of -10.8 dB re: 1 gravity unit and 8.5 dB re: 1 dynes/cm^2. In the rate experiment, interpeak latencies for peak I and peak V were significantly dependent on rate. In the masking experiment, signal-to-noise ratios ranged from -3.5 to -8.5 dB ($x = -5.2 \pm 2.4$).

The broadband click stimuli elicited synchronous neural activity of the hair cells and was determined to be the most efficient stimulus to use when recording threshold from the loggerhead sea turtle. An increase in the stimulus rate resulted in the disruption of neural synchrony and thus interpeak latencies increased with rate of stimulus. Finally, loggerheads appear to be able to resolve the stimulus through a high level of white noise. These techniques of auditory evoked potentials may be utilized in two fields of applied research; (a) the development of an acoustic repelling device, and (b) the identification of diseases of the brain of sea turtles.

This study by Moein (1994) represents one of the first steps in understanding the loggerhead's hearing mechanism. Auditory responses for loggerheads were most sensitive from at least 250 to 1,000 Hz. The latencies of peak I and peak V were dependent on the rate, and thus the interpeak latency increased with the increase in stimulus rate. Finally, loggerhead sea turtles appear to be able to distinguish signals through a relatively high level of ambient noise.

Evaluation of the response of loggerhead sea turtles (*Caretta caretta*) to a fixed sound source

Use of a fixed sound source acoustic stimulus has been proposed to repel sea turtles from hopper dredges. The purpose of this study by Lenhardt et al. (1994) was to document behavior to acoustic stimulation of unrestrained sea turtles swimming in a net in the York river and in a tank.

A net enclosure (approximately 18 m × 61 m × 3.6 m, 3.8 cm bar) was erected in the York River, VA, to contain the turtles. The enclosure was stratified into two equal sections; near and far. A sound projector was suspended at one end of the net.

The output from the hydrophone was fed to a real-time spectral analyzer for spectra calibration. Tone bursts of 250, 500-, and 750-Hz were used. Rise and fall times were 30 cycles for the 500- and 750-Hz tone burst and 15 cycles for the 250-Hz tone burst. Tonal burst duration was approximately 120 ms at a repetition rate of 1.1 per second for 5 min. Interstimulus intervals were 15 min.

Five loggerhead turtles were tested in the net. Behavior after the initial firing of the horn was categorized into two types. If the turtle entered the zone adjacent to the sound source, the response was termed an approach. If the turtle entered the zone opposite the sound source, the response was termed an avoidance. The amount of time in each trial the turtle stayed in the sections of the net was also categorized. If the turtle stayed in a zone for at least 2.5 min (i.e., half of the trial or more), the response was either a sustained approach or sustained avoidance. However, if the turtle exhibited behavior of swimming from one end of the net and then back again repeatedly, this was considered non-directed swimming response. In 30 sound trials in the net study, turtles initially moved toward the sound source (approach response) 13 times and away from the sound source (avoidance response) 17 times. The Cochran's Q test found no significant difference between avoidance and approach responses for the three tone burst stimuli. Moreover, non-directed swimming occurred 83.3 percent of the time.

A large outdoor tank (6.9 m × 4.6 m × 1.3 m) in Gloucester Point, VA, also was used to evaluate the turtles. The tank was divided into three sections; near, mid, and far from the source. The sound projector was again suspended at one end of the tank. Because the water was clear, the tank study was utilized to directly observe any reaction to sound.

Five loggerhead turtles were tested in the tank five separate times with at least 2 days between each test. Tone burst, noise bursts, and frequency sweeps (linear frequency modulation) stimuli were generated by the sound projector. For each test, a single loggerhead was placed in the tank and allowed to acclimate. Turtles were exposed to three different stimuli (250 Hz, 500 Hz, and white noise) in separate presentations with two replicates for each type of stimulus (six trials), with 15 min of no stimulus between each trial. Of the 175 trials performed in the tank, startle responses were observed 14 times. It did not appear that any specific stimuli produced this startle response.

Auditory brainstem evoked response testing was performed in both the net and tank studies prior to testing to obtain a baseline auditory threshold and subsequent to testing to determine if hearing damage had occurred. Evoked potential testing, carried out at the completion of testing for each animal, revealed no change in threshold or evoked waveform morphology. Thus, there was no damage to the hearing mechanisms of the turtles due to testing.

The key concepts in applying the usefulness of this method to reduce turtle mortality during dredging operations are repeatable directional swimming responses by turtles. Neither directionality nor repeatability was observed with sound in the net or tank. Turtles showed no significant approach or avoidance behavior. Each turtle always continued in the direction it was headed when the sound projector was activated. It can be speculated that the responses exhibited by the turtles could be a result of the confined nature of both the net and the tank. The next step should be to use telemetry to track turtles's behavioral response to a sound source in situ. Until unrestrained animal behavior is observed when approached by a moving sound emitter, any assessment of acoustic turtle repellants will be inconclusive.

Auditory assessment of the West Indian manatee (*Trichechus manatus*): Potential impacts of low frequency activities on manatee acoustic behavior and communication

Any deterrent techniques developed for sea turtles must be assessed for the effects on other marine animals occurring in the same locations. The West Indian manatee is an endangered marine mammal of primary concern. This basic hearing study was conducted by Gerstein (1994a) to evaluate potential effects of deterrents and hopper dredges on manatee hearing and behavior. The research was conducted at The Lowry Park Zoo, Tampa, FL, where two manatees were tested. While the sample size is arguably small, the definitive results of this comprehensive hearing study remain our best estimate of what manatees are capable of hearing.

The measured manatee audiogram demonstrates that in quiet conditions @ 20 dB sea state zero, manatees have a hearing range of 500 Hz to 38 kHz. The manatee's most sensitive region of hearing is 10 to 20 kHz. In this region, amplitude levels as low as 50 dB *re*:1μ*Pa*. are detectable. Below 1.6 kHz manatee hearing sensitivity falls off rapidly (20 dB per octave). In near-field projections at very high energy levels (111 dB *re*:1μ*Pa*.), one manatee was able to detect infrasonic signals of 15 Hz, possibly through air resonance or tactile sensations.

Masked threshold tests demonstrated critical signal-to-noise ratios from 14 to 26 dB *re*1μ*Pa* with standard deviations of < 3 dB, indicating that background noise significantly raised the hearing thresholds of the animal. In moderate noise conditions at sea state 2 (noise level of an inland spring), the manatee would require a minimum of a 15-dB increase in order to hear 3 kHz, and a 29-dB increase at 500 Hz. In intracoastal corridors, sea state levels can reach 4 and 7, and could require as much as a 50-dB increase for boat-related frequencies. Masked threshold probes suggest that manatees are consistent with other mammals in their ability to better detect pulsed signals than continuous signals from background noise. Boat noise is characterized as broadband noise with limited frequency or amplitude fluctuation. As the manatee requires significantly more energy behind a pulsed signal to detect it from the background, it is not unreasonable to infer that even greater energy would be required for the manatee to detect the continuous broadband noise of an approaching boat from the background.

Directional sensitivity tests demonstrated that the manatee was relatively poor at locating sound sources below 3 kHz. The animal could not utilize phase detection cues. The manatee demonstrated increased localization performance at higher frequencies, and required repetitive pulsed signal trains to localize sounds. The manatee was less effective at localizing short pulses and required more time to scan the sound field before localizing a sound source. Dolphins and other mammals are much more effective at localizing signals than manatees.

Conclusions from this study by Gerstein (1994a) regarding manatee hearing include the following; (1) Manatees are not sensitive to low-frequency mechanical noise of hopper dredging or the proposed acoustical deterrents being designed to ward off sea turtles. Only in near-field projections could manatees be able to detect blast signals at sound pressure levels approximating 110 dB $re{:}1\mu Pa$ at 1-m distances. Furthermore, in moderately noisy environments signals would need to be >130 dB before manatees would be able to detect deterrents or ship operations. (2) Recorded manatee vocalization and measured hearing ranges indicate that low-frequency noise associated with dredging and sea turtle deterrents would not interfere or compete with intraspecific communication. (3) There are no measurable acoustic effects of low-frequency noise (5 - 500 Hz) produced by Army Corps of Engineers hopper dredges on manatee hearing thresholds. Frequencies from 1 - 2,000 Hz are subject to Lloyd mirror effects in shallow areas where manatees would be at risk. The majority of noise produced by dredges and deterrents would be dispersed and canceled. Manatee hearing thresholds at these frequencies would be unaffected. (4) Manatees cannot accurately detect the low-frequency sounds produced by hopper dredges and associated Army Corps vessels traveling in manatee-inhabited waters and are at risk of collision with these vessels. (5) The subject manatees were not attracted, dispersed, or measurably affected by controlled simulated deterrent noise projections. Manatees may not be able to detect these signals from less than 1-meter distances. (6) Manatees will habituate to continuous wave background noise.

Acoustic-Dispersal Evaluations

Characterization of a seismic air gun acoustic dispersal technique at the Virginia Institute of Marine Science sea turtle test site

Acoustic-dispersal techniques have been proposed for repelling sea turtles from the vicinity of hopper dredging operations. Seismic energy sources have been widely and safely used by the petroleum exploration industry in offshore environments for more than three decades. Recent studies have indicated that seismic sources are not harmful to marine life except at extremely close distances. Research by Zawila (1994a) addressed these objectives; (1) develop an acoustic attenuation and absorption prototype model for the Virginia Institute of Marine Science test site, (2) characterize seismic sources used in study of sea turtle behavioral responses, and (3) collect data that can be used to develop a safe, effective method of utilizing seismic sources to repel sea turtles from dangerous areas.

A controlled sea turtle behavior reaction experiment was conducted on 28 June - 17 July 1993 at the Virginia Institute of Marine Science in Gloucester Point, VA. A pen of netting approximately 60 by 240 ft was installed just off the end of the ferry pier. The depth of water around the pier ranged from 10 to 15 ft. The seismic sources, a Bolt Technology Par 2800 air gun and Water/Air 2800 combo gun were placed 4 ft under water at opposite ends of the net. The 2800 air gun was positioned downstream and the 2800 combo gun operating in the air mode was positioned upstream. The closest distance a sea turtle could approach the seismic guns was 5 ft.

Eleven endangered loggerhead (*Caretta caretta*) sea turtles were tested to characterize their behavioral response to seismic gun signatures. One sea turtle at a time was placed within the net and allowed to acclimate to the environment for 1 hr before testing. The testing procedure started with one gun set at the lowest air input pressure discharging for 5 min at a 5-sec repetition rate. As the test progressed, the acoustic signature of the seismic gun was recorded and the sea turtle behavioral response was monitored. After 5 min, the gun would cease discharging for 10 min to allow the sea turtle to rest before the next trial initiated. For the next trial, the other seismic gun would discharge at its lowest air input pressure for 5 min at a 5-sec repetition rate. This procedure would be followed two more times at medium and high air input pressure levels for a total of six trials. The low, intermediate, and high air input pressures during the sea turtle trial tests for the combo and air guns were 1,000, 1,500, and 2,000 psi and 800, 1,000, and 1,200 psi, respectively. After the six trials were completed for the sea turtle, it was removed from the pen and examined for any hearing or physical impairment while another sea turtle was placed into the pen to be tested using the same procedure.

Data from the sea turtle tests were analyzed and examined for intensity levels at the peak pressure time history wave and 125, 250, 500, and 1,000 Hz. The average sound pressure level during the sea turtle tests decreased as the frequency increased, therefore 125 Hz was the most intense frequency and 1,000 Hz was the least intense. A spreading and attenuation model was developed based upon the average sound pressure level 40 yd from the source and the spherical spreading attenuation characteristics of the shallow-water net environment at the Virginia Institute of Marine Science.

Based upon the source level characteristics of the seismic guns, the spherical spreading attenuation environment at the Virginia Institute of Marine Science, and the estimated hearing thresholds of the sea turtles, a sea turtle 'scare response' model was calculated. Assuming that the sea turtles respond to the seismic guns at a peak pressure level of 170 dB re 1 μPa, they would be affected by the peak pressure wave at a distance of 100 yd for the combo gun operating at 1,000 psi. Assuming the upper threshold limit is 20 dB re 1 μPa above the hearing threshold, or 190 dB re 1 μPa for sea turtles, then the sea turtles would have been exposed to high sound pressure levels of approximately 200 dB re 1 μPa if they were within 5 yd of the combo gun operating at 1,000 psi. Therefore, by knowing the acoustic and upper limit thresholds of sea turtles or the distance at which sea turtles detected/responded to the seismic source, the other can be determined. For example, if sea turtles responded to a peak pressure wave of 180 dB re 1 μPa, then the corresponding response distance is 25 yd (Zawila 1994a).

Evaluation of seismic sources for repelling sea turtles from hopper dredges

Air gun tests were conducted by Moein et al. (1994) to evaluate the effects of distance of turtles from the gun, gun chamber pressure, and gun firing rates in repelling sea turtles. A net enclosure (approximately 18 m × 61 m × 3.6 m, 3.8-cm bar) was erected in the York River, VA, to contain the turtles. The enclosure was stratified into two equal sections; near and far. Two air guns were positioned at each end of the net, and the guns were calibrated to create equal seismic and auditory output. A hydrophone was positioned equidistant from the air guns to monitor the output.

Ten loggerhead turtles were tested, and seven of these were retested for a total of seventeen tests. A float was attached to the posterior end of the carapace of each turtle with a 3-m line so position could be monitored. For each test, a single loggerhead was placed in the enclosure and allowed to acclimate for 1 hr prior to exposure to stimuli.

The first task was to test whether a significant difference existed in the response of the turtle to each of the two air guns. Once establishing that response to these air guns was not statistically different, analysis of behavior was continued by combining data from the two air guns.

On first exposure to the air guns (trial one), naive turtles occupied a significantly higher number of positions in the far section of net than expected by chance. This suggests an avoidance response to the air gun emissions. However, in the second exposure, no difference in observed and expected response was seen. This response suggests that the turtles are habituating to the stimuli.

To pursue the idea of habituation, the response of each turtle in all the trials of each exposure group was analyzed. In the first exposure group, number of positions in the sections of the net were not the same for each trial. Turtles avoided the air gun in the first three trials, but did not avoid emissions in trials 4-6. The second exposure group did not avoid the emissions throughout all six trials. This suggests that turtles are habituating to the stimuli after approximately three exposures, and do not lose this habituation over days of no exposure.

Moein et al. (1994) investigated whether turtles have enough time to avoid a dredge with an air gun on the draghead emitting every 5 sec. Dredges operate at speeds up to 5 knots (or 2.57 ms^{-1}). Mean response time was 39.5 s, and in this time the dredge would be 101.5 m away. However, turtles probably would not respond at that distance. The average response and turn distances were 20.8 m and 15.0 m, respectively. A dredge traveling at 2.57 ms^{-1} would cover 13 m in the 5 s between emissions from the air gun. Using 15.0 m as a conservative distance at which turtles will respond to first encounters with a dredge, it appears the turtles would avoid the dredge.

However, a turtle subsequently encountering a dredge may or may not avoid the dredge. These preliminary results need to be further explored to see how turtles would react under field conditions. If a turtle begins to respond to the emissions of the air gun 23.7 m away from the approaching dredge and continues to respond 23.7 m after the dredge passes, the turtle will be exposed to four emissions from the air gun. A possible experimental design to address the question of habituation under normal dredge conditions in the field would be to expose the turtle to four emissions, allow the turtle to rest for several days, and then expose the turtle to four more emissions. A study should be conducted to use telemetry to track turtles' behavioral response to air gun emissions in the field.

Analysis of a seismic air gun acoustic dispersal technique at the Fort Pierce sea turtle trial site

The objectives of this research by Zawila (1994b) were to (a) determine the feasibility of using seismic air guns on hopper dredges to repel sea turtles from dredging operations, (b) characterize the acoustic source signatures during both dredging and non-dredging shallow-water environment tests, and (c) develop an attenuation and absorption prototype model.

The acoustic dispersal tests were conducted on 1-7 June 1993 at a 240-ft by 1,000-ft site 5 miles east of the Ft. Pierce, FL, ship channel. The seismic sources, a Bolt Technology PAR 2800 air gun and Water/Air 2800 combo gun, were placed on the port drag arm of the U.S. Corps of Engineers (USCE) hopper dredge *McFarland*. Assuming a drag head depth of 48 ft, the air gun was positioned 21 ft from the sea bottom and 36 ft up the drag arm from the drag head. The water gun was positioned 10 ft from the sea bottom and 23 ft up the drag arm. Operation of the seismic guns in the dredging environment was successful. The seismic guns were not physically damaged or operationally hindered by the *McFarland* and the *McFarland* operated effectively without impairment or damage caused by the seismic guns. The data sets that were collected are (a) the background noise level of the shallow-water environment, (b) the noise level during dredging activity without the seismic guns operating, (c) the noise level during dredging activity with the seismic guns operating, and (d) the noise level of the seismic guns while the *McFarland* was idle.

When data on the background noise level were collected, a hydrophone launch was anchored between 50 and 160 yd starboard of the *McFarland*. During dredging operations the launch was anchored at one end of the test site while the *McFarland* approached the launch from the other end of the test site. This produced a data set of distances ranging from 160 to 420 yd. When the *McFarland* was idle and the seismic guns were operating, the launch collected acoustical signatures at approximately 100, 500, 1,000, 2,500, and 5,000 ft aft of the *McFarland*. These distances are approximate because the launch was not anchored and did drift during each seismic discharge. The distance between the *McFarland* and launch was computed by using a radar distance measuring system on the *McFarland*, which has an accuracy of 15 ft. During the tests, the seismic guns were discharged simultaneously at input pressures of 1,000, 1,500 and 2,000 pounds per square inch (psi).

With the air guns discharging while the *McFarland* was idling, the data demonstrated that the most intense energy is around 125 Hz, which is expected for the air gun. In decreasing order of spectral energy is 250, 500, and 1,000 Hz. The fastest rate of attenuation is at 125 Hz whereas the other frequencies attenuate relatively at the same rate. Initially, there is more energy in the 125 Hz band at close distances, but beyond 1,000 ft there is more energy around 250 Hz. A possible reason for the 250 Hz energy at far distances is that the shallow water environment causes the longer wavelengths/shorter frequencies (i.e., 125 Hz) to attenuate more rapidly or even possibly shift into a shorter wavelength/higher frequency (250 Hz).

Analysis of the spectral amplitudes of the air and water gun signatures at each input pressure concluded an increase of 3-5 dB re 1 μPa for the water gun when the air input pressure increased from 1,000 to 1,500 psi. Increasing to 2,000 psi tended to increase the spectral amplitudes by 1-3 dB re 1 μPa. The air gun spectral amplitudes increased by 1-2 dB re 1 μPa when the air pressure input increased from 1,000 to 1,500 psi. Increasing to 2,000 psi caused an increase of 1-3 dB re 1 μPa in the spectral amplitudes. At 2,500 ft and beyond, specific spectral signatures of the air gun were below the hydrophone's resolution limit.

Another set of tests were conducted at the Ft. Pierce site to determine the interaction between the seismic guns and the *McFarland* under dredging conditions. This was conducted by anchoring the launch at one end of the test site and having the *McFarland* approach it from the other end of the test site. The seismic guns were operated at 1,000, 1,500, and 2,000 psi at a 20-second interval for a variety of distances ranging between 160 and 420 yd from the *McFarland*. The number of passes the *McFarland* made at 1,000, 1,500, and 2,000 psi are 1, 1, and 2, respectively.

These data demonstrate that the most intense energy is around 125 Hz beyond 30 yd from the *McFarland*. The sound pressure decreases as frequency increases. The spectral attenuation rates vary depending on the air input pressure, but overall the 125-Hz range attenuates the slowest and the higher frequencies attenuate more rapidly. This is the exact reverse case when compared to the spectral characterizations of the seismic guns during non-dredging activity. Because the data were clustered in a small range of distances (150-450 yd), attenuation rates and extrapolated source levels are not as accurate as the data during non-dredging activity. The attenuation rates and extrapolated source levels are very sensitive to variations within the data.

An objective of this study by Zawila (1994b) was to determine at what distance a sea turtle will disperse from an area of an incoming dredge. Assuming a turtle will disperse if the acoustic level reaches 180 dB re 1 μPa at 250 Hz, then the dredge during dredging operation (source level = 188 dB re 1 μPa) will disperse the sea turtle when the dredge is on top of the sea turtle. This is too late. If the same turtle is subjected to the seismic guns (source level = 200 dB re 1 μPa at 250 Hz) at 1,000 psi, the sea turtle will disperse at a distance of 10 yd if it is scared only by the spectral wave characteristics. The same turtle will experience the peak pressure level (source level = 230 dB re 1 μPa) of the seismic guns. If the turtle will disperse at 190 dB re 1 μPa for the peak pressure level, it will disperse at 100 yd from the dredge. Knowing that the dredge moves 5-7 knots = 2.5-3.5 yd/sec and assuming the sea turtle needs 15 sec to move from the path of the dredge, then the safety dispersal zone is 37.5 to 52.5 yd (2.5 yd/sec × 15 sec = 37.5 yd, 3.5 yd/sec × 15 sec = 52.5 yd).

Dredging-Equipment Development and Evaluation

Development and evaluation of a sea turtle-deflecting hopper dredge draghead

A cooperative effort the between the U.S. Army Corps of Engineers Marine Design Center, Philadelphia District, Jacksonville District, and WES resulted in contract specifications for a prototype rigid deflector draghead construction. The prototype, built by NORSHIPCO in Norfolk, VA, was a modified California draghead with a radically redesigned V-shaped heel pad. The rigid deflector prototype draghead was constructed for the Corps of Engineers hopper dredge *McFarland*. The *McFarland* is operated by the Philadelphia District and works along the Eastern U.S. coastline. Design specifications for the prototype draghead were based on an operating depth of 48 to 52 ft and available on-deck ship clearances. Testing of the rigid deflector draghead in a model (mock) turtle field off Fort Pierce, FL, by the *McFarland* is described by Banks and Alexander (1994).

The rigid deflector draghead tests were designed to thoroughly evaluate the effectiveness of the rigid deflector draghead. Two general test goals were addressed; (a) visual observation of effectiveness, and (b) comparative performance of the California draghead with a rigid deflector, the California draghead with a chain deflector, and the California draghead unmodified.

For the rigid deflector draghead, multiple tracklines through the model (mock) turtle field provided a total of 39 encounters with model (mock) turtles. Most of the encounters were successful deflections. Two model (mock) turtles were entrained in the draghead suction when the draghead lost contact with the bottom as it moved over a depression. The two entrained models (mocks) were in a noticeable depression; and on this particular test run, the crew was advised to follow their normal draghead positioning procedure and ignore (for comparative test purposes) the hard-on-bottom, straight-pipe condition. This case of model (mock) turtle entrainment points out that design operation procedures should be followed for maximum deflecting capability. The ship captain reported somewhat easier steering with the V-shaped prototype than conventional dragheads. The V-shape apparently reduces drag forces encountered with conventional draghead shapes. It is significant that the new design did not adversely impact maneuverability.

For the California draghead with chain deflector, dredged tracklines through the model (mock) turtle grid resulted in 34 model (mock) turtle encounters. Four model (mock) turtles slid under the deflector and were entrained with dredged material. One other model (mock) turtle was damaged. Of the four entrained (mock) turtles, one of these was initially pinned under the forward support cable on the front of the chain deflector before it slid under.

The final draghead field test evaluated a standard California draghead without any turtle deflecting modifications. This provided a statistical base condition with which the rigid deflector and chain deflector effectiveness could be compared. The chain deflector was removed from the starboard draghead leaving the conventional California draghead without any sea turtle-deflecting mechanism. To be statistically compatible with the rigid deflector prototype and chain deflector tests, the standard California tests were conducted with the same straight dragpipe and hard-on-bottom draghead operation. The standard California draghead encountered 28 model (mock) turtles during test runs. Fourteen of these were entrained with dredged material. Another 14 were deflected, but 9 of these were damaged as they were deflected.

Results of these field tests by Banks and Alexander (1994) are believed to be conservative when considering a live turtle. A live turtle would naturally swim away from immediate danger, and the turtle's effort could be expected to reduce, at least, the number of damages. The rigid deflector draghead successfully deflected 95 percent of the model (mock) turtles it encountered. The chain deflector was comparatively effective, deflecting 85 percent of the models (mocks) it encountered. The standard California draghead only successfully deflected 18 percent of the models (mocks) that it encountered. Qualifying deflecting capability with the specified operating procedures and adjustments is important.

Effectiveness of a sea turtle-deflecting hopper dredge draghead in Port Canaveral entrance channel, Florida

The purpose of this study by Nelson and Shafer (1996) 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 (a) determine sea turtle presence and relative abundance in Canaveral Harbor entrance channel, (b) determine the percentage of time the turtles are on the bottom, and (c) assess the number of sea turtles entrained on the inflow screens during dredging with the rigid deflector draghead.

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.

In order to establish the presence of sea turtles in Canaveral Channel and estimate their abundance, three standardized sea turtle trawl surveys were conducted. 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, 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).

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 injured. It was transported to Sea World in Orlando, FL, for further observation.

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. 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, 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).

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 those channels was conducted using a standard California draghead in an area where levels of abundance of sea turtles were similar to those recorded in this study by Nelson and Shafer (1996). 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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13. ABSTRACT *(Maximum 200 words)*

The USACE Sea Turtle Research Program (STRP) was conducted to minimize the risk to sea turtle populations in channels along the southeast Atlantic region of the United States from hopper-dredging activities. Relative abundance studies determined indices of sea turtle abundance at six harbor entrance channels maintained by hopper dredges; (a) Canaveral, FL, (b) Fernandina/Kings Bay, FL, (c) Brunswick, GA, (d) Savannah, GA, (e) Charleston, SC, and (f) Morehead City, NC. Behavioral studies monitored movement of sea turtles over time and distance with telemetry techniques. Acoustic-detection studies evaluated acoustic techniques for faster sea turtle surveys. Bioacoustic studies determined acoustic thresholds and auditory behavior of sea turtles and manatees. Acoustic-dispersal studies evaluated a technique for dispersing sea turtles. Dredging equipment studies developed a rigid deflector for the California-style hopper dredge draghead. Prototype field tests demonstrated that the deflector was effective in deflecting model (mock) sea turtles with no adverse impact on dredge production. Effectiveness in reducing entrainment of live sea turtles was confirmed during actual production dredging operations in Canaveral entrance channel.

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