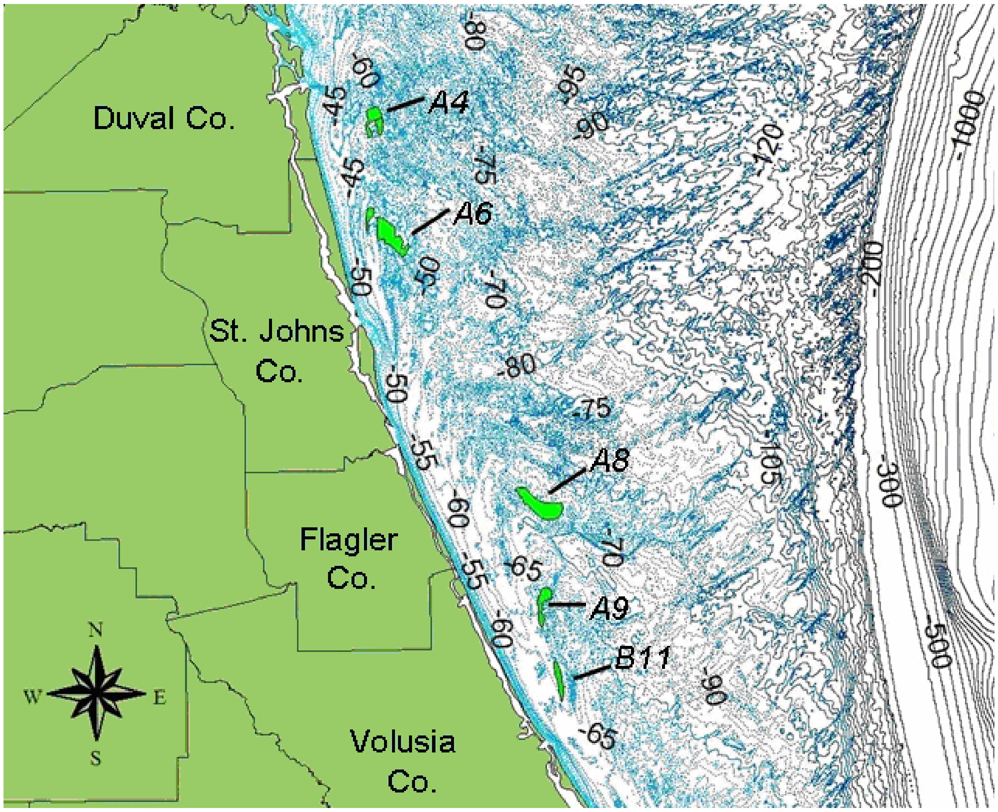
MMS 2008-060

Final Biological Characterization and Numerical Wave Model Analysis within Borrow Sites Offshore of Florida's Northeast Coast Report-Volume I Contract No. 1435-01-05-CT-39075-M05PC00005



Submitted to:

U.S. Department of Interior Minerals Management Service (MMS) Sand and Gravel Leasing Division
Herndon, VA

Prepared by:

Scientific Environmental Applications, Inc. (S.E.A.)

In Cooperation with:

The Louis Berger Group, Inc.

March 2009

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REPORT AVAILABILITY

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Colleen Finnegan, Marine Scientist, COTR for Department of Interior Minerals Management Service (MMS) Sand and Gravel Leasing Division, Herndon, VA
Will Waskes, Oceanographer for Department of Interior MMS Sand and Gravel Leasing Division, Herndon, VA
Roger Amato, Physical Scientist for MMS Sand and Gravel Leasing Division, Herndon, VA
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CONVERSION FACTORS

Metric to U.S. Customary

Multiply	by	To Obtain
millimeters (mm)	0.03937	inches (in)
centimeters (cm)	0.3937	inches (in)
meters (m)	3.281	feet (ft)
kilometers (km)	0.6214	miles (mi)
square meters (m^2)	10.76	square feet (ft^2)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons (gal)
cubic meters (m^3)	35.31	cubic feet (ft^3)
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces (oz)
grams (g)	0.03527	ounces (oz)
kilograms (kg)	2.205	pounds (lb)
metric tons (t)	2205.0	pounds (lb)
metric tons (t)	1.102	short tons
Celsius degrees (ºC)	1.8(ºC)+32	Fahrenheit degrees

U.S. Customary to Metric

Multiply	by	To Obtain
inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles	1.609	kilometers
nautical miles	1.852	kilometers
square feet	0.0929	square meters
square miles	2.590	square kilometers
acres	0.4047	hectares
gallons	3.875	liters
cubic feet	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28.35	grams (g)
pounds (lb)	0.4536	kilograms
short tons (ton)	0.9072	metric tons
Fahrenheit degrees	0.5556(ºF – 32)	Celsius degrees

LIST OF ACRONYMS

ASTM	American Society of Testing Materials
CFR	Code of Federal Regulations
CHL	Coastal Hydraulics Laboratory
CMS	Coastal Modeling System
CPUE	Catch-Per-Unit Effort
CTD	Conductivity Temperature Depth
CZMA	Coastal Zone Management Act
DO	Dissolved Oxygen
DOI	U.S. Department of the Interior
EA	Environmental Assessment
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDC	U.S. Army Corps of Engineers Research and Development Center
ESA	Endangered Species Act
FDEP	Florida Department of Environmental Protection
FWC	Florida Fish and Wildlife Conservation Commission
FGS	Florida Geologic Survey
FI	Fullness Index
FMP	Fishery Management Plan
FWRI	Florida Fish and Wildlife Research Institute
GPS	Global Positioning System
ha	Hectare
HAB	Harmful Algal Bloom
ICONS	Inner Continental Shelf and Structure Program
IRI	Index of Relative Importance
Ma	Million years ago
MARMAP	Marine Resources Monitoring, Assessment and Prediction
MBTA	Migratory Bird Treaty Act
MDS	Multi-dimensional Scaling
MMP	Marine Minerals Program
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MRFSS	Marine Recreational Fishery Statistics Survey
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSL	Mean Sea Level
NAVD	National Atmospheric Vertical Datum
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic & Atmospheric Administration
NOS	National Ocean Survey
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
ODMDS	Ocean Dredged Material Disposal Site

OIP	FDEP Office of Intergovernmental Programs
PSU	Practical Salinity Units
Qa	Pleistocene Anastasia Formation
Qbd	Beach Ridge and Dune Sands
Qh	Holocene Sediments
ROSS	Reconnaissance Offshore Sand Search
ROV	Remotely Operated Vehicle
SAB	South Atlantic Bight
SCDNR	South Carolina Department of Natural Resources
SCUFA	Self-Contained Underwater Fluorescence Apparatus
S.E.A.	Scientific Environmental Applications, Inc.
SEACOORA	SouthEast Coastal Ocean Observing Regional Association
SEACOOS	Southeast U.S. Atlantic Coastal Ocean Observing System
SL	Standard Length
SMS	Surface Water Modeling System
Sv	Sverdrups
TSHD	Trailer Suction Hopper Dredge
USACE	U.S. Army Corps of Engineers
U.S.C.	U.S. Code Citation
USCS	Unified Soils Classification System
USFWS	U.S. Fish and Wildlife Service
WABED	Wave-Action Balance Equation with Diffraction
WES	Waterways Experiment Station
WIS	Wave Information System

LIST OF PREPARERS

Individual	Affiliation	Responsibility
	List of Preparers	
Kim A. Zarillo, M.S.	Scientific Environmental Applications, Inc.	Program Manager
Gary A. Zarillo, Ph.D., PG	Scientific Environmental Applications, Inc.	Geology/Physical Oceanography/Numerical Modeling
Mary Jo Barkaszi, M.S.	Scientific Environmental Applications, Inc.	Marine Mammals, Seabirds/Protected Species
Eric A. Reyier, Ph.D.	Scientific Environmental Applications, Inc.	Fisheries/Plankton
Jonathon Shenker, Ph.D.	Scientific Environmental Applications, Inc.	Fisheries/Plankton
Allison M. Connell	Scientific Environmental Applications, Inc.	Marine Mammals, Seabirds/Protected Species
Jeffrey A. Reidenauer, Ph.D.	The Louis Berger Group, Inc.	Biological Communities/Benthic Ecology
Thomas Shinskey, M.S.	The Louis Berger Group, Inc.	Biological Communities/Benthic Ecology
Michelle Verdugo	The Louis Berger Group, Inc.	Biological Communities/Benthic Ecology
Nicole Weiss, M.A.	The Louis Berger Group, Inc.	Biological Communities/Benthic Ecology
Heather Shaw	The Louis Berger Group, Inc.	GIS/Spatial Databases

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1.0 INTRODUCTION

This report is a product of literature research and field studies conducted from 2005 to 2008 in fulfillment of the U.S. Department of the Interior (DOI), Minerals Management Service (MMS) Contract No. 1435-01-05-CT-39075 modified in 2008 to M05PC00005 *Biological Characterization/Numerical Wave Model Analysis within Identified Borrow Sites Offshore the Northeast Coast of Florida.* The study was designed to analyze physical and biological data to determine the potential impacts that may result from extracting sand and gravel from Federal waters for beach restoration. MMS's Marine Minerals Program (MMP) provides policy direction and administers lease agreements for the development of marine mineral resources on the outer continental shelf (OCS).

This study concentrated on Florida's northeast coast from Volusia to Duval counties. It is one of several completed OCS studies directed by the MMP in cooperation with states along the Atlantic coast and in the Gulf of Mexico. In previous studies, geological and environmental information was collected and analyzed on OCS sand deposits that may be suitable for beach nourishment and wetlands protection projects. Studies of OCS resources offshore of East Central and Northeast Florida were initiated because of the increased demand for beach-quality sand in the state. In the report *Critically Eroded Beaches in Florida* (FDEP 2006) there were 332.4 miles of critically and noncritically eroded beaches statewide in 1989 and about 485 miles in the latest update of the report based on 2006–07 data (FDEP 2007). Within the study area (Volusia, Flagler, St. Johns, and Duval, counties), there are nearly 57 beach miles considered critically and noncritically eroded (FDEP 2007). Other factors such as human-induced alterations of inlets and inlet management, beach fill, and armoring in coastal areas have contributed to the need for ongoing beach-fill maintenance. Another factor driving the search for beach-compatible material is population growth in coastal counties. In 2005, of the 16 million people residing in Florida, 80% lived in 35 coastal counties. By 2025, Florida's total population is estimated to reach 25 million (FDCA 2006).

Much of the increase in beach erosion is attributed to tropical depressions, tropical storms, and hurricanes that impacted Florida from 1994 to 2005. The combined impact of the 2004 hurricanes Frances and Jeanne was responsible for increases in critically eroded areas within Flagler (2.3 miles), Volusia (5.4 miles), and a minor increase in St. Johns (0.2 mile) counties. Ponce de Leon, Ft. Mantanzas, St. Augustine, and Mayport inlets are also influential in the sediment budget of the study area.

The MMS is authorized to convey rights to OCS sand, gravel, or shell resources for shore protection, beach or wetland restoration projects, or construction projects wholly or partly funded or authorized by the federal government. The vehicle for conveyance is normally a lease agreement between MMS and the lessee. The negotiated leases are based in part on results from environmental studies such as this current study. Exploration and development of mineral resources on submerged federal OCS lands is governed by several laws and policies, including the OCS Lands Act, National Environmental Policy Act, Endangered Species Act, Marine Mammal Protection Act, National Historic Preservation Act, Clean Water Act, Magnuson–Stevens Fishery Conservation and Management Act (Sustainable Fisheries Act, and regulations e.g., 30 Code of Federal Regulations [CFR] Parts 280, 281, and 282), and others. Until 2005, the MMS directed and funded environmental studies, similar to this study, to obtain information useful for policy decisions related to marine mineral activities. As of 2005, budget cuts and a realignment of program services provided by the MMS, such as the new alternative energy programs, have resulted in future environmental studies being funded by lease applicants (MMS 2006).

1.1 Study Objectives

The primary goal of the study, as directed by MMS, is to characterize the physical and biological environments of northeast Florida's offshore sand sources and to identify and address potential environmental impacts that may result from dredging specific sand borrow sites. Research and field study information was collected and analyzed to assist in developing criteria for future negotiated agreements, National Environmental Policy Act (NEPA) documents, including environmental assessments (EA) and environmental impact statements (EIS), and other requirements for use of federal sand and gravel deposits from the study areas.

The following objectives were set forth by MMS for physical and biological characterization of sand source sites and potential onshore impacts:

Identification of Physical Characteristics

- Examine the potential alteration in the local wave field following dredging and the sand excavation from within potential sand borrow sites located offshore of Florida's northeast coast.

- Examine the potential for increased wave action after dredging within potential sand borrow sites. Also, examine any resultant adverse localized changes in erosional patterns and longshore coastal transport, which could result in significant losses of beach sand after renourishment.

- Examine the potential for changes in local sediment transport rates from altering the local bathymetry, particularly in light of the recent studies that indicate bathymetry influences the manner in which waves approach the shoreline during storm events.

- Examine the cumulative physical effects of multiple dredging events as well as the extractions of large volumes of material within the identified borrow sites.

Identification of Biological Characteristics

- Evaluate benthic habitats, biological communities (infauna, epifauna, and demersal and pelagic fishes), and sediment grain size within and near potential borrow areas. Biological field data collected during the study will be used in conjunction with existing literature to provide a more complete characterization of the resident biota.

- Assess the potential effects of offshore sand dredging on benthic and pelagic communities, including an analysis of the potential rate and success of re-colonization following cessation of dredging.

- Develop a time schedule of environmental windows that best protects benthic and pelagic species from adverse environmental effects associated with dredging using the procedures and conclusions set out in the National Academy of Sciences (NAS) Special Report 262: *A Process for Setting, Managing, and Monitoring Environmental Windows for Dredging Projects*.

1.2 Study Area Description

The project study area begins in federal waters three nautical miles offshore of the four northern counties on Florida's east coast (Figure 1-1). The five specific shoals chosen for this study, within a combined area of 46 square miles, were designated as B11, A9, A8, A6, and A4 by Meisburger and Field (1975) in a reconnaissance survey to identify sand and gravel resources on the inner continental shelf. Shoals B12 and A5, also surveyed by Meisburger and Field (1975), were examined in the numerical models because they match the criteria of the five specific shoals B11, A9, A8, A6, and A4. B12 is adjacent to the B11 shoal, and A5 is in close proximity to the A4 shoal. These shoals were selected from among others on the northeast Florida continental shelf because of their potential for holding beach-quality sand. Shoals A8, A6, A5, and A4 are compound shoals having distinct lobes or coalescing linear ridges. Shoals B12, B11, and A9 are more linear, originating from a single major ridge. The five study shoals are located offshore of Duval, St. Johns, Flagler, and Volusia counties, as shown in Figure 1-1. Table 1.1 summarizes the spatial features of the shoals considered in this study

Shoal B12 is located just to the east of B11 offshore of Volusia County. The crest of B12 reaches a maximum elevation of about -45 ft and covers a total area of 3.2 square miles. This shoal was investigated for sand recovery by Volusia County, Florida. Shoal B11 lies 5.5 miles offshore of Daytona Beach in Volusia County. It is a single linear sand ridge that is oriented in a north–south direction with respect to the long axis. The minimum crest elevation of B11 is about -45 ft MSL. The B11 ridge is the smallest of the six features studied, having a perimeter of 10 miles and a total area of 2.6 square miles. Shoal A9 begins 6.5 miles offshore of Volusia County and appears to be a single continuous topographic feature. Minimum elevation of A9 is -50 ft below MSL. The perimeter of A9 is 13 miles, and the total area is 6 square miles. Shoal A8 lies 12 miles offshore of Flagler County in a water depth of -65 ft, whereas the minimum elevation at the crest of A8 is at -50 ft MSL. The perimeter of A8 is 16 miles, covering an area of 12.4 square miles. Shoal A6, located 6 miles offshore of St. Johns County, is irregularly shaped and consists of several northeast–southwest-trending sand ridges. It has a perimeter of 17 miles and a total area of 11 square miles. The A6 Shoal is currently being considered as a potential source of sand for beach restoration in St, Johns County. Shoal A5 is located between the 3-nautical-mile federal limit and A4, reaching a maximum elevation at the crest of -45 ft. A5 has a perimeter of about 7.5 miles and covers an area of about 2 square miles.

The center of A4 is 7.5 miles offshore Duval County near Little Talbot Island and Jacksonville Beach, reaching a maximum elevation of nearly -45 ft with respect to mean sea level (MSL). Its perimeter is 12 miles and covers a 4.5-square-mile area.

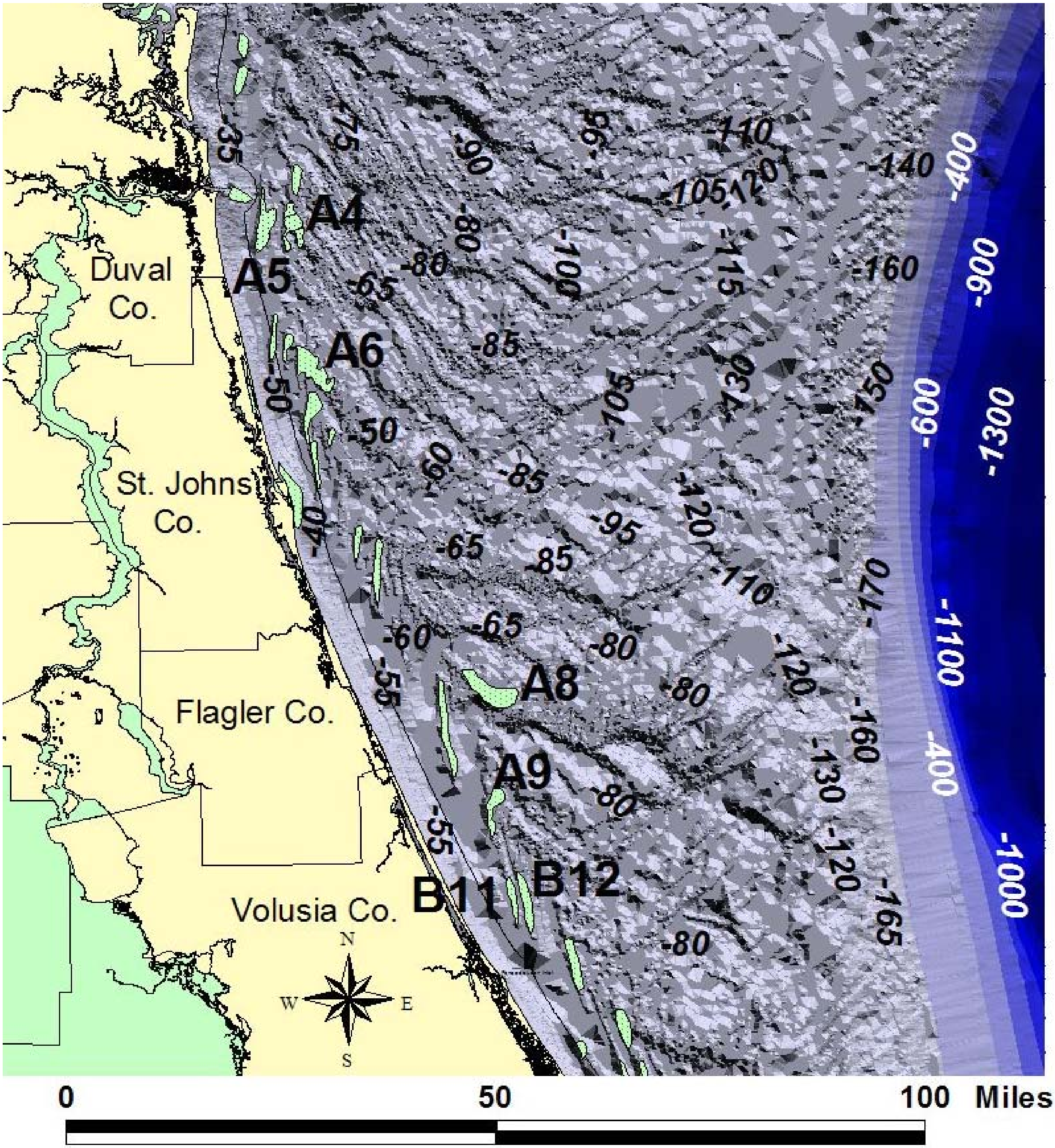


Figure 1-1. Locations of compound and individual sand ridges selected for biological and physical characterization along the inner continental shelf of Northeast Florida. The federal three nautical mile limit is marked. Numbers in italics identify depth values relative to MSL.

Table 1.1. Shoal Dimensions

Shoal Name	Distance from Shoreline (miles)	Minimum Crest Elevation (feet, MSL)	Perimeter (miles)	Area (miles)
A4	7.5	-45	12	4.5
A5	4.5	-45	7.5	2
A6	6	-45	17	11
A8	12	-50	16	12.4
A9	6.5	-50	13	6
B11	5.5	-45	10	2.6
B12	6.5	-45	10	3.2

2.0 EXISTING PHYSICAL AND BIOLOGICAL INFORMATION

2.1 Introduction

Physical oceanographic and geologic research of the inner continental shelf environments along Florida's east coast has not been as comprehensive as the body of work completed for the west central Florida shelf, Southeast Florida, and in the Florida Keys regions. These other Florida regions have benefited from the presence of the U.S. Geologic Survey Marine Geology Office in St. Petersburg, Florida, the Rosenstiel School of Marine and Atmospheric Sciences in Miami, and interest in Gulf Stream dynamics where the Florida Current dominates the coastal ocean dynamics in Southeast Florida. Despite the limited federal and state observational resources in Northeast Florida, several data collection and research efforts have contributed to the geologic and physical database in this region. In 1975, the U.S. Army Corps of Engineers (USACE) documented the sand and gravel resources on the inner continental shelf along the Eastern U.S., including a focus on the northeast Florida inner shelf (Meisburger and Field 1975). These early reconnaissance studies were expanded by the Florida Geologic Survey (FGS) on behalf of the MMS using more recent sampling technology. Recent phases of this ongoing work are summarized by Phelps et al. (2003, 2004). The Florida Department of Environmental Protection (FDEP) sponsored a regional investigation titled the Florida Northeast Coast Reconnaissance Offshore Sand Search (ROSS) that began in 2001 (URS 2007). The results of the Northeast regional study were archived in the ROSS database (URS 2007) along with much of the historical and more recent data sets pertaining to sand resources of the inner continental shelf of Florida.

The Southeast Atlantic Coastal Ocean Observing System (SEACOOS) is a regional partnership that has recently provided some integration of coastal ocean observing systems over four states of the southeastern coastal U.S., including Florida. The Beaches and Shores Program of the FDEP also provides a database of nearshore morphologic change and shoreline change over time that supports the characterization of nearshore sand resources.

Several comprehensive studies have characterized the biological resources within the South Atlantic Bight (SAB) and the continental shelf from the 1980s to the present (e.g., Foster 1971, Coull et al. 1982, Wenner and Read 1982, Tenore 1985, BVA 1999a, Lotspeich and Associates 1997). Broad surveys of the fish and invertebrate communities present along the northeast Florida shelf are limited (although see Sedberry and Van Dolan 1984, Wenner and Sedberry 1989, and ASMFC 2000). Most regional ichthyofaunal surveys (e.g., Snelson 1983, Mulligan and Snelson 1983, Tremain and Adams 1995, Paperno et al. 2001) have focused on characterizing estuarine faunas, although these efforts have also provided life history for certain continental shelf taxa that utilize estuaries as juvenile nurseries. In addition to these fisheries-independent surveys, commercial fisheries landings for each Florida ccounty are compiled by the Fish and Wildlife Research Institute (FWRI) of the Florida Fish and Wildlife Conservation Commission. Summary data are available at the FWRI web site http://www.floridamarine.org. Recreational fisheries landings are monitored by a joint effort of FWRI and the National Marine Fisheries Service (NMFS) and compiled in the Marine Recreational Fishery Statistics Survey (MRFSS) database at http://www.st.nmfs.gov/st1/recreational/index.html.

2.2 Geologic History of Northeast Florida Coastal Area

The geologic history of the Florida Peninsula provides the structural framework and sediment sources that evolved to form Florida's modern coastal and continental shelf environments. Publications by Lane (1994) and White (1970) provide an overview of the surficial geology of Florida that describes the Holocene and modern coastal and shelf sediments of Florida.

Florida has experienced cycles of sediment deposition and erosion in response to sea-level changes throughout the Cenozoic Era (the last 65 million years). Florida's Cenozoic-aged sediments include two major groups: the Paleogene and the Neogene-Quaternary. During the Paleogene Subperiod (66–24 million years ago [Ma]), carbonate sediments formed from whole or broken fossils including foraminifera, bryozoa, mollusks, corals, and other forms of marine life. Very little siliciclastic sediment (quartz sands, silts, and clays) was able to reach Florida because the "Gulf Trough" separated the Florida Platform from the siliciclastic source area of the Appalachian Mountains.

The Geologic Map of Florida, now available in GIS format, summarizes the Tertiary and Quaternary geologic formations and surficial geology (Scott 2001). During the Paleogene Subperiod, the Florida Platform was very similar to the modern Bahama Banks; it consisted of a broad area over which carbonate sediments were deposited. The carbonate sediments were deposited by biological processes and consisted largely of the fossil remains of marine organisms. Very little siliciclastic material (sand, silt, and clay) was deposited on the Platform due to the scouring action of a marine current similar to the modern Gulf Stream. In the late Paleocene Epoch, a renewed uplift of the Appalachian Mountains produced large volumes of siliciclastic sediments that inundated the Platform and encroached upon the carbonate-depositing environments. Siliciclastic deposition became dominant in the Neogene Subperiod (24–2 Ma) in which carbonate deposition occurred only as thin beds and lenses within siliclastic deposits. Phosphate deposition also began at this time in response to upwelling of phosphorus-rich water from deep ocean basins. Low stands of sea level during periods of glaciation in the Quaternary exposed large areas of the Platform and allowed the erosion and dissolution of carbonate deposits, resulting in the ubiquitous karst topography found throughout much of Florida. The subsequent sea level rise following glaciation intervals submerged much of the Platform again. Siliciclastic and carbonate deposition continue to occur in modern times, although the action of the Gulf Stream restricts the amount of sediment deposited.

Much of Florida is covered by a blanket of Pliocene to Holocene, undifferentiated siliciclastics that range in thickness from less than 1 ft to greater than 100 ft As a result, in developing the Geologic Map of Florida, FGS mapped the surficial geology or the first recognizable lithostratigraphic unit occurring within 20 ft of the land surface. In areas where highly karstic limestones underlie the undifferentiated siliciclastics, paleosinkholes may be infilled with significantly thicker sequences of siliciclastics. If the shallowest occurrences of the karstic carbonates were 20 ft or less below land surface, the carbonate lithostratigraphic unit was mapped. If the carbonates lie more than 20 ft below land surface, an undifferentiated siliciclastic unit was mapped. These criteria guided the construction of the Florida Map as the basis for describing the surficial geologic features of Northeast Florida that influence the modern coastal and inner shelf environments.

Figure 2-1 shows the distribution of the surficial sediments and rock formations in the Northeast Florida area between Cape Canaveral and the Florida–Georgia border. The major formations in the coastal region of Northeast Florida include undifferentiated Holocene sediments (Qh), the Pleistocene Anastasia Formation (Qa), and beach ridge and dune sands (Qbd) along the shoreline. Each formation has a range of compositions that result in locally distinctive features. The beach and dune ridge sand of the Qbd classification (see Figure 2-1) have the greatest areal extent throughout the northeast region of Florida. The age of these sediments ranges from Pleistocene to very recent and modern. In some areas, Qbd well-sorted, quartz-rich sands form distinctive topographic ridge expressions of the late Pleistocene shoreline complex. Along the present shoreline, this classification is associated with modern beach and dune deposits of the Atlantic Ridge. There are several outcrops of the Anastasia on the modern beaches between St. Johns County and Palm Beach County. In addition, the Anastasia often forms nearshore rock outcrops seaward of the beach from the surf zone to the base of the shoreface and beyond. The so-called “rock reefs,” or submerged outcrops of the Anastasia, are considered valuable habitat for fish and benthic organisms and are often considered in the environmental permitting for offshore dredging and beach fill projects. The Anastasia Formation generally outcrops near the coast but extends inland as much as 20 miles. The Anastasia Formation is composed of interbedded sands and coquinoid limestones. The most recognized facies of the Anastasia sediments is an orange-brown, unindurated to moderately indurated coquina of whole and fragmented mollusk shells in a matrix of sand often cemented by sparry calcite. Sands occur as light gray to tan and brown, unconsolidated to moderately indurated, unfossiliferous to very fossiliferous beds. The Holocene sediments in Florida (Qh) occur near the present coast at elevations of less than 5 ft generally. These Qh sediments include quartz sands, carbonate sands, silts, and organics.

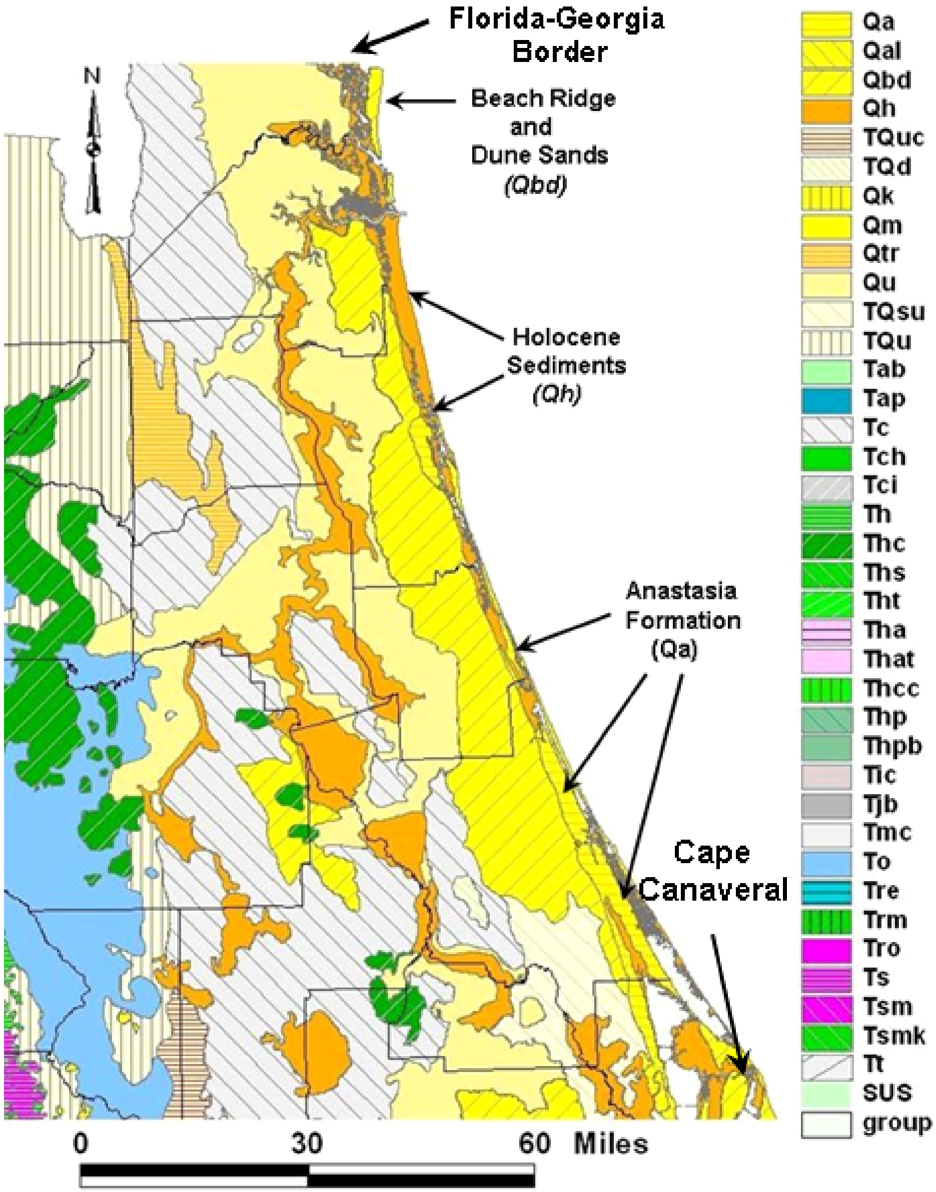


Figure 2-1. Surficial geology of Northeast Florida. Examples of the beach ridge and dune sand (Qbd), undifferentiated Holocene sediments (Qh), and the Pleistocene Anastasia Formation (Qa) are indicated (from the Florida Geologic Survey Geologic Map of Florida, Scott 2001).

Topographically, the Atlantic coast of North Florida consists of a low-relief coastal plain of low elevation punctuated by relic Pleistocene coastal terraces and relic beach ridge deposits. White (1970) stated that the surface morphology is determined by preservation of these coastal terraces and the associated profile of the Pleistocene shoreface. A secondary controlling process is the modification of the relic topography by differential erosion and solution collapse that has occurred during the Holocene. The best preserved and youngest relic coastal or strandline system, termed the Atlantic Coastal Ridge, is underlain by the Anastasia Formation from St. Johns County south to Palm Beach County.

2.2.1 Geology of the Continental Shelf

The near-surface and surficial structure and sediments on the inner continental shelf of Northeast Florida are likely to be similar to the onshore Quaternary geology, with the exception of the distinctive beach ridge and dune deposits, which are likely to have been re-worked during the Holocene transgression. Many local investigations of inner shelf sand deposits have been considered and developed for beach replenishment of northeast Florida beaches. These studies (USACE 1975, 1990a, 1990b, 1998) provide local knowledge of topography and shallow structures. The most comprehensive regional investigations of inner shelf sediments include a wide-ranging federal study conducted in the late 1960s to mid-1970s and a more recent series of field studies conducted by the FGS beginning in the early 1990s (Nocita et al. 1991).

Publications by Meisburger and Field (1975, 1976) summarize the findings of the federal study of the Florida inner continental shelf from Cape Canaveral to the Georgia border. During this study, more than 1,153 nautical miles of seismic-reflection profiles were collected along with 197 vibracores. This project was part of the Inner Continental Shelf Sediment and Structure (ICONS) study. Nocita et al. (1991) began the second of a series of studies of sand and gravel resources, followed by more recent studies conducted by the FGS. FGS further analyzed the vibracores collected for the ICONS study and, based on minimal occurrence of silts and clays suggested that the region has several be suitable potential borrow sites characterized by clean beach quality sand.

The ICONS publications by Meisburger and Field (1975, 1976) addressed the sub-bottom structure of the inner continental shelf as well as the surficial and shallow sub-bottom sediments in the study area. This work had two areas of emphasis. One emphasis was on the overall sub-bottom structure based on seismic reflection records combined with a few deep core borings. The second emphasis was on sediment types contained in shallow lithologic units to define areas of beach-quality sand deposits. The database for this portion of the work was a set of 15- to 20-ft cores as well as an indication of near-surface units from the seismic reflection survey. Figure 2-2 shows the nearshore to inner continental shelf area included in the ICONS study as well as the locations of selected cross-shelf profile lines used by Meisburger and Field (1976) to illustrate representative patterns of seismic stratigraphy.

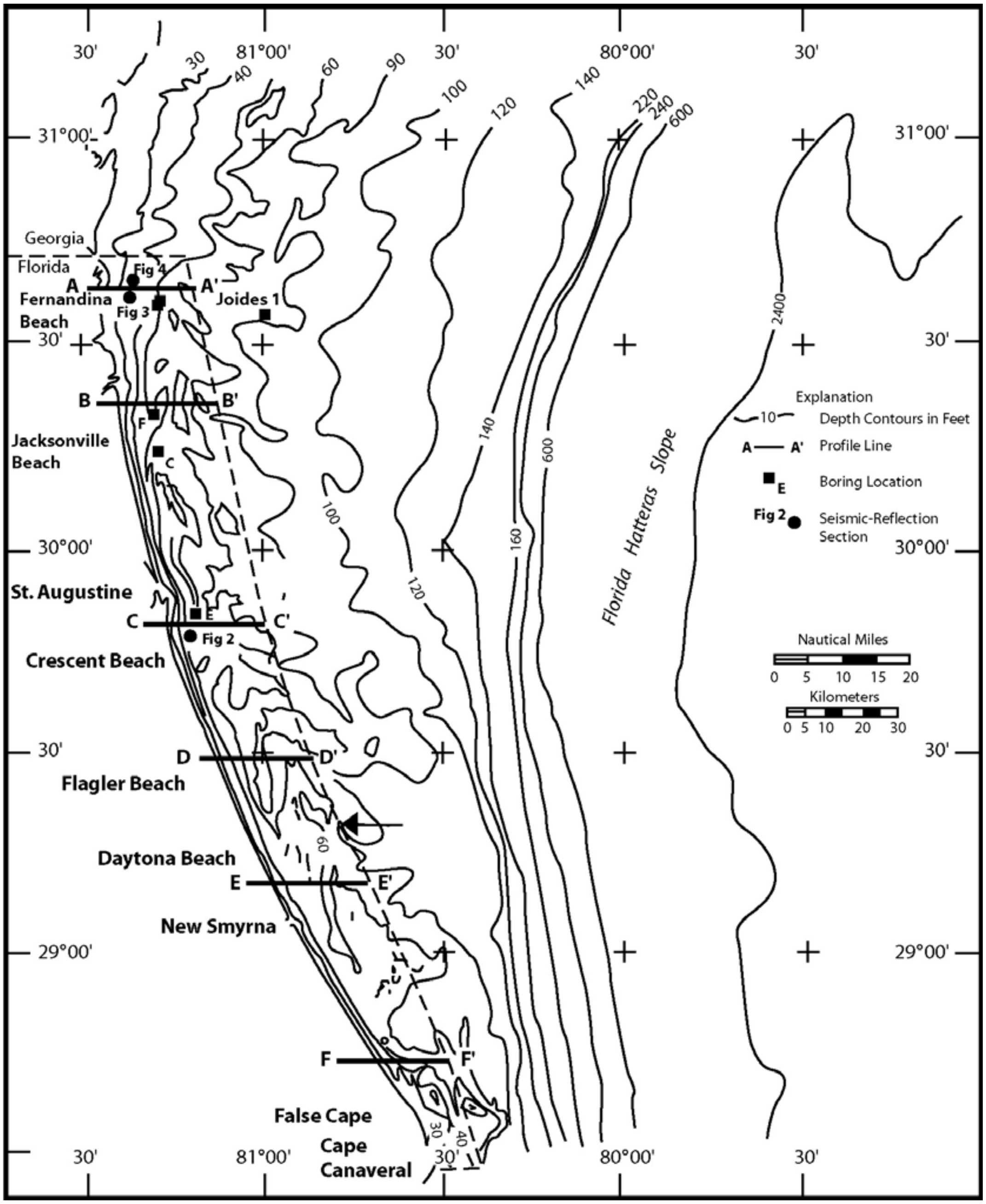


Figure 2-2. Boundary of the ICONS study area (dashed line) and location of cross-shore profiles used to illustrate interpretation of sub-bottom seismic reflectors (from Meisburger and Field 1976).

Based on the sub-bottom seismic reflection data, Meisburger and Field (1976) identified several reflectors that appeared to be nearly continuous throughout the study area and that were likely to correspond to erosional horizons related to sea level fluctuation in the Tertiary period. Meisbuger and Field (1975) found five continuous acoustic reflectors they believed to mark sedimentary units deposited during major episodes of sedimentation in the Tertiary. These reflecting horizons were arbitrarily designated, from deepest to shallowest, the green, purple, white, red, and blue reflectors. Because the majority of the nearly 200 cores obtained in the northeast Florida area penetrated only 20 ft, most of the sedimentary units bounded by the reflectors were not directly sampled. Figure 2-3 shows a regional interpretation from

Fernandina Beach to Cape Canaveral of the sub-bottom units interpreted from the seismic stratigraphy. The units bounded by the major reflectors were labeled Units A, B, C, D, and E.

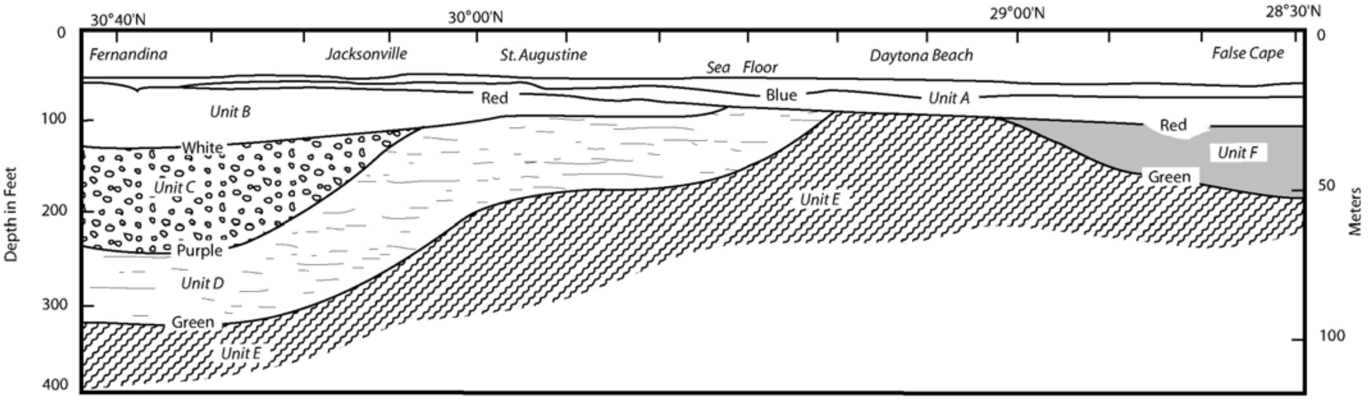


Figure 2-3. Regional extent of major sedimentary units bounded by seismic reflectors found in the ICONS study between Fernandina Beach and Cape Canaveral, FL (from Meisburger and Field 1976).

Only Unit A, located above the near surface blue reflector, was directly sampled, along with occasional samples of Unit B when the thickness of Unit A was minimal or absent and the cores extended below the elevation of the red reflector. Meisburger and Field (1976) did not establish a direct correlation between the seismically-defined units and onshore lithostratigraphic units known from land-based geologic investigations. However, they based the interpretation on the lithology and faunal assemblages found in four deeper core borings that reached the lower units. Meisburger and Field determined that Units B, C and D lie at elevations in nearshore profiles that are consistent with elevations of impermeable strata that confine the Floridan Aquifer found in coastal wells. Thus the rocks and sediments of seismic Unit D and upward are probably Miocene and Pliocene in age, or in other words, these units are pre-Quaternary and probably late Tertiary in age. Unit E was not directly sampled, but based on the elevation of samples from onshore deep wells, Unit E and the bounding green reflector may correspond to the top of the Floridan Aquifer. The green reflector may correspond to the boundary between Eocene limestone below and impermeable Micoene rock above. However, this interpretation may not represent conditions north of Jacksonville, where the top of the Eocene in onshore wells is below the elevation of the green reflector.

Sediments deposited above the blue reflector are the Holocene and modern sediments directly sampled during the ICONS study and are of greatest interest to the present MMS borrow site characterization project. Meisburger and Field (1976) described these sediments in detail and attempted to define six distinctive facies (sediments types) recovered from the cores and from surficial grab samples. Table 2.1 briefly outlines the sediment types, which range from coarse, poorly sorted, carbonate-rich sands to fine, silty sands having a minimum of soluble or carbonate fraction. The goal of the more detailed descriptions was to identify and rank potential borrow areas. Sub-bottom surveys and sampling during recent studies by FGS and MMS were originally designed from the results of the detailed ICONS descriptions of near-surface sediments.

Table 2.1. Summary of sediment facies described by Meisburger and Field (1976) from ICONS core samples.

Sediment Type	Texture	Composition	Distribution
Quartz sand	Fine to very fine	85–90% quartz, 10-15% carbonate	Predominant surface sediment of shoreface and inner shelf; 6–12m
Quartz sand	Fine to coarse sand, well-graded	85–90% quartz, 10% carbonate	Predominant surface sediment of inner shelf; 12–25m
Carbonate-rich sand	Medium to coarse sand	50% quartz and 50% carbonate, large shell fragments	Local patchy occurrences in southern study area
Fine, dolomitic quartz sand	Bimodal distribution of fine to medium sand and fine to very fine carbonate sand	Quartz 40–80%, carbonate 20–60%	Local exposures north of St. Augustine, commonly subsurface to 3m depth
Greenish-gray silt and clay	Compact silt and clay, some sand	Sand, mostly quartz, silicious and carbonate microfossils	Largely buried Tertiary and Pleistocene sediment, local surficial exposures

Figure 2-4 shows the general distribution of surficial sediment types in the ICONS study area. Sediments of the very inner shelf and lower shoreface were fine quartz-rich sand, whereas surficial sediments found further offshore at water depths beyond the base of the shoreface (greater than 30 ft) were a patchy mixture of sediment types that included all of the categories listed in Table 2.1. The number of cores and samples obtained during the ICONS study were not dense enough to characterize the surficial distribution of sediment types. In addition, the ICONS work did not describe in detail the relationship between bottom topography and sediment texture. The ICONS database was extensive enough to recognize that the areas of greatest potential for recovering beach-quality sand were associated with distinctive sand ridges. Shoreface sands were described as quartz-rich, well-sorted, fine sand, whereas sediment types designated as inner shelf sands were described as ranging from medium, quartz-rich sands to medium, carbonate-rich sands. Surficial occurrences of fine carbonate-rich sand were also cited by Meisburger and Field (1976). The residual facies remaining after the late Holocene sea level transgression shown in Figure 2-4 were described as a compact silt and clay with some sand component. This type of sediment is consistent with the Tertiary sediments underlying the Holocene and modern surficial sediments.

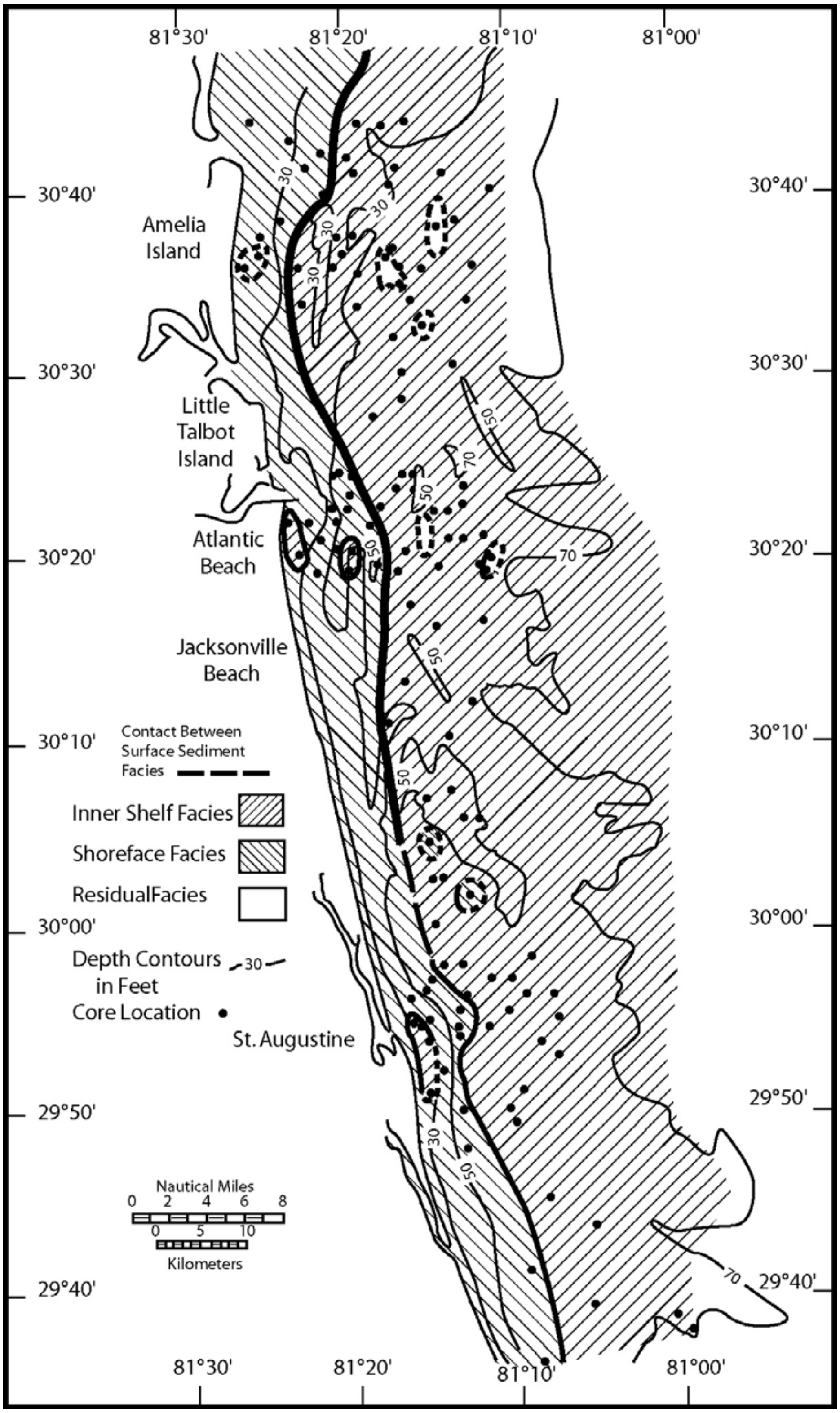


Figure 2-4. Distribution of sediment types in the MMS northeast Florida project area (from Meisburger and Field 1975).

Figure 2-5 shows a figure from Meisburger and Field (1975) that identifies the areas of potential beach-quality sand resources in the Fernandina Beach to Jacksonville area. Meisburger and Field recognized that sediments associated with shoals and sand ridges on the northeast Florida shelf have the best potential as beach-quality sand with respect to sediment size and volume. These areas were ranked either "A" and "B" sites, with "A" sites having been confirmed with one or more core borings and "B" sites selection based on topographic relief, but not confirmed by sampling.

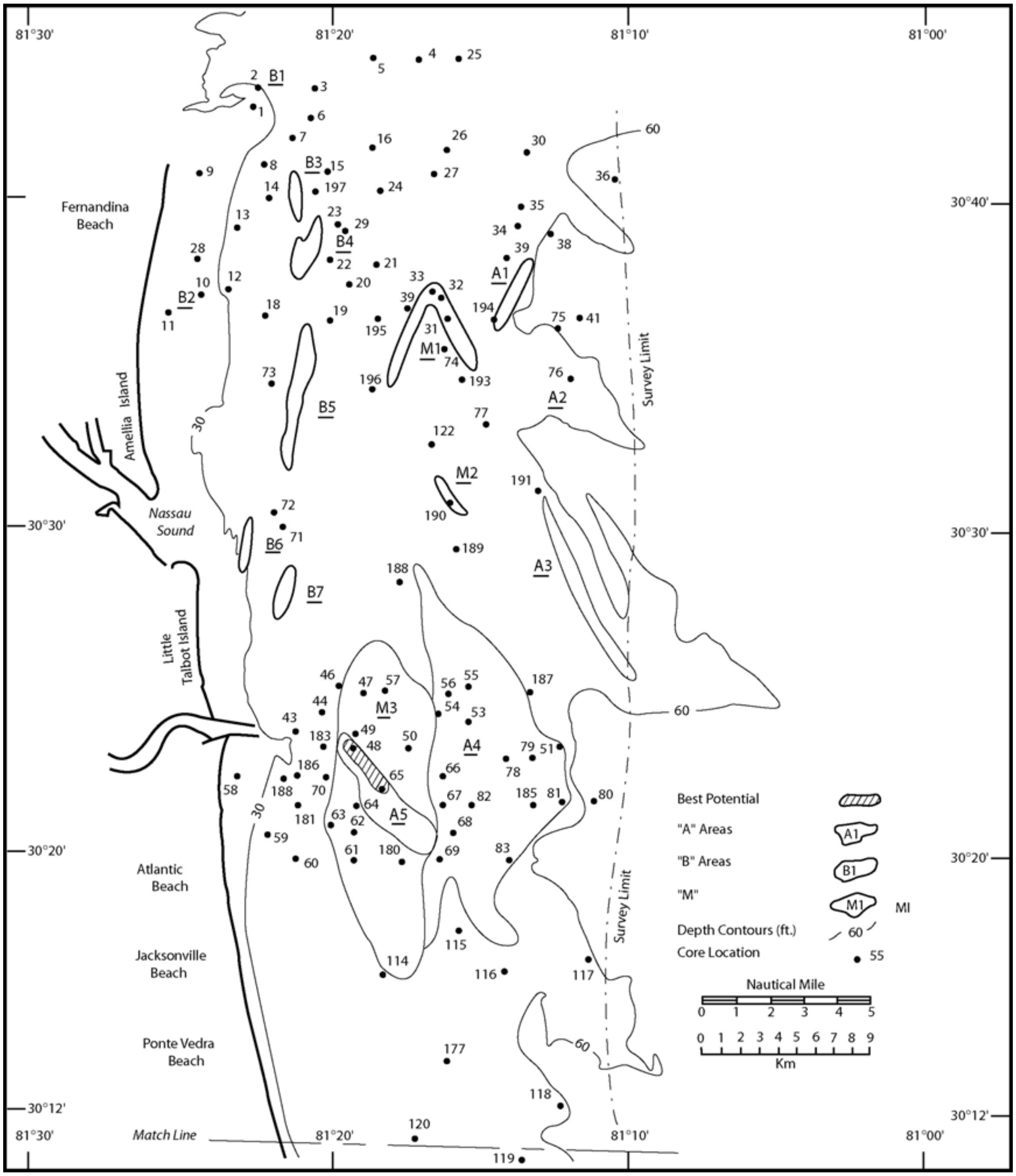


Figure 2-5. Location of potential sand borrow areas identified by Meisburger and Field during the ICONS study. The "A" areas have the best potential confirmed by samples (from Meisburger and Field 1975).

Since the 1990s, in studies conducted under a cooperative agreement with MMS, the FGS has been evaluating the shallow structures and sedimentology of the inner continental shelf off the northeast and east-central coasts of Florida (Phelps et al. 2003, 2004; Phelps and Holem 2005). Goals of the FGS investigations included locating and characterizing the spatial extent and volume of available sands suitable for beach renourishment. Over the span of the projects from 2002 through 2006, the FGS projects off the northeastern coast of Florida extended from Nassau to Duval County. In 2006, the project was extended to Volusia County. The east central region of the Florida coast was completed in 1999 (Freedenberg et al. 1999).

The FGS survey of inner shelf resources was conducted in federal waters using the federal ICONS study (Meisburger and Field 1976) as an initial guide to locate regions where beach-quality sand was likely to be present. The FGS approach was based on interpretation of subsurface acoustic profiles as well as analysis of grab samples and vibracores. In Year 1 (Phelps et al. 2003), approximately 230 miles of seismic data were collected and interpreted to identify deposits of beach-quality sand. In addition to the sub-bottom survey, grab samples from nine offshore locations were collected, along with 106 beach samples to characterize the existing grain size distribution of beach sands in the area. Three push cores were also collected on Bird Island, which is part of the ebb shoal of the Nassau River. Descriptions were made and grain size distributions were determined for all beach and offshore samples and push cores. A reconnaissance-level stratigraphic analysis of the sub-bottom profiler data was completed.

In Year 2, 190 miles of seismic data were collected offshore of Nassau, Duval, and St. Johns counties. A total of 52 core borings were also collected offshore of Nassau and Duval counties, along with a total of 127 beach samples collected from St. Johns and Flagler counties. These data were processed, interpreted, and integrated with the data collected in Year 1. Figure 2-6 shows the pattern of seismic track lines run by FGS as of the close of Year 2 investigations in 2005. Sub-bottom data from these lines, along with the core borings, were used to evaluate the potential for beach-quality sand resources in the area. Figure 2-7 shows the FGS core and grab sample locations from Years 1 and 2 investigations along with cores previously obtained by the Jacksonville District of the USACE. Also shown within the rectangular patterns are borrow areas that have already been accessed for beach-quality sands under projects authorized by the USACE (USACE 1990a). The channel patterns shown in Figure 2-7 are based on seismic stratigraphy interpreted by the FGS from sub-bottom seismic reflection data. The seismic reflectors in these areas were interpreted to be a complex of relict channels and disturbed sediments associated with relic ebb shoal/estuarine complexes of the ancestral St. Johns, Nassau, and St. Mary's rivers. This interpretation was considered by FGS to be consistent with Meisburger and Field's (1975) findings that portions of the channel–related features were sand-rich, whereas, other portions contained a mixture of finer grained material unsuitable for beach restoration use. The compatibility of sediment in-filling the paleochannel shown in Figure 2-7 awaits the results of sampling at higher resolution.

Some reflectors found further offshore of Nassau and Duval counties were interpreted as dissolution collapse features of karst topography. These features were vertically persistent to the base of the recorded seismic data, apparently of limited areal extent, and do not have modern bathymetric expression. Individually they were found on single east–west (dip) sub-bottom profile lines but not on the adjacent dip lines to the north and south. These karst features were usually found approximately six to seven miles offshore.

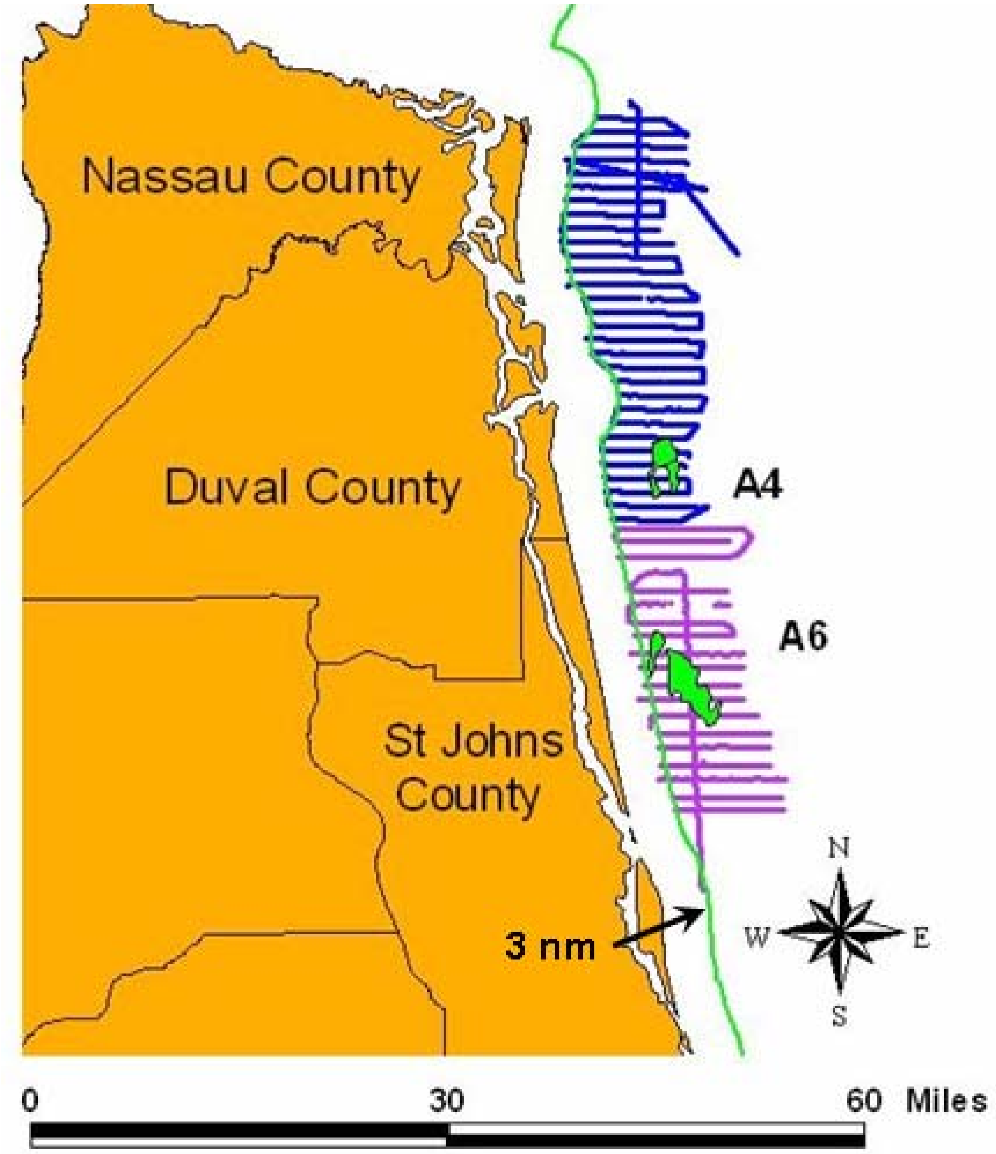


Figure 2-6. Seismic track line patterns from the FGS Years 1 and 2 sub-bottom survey in Northeast Florida. Sand resource areas A4 and A6 originally identified by Meisburger and Field (1975) are also shown (from Phelps et al. 2004).

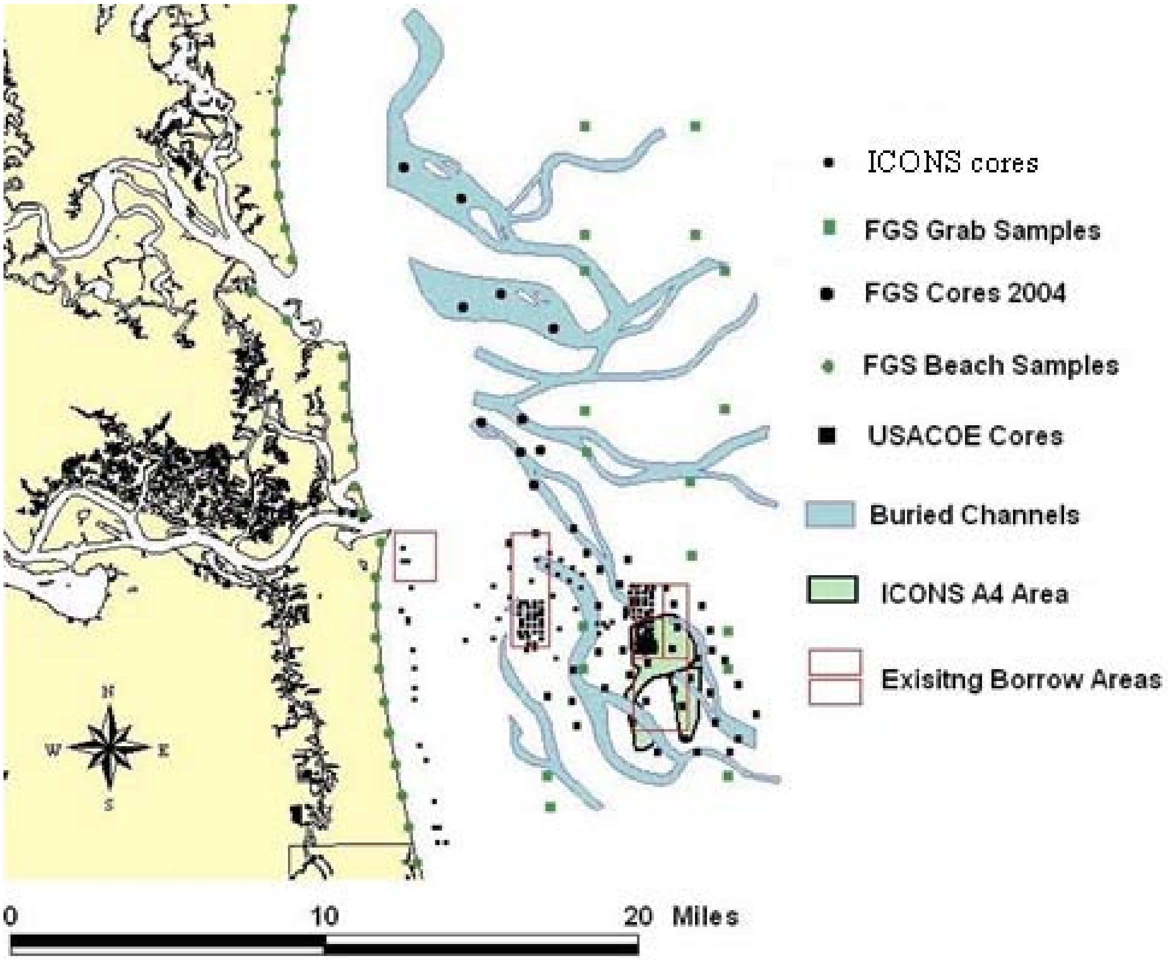


Figure 2-7. Location of FGS and USACOE cores and samples described in Year 2 of FGS studies. Channel patterns identified from seismic stratigraphy are also shown (from the Florida Geologic Survey 2004).

The interpretation of the locally and regionally shallow stratigraphy and sedimentology by FGS was based on the core borings collected during the Year 1 and 2 surveys along with the analysis provided by Meisburger and Field (1975) and local studies by the USACE (1998). In general, clean sand having low silt content and textural properties consistent with modern beach sand was found in the upper elevation of shoal features. Silty sands and compacted silt and clay deposits were found in the topographically low areas between shoals.

With the addition of core borings provided by the USACE, combined with the reconnaissance level sub-bottom data collected by the FGS, more detail on sub-surface lithology was provided by Phelps and Holem (2005). Figure 2-8 shows the location of two lithologic cross-sections from Phelps and Holem shown in Figures 2-9 and 2-10. These cross-sections show that sand units 5–10 ft thick or more, having low silt and clay content, are associated with the higher elevations of the A4 shoal. Sediments contained in core borings obtained in water depths of about -55 ft or deeper contained thinner units of clean sand and included thick units of silty sands and clays. In the A4 area, Phelps and Holem estimated that approximately 22 million cubic yards of beach quality sand may be available.

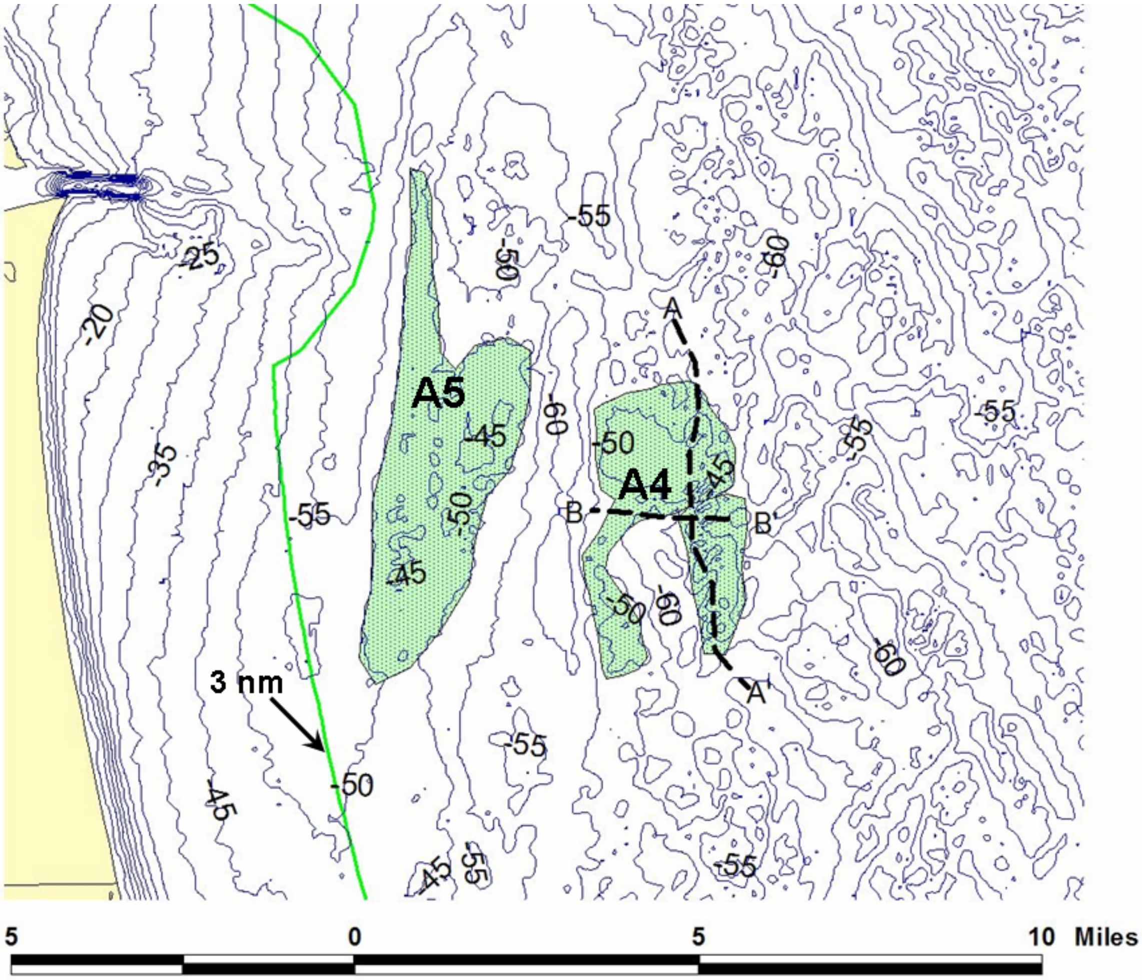


Figure 2-8. Location of two lithologic cross-sections, A-A' and B-B', of Shoal A4 from the analysis of Phelps and Holem (2005).

Further south, reconnaissance-level sub-bottom surveys conducted by the USACOE (2007) and by St. Johns County indicated similar sub-bottom lithology associated with the sand ridges and broader sand banks exemplified by the A7 and the A6 shoals (Figure 1-1). Figure 2-11 shows the location of core borings collected by the USACE between 1996 and 2006, offshore of St. Johns County. Also shown are the lithologic cross-sections based on core borings collected by the USACE. Figure 2-12, from the 2007 draft USACE report, shows clean sand reaching a maximum thickness of about 11 ft under the crest of the A6 Shoal, whereas the layer of clean sand is much thinner in the flank area of the shoal before silts and clays are reached. The relationship between shoal topography and lithology is also well-illustrated in Figure 2-13, which shows a series of core borings from the A7 and A6 shoals along the H-H' cross-section shown in Figure 2-11. In both figures, the sand layers are likely to yield beach-quality sand.

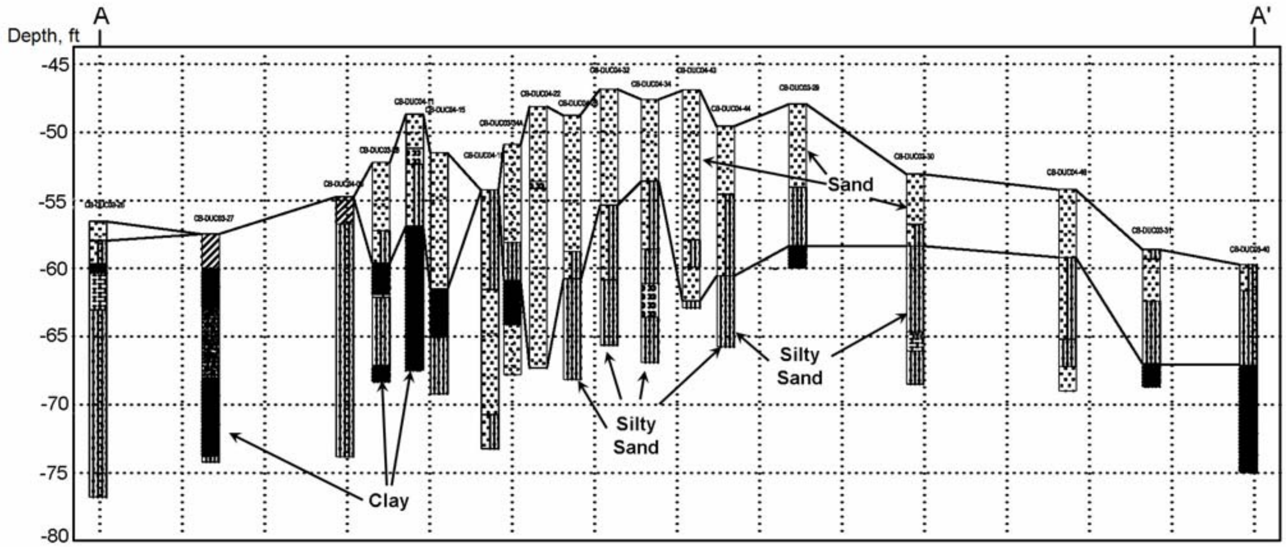


Figure 2-9. Lithologic cross-section A-A' of Shoal A4 showing clean beach-quality sand below the crest and silty sand and clays occurring where the sea floor elevation are greater than -55 ft below mean sea level. The location of the section is shown in Figure 2-8 (from Phelps and Holem (2005).

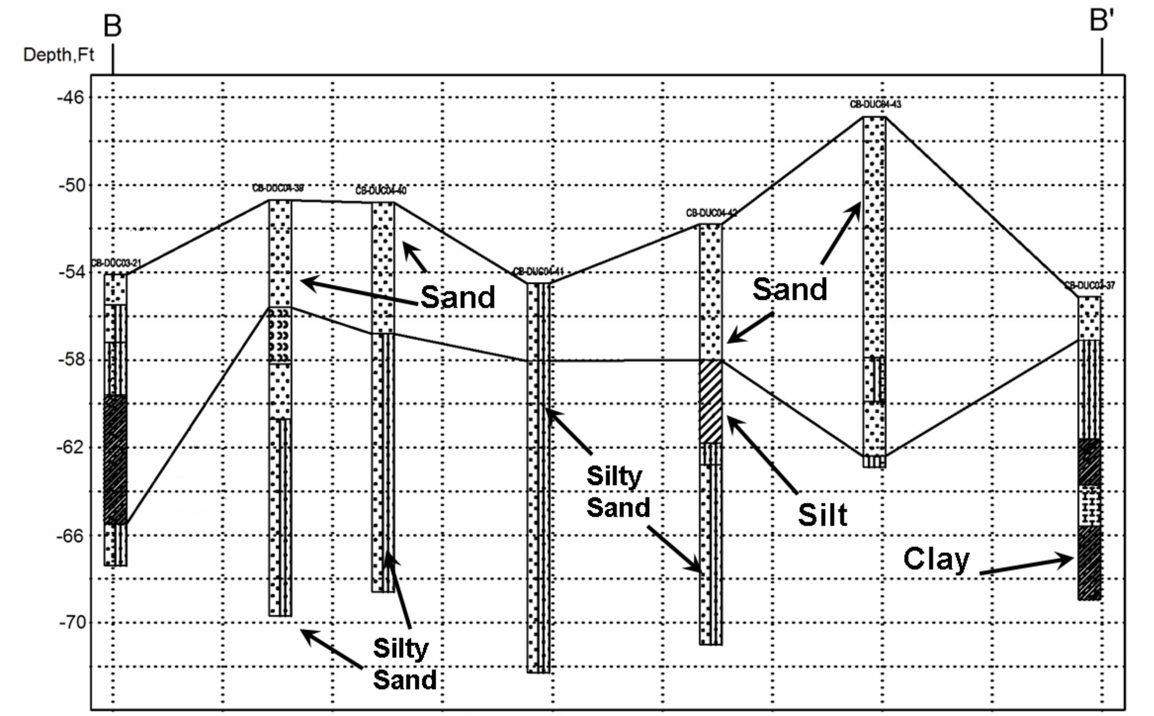


Figure 2-10. Lithologic cross-section B-B', oriented west–east, across Shoal A4. The location of the section is shown in Figure 2-8. Units of clean sand 5- to 10-ft thick occur under the crest of the shoal, whereas silty sand, silts and clay units occur in areas deeper than about 55 ft. (fromPhelps and Holem (2005).

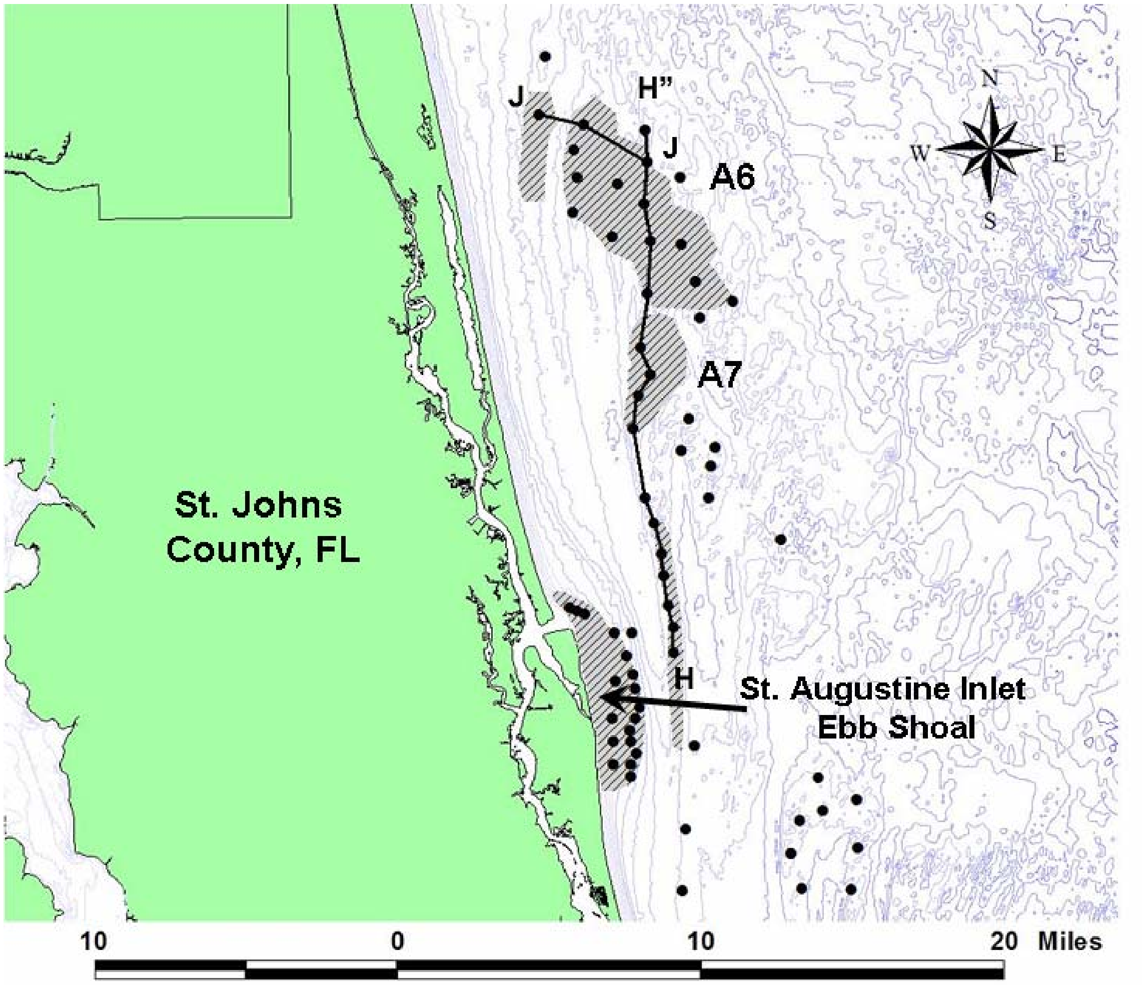


Figure 2-11. Location of lithologic transects H-H', J-J', and core borings from the USACE reconnassiance study of the A7 and A6 shoal system offshore of St. Johns County, Florida (from USACE 2007).

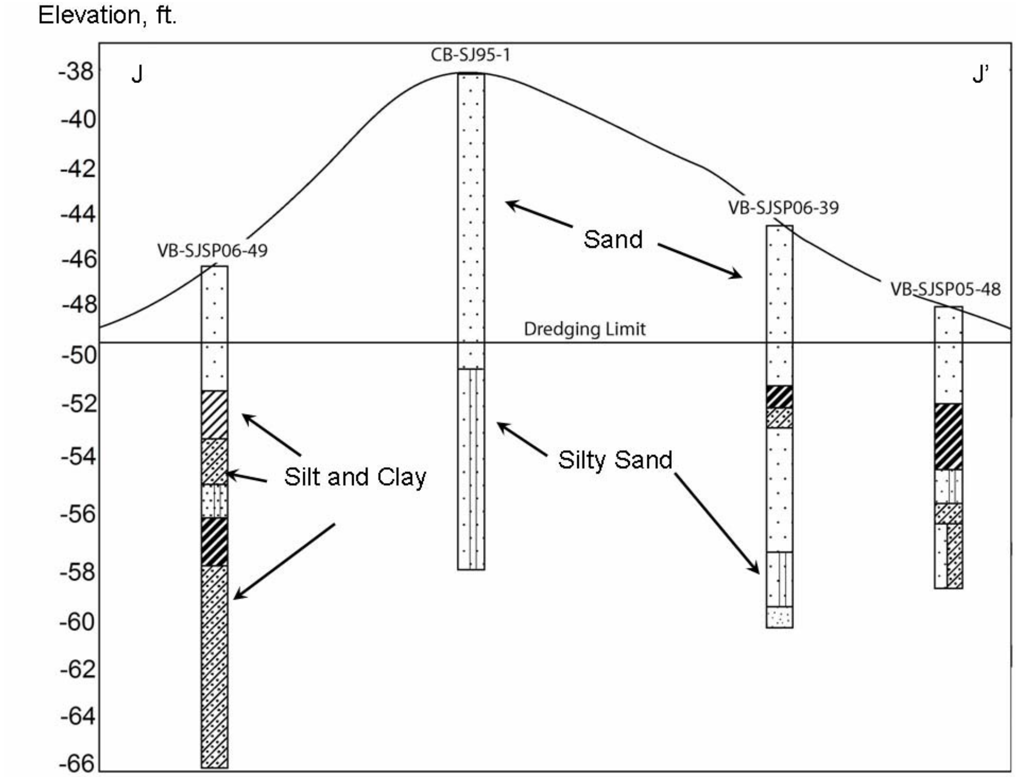


Figure 2-12. East–west lithologic cross-section over the A6-A7 shoal system based on core borings collected by the USACE (2007). Location shown in Figure 2-11.

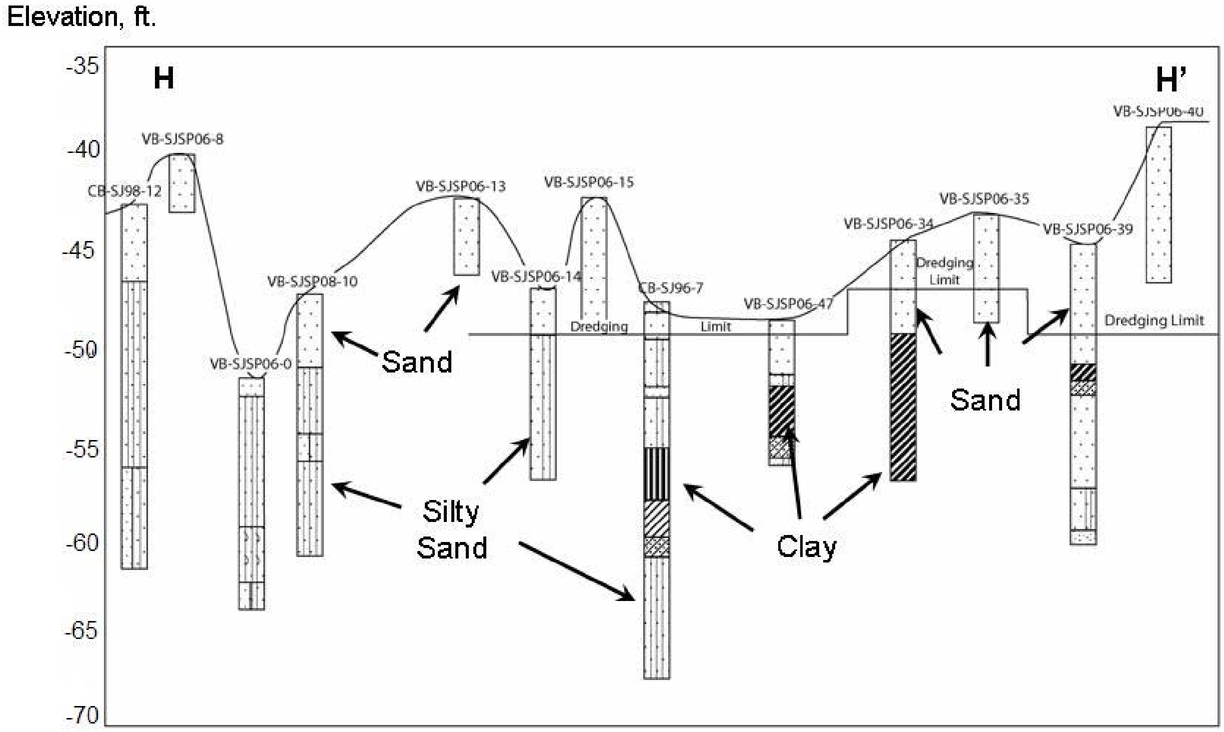


Figure 2-13. North–south lithologic cross-section over the A7-A6 shoal system based on core borings collected by the USACE (2007). Location shown in Figure 2-11.

Analysis of the sub-bottom records from the A7-A6 area indicates a potential for up to 157 million cubic yards of beach-quality sand (Zarillo 2009). In this assessment, each shoal feature was addressed separately. For instance, an isopach analysis was compiled for the main lobe of the A6 shoal (Figure 2-14), which indicated the presence of up to 96 million cubic yards of clean sand. Figure 2-15 is an example of a seismic record over the crest of the A6 shoal, showing the interpretation of a surface layer of clean sand that was correlated with core borings from the USACE (2007).

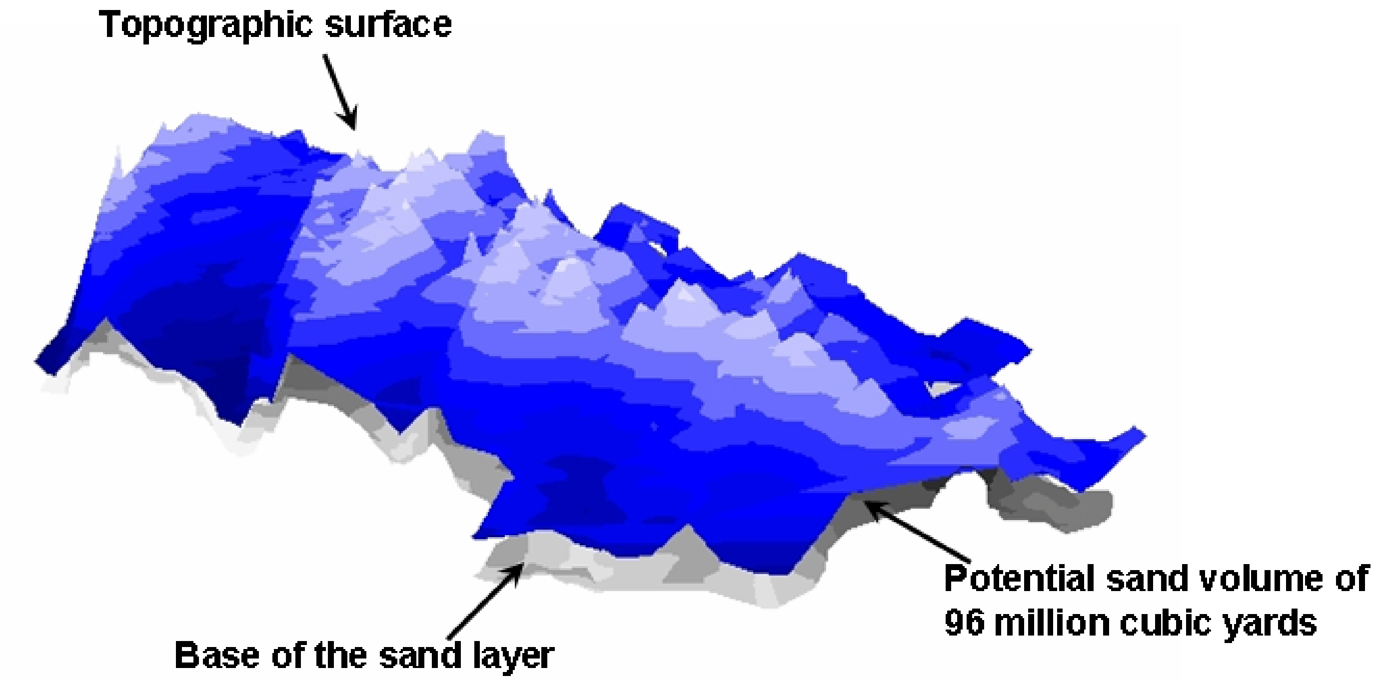


Figure 2-14. Perspective view of the A6 shoal topographic surface (in the shaded blue) over the surface defined as the base of the sand layer from seismic records. The view is from the southwest and the vertical exaggeration is 175x.

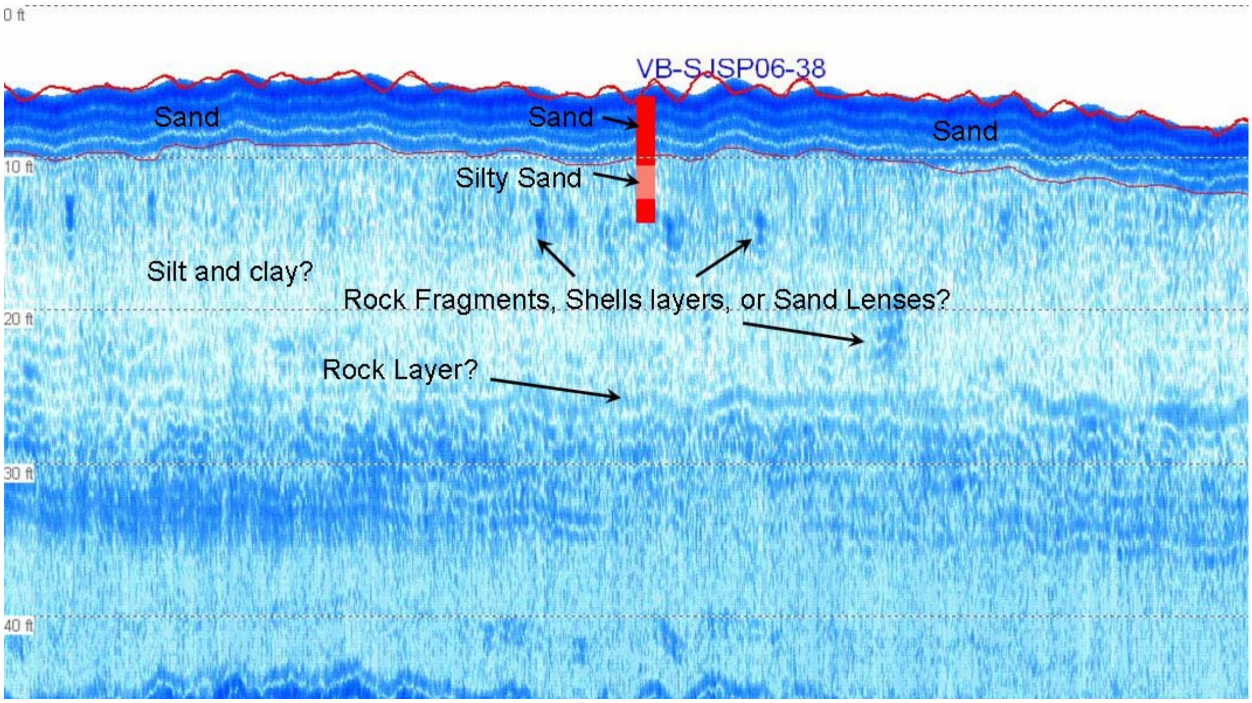


Figure 2-15. Interpretation of the east–west seismic profile line across the crest of Shoal A6. Lithology of a core boring from the USACE study is shown for comparison (Zarillo 2009).

Figure 2-16 shows a cluster of inner shelf and shoreface-connected sand ridges offshore of Volusia and Flagler counties that are similar in configuration to sand ridges and linear shoals studied in other areas of the U.S. Atlantic continental shelf. Sand ridges B12, B11, A9, and A8 are included in the current MMS characterization study (Figure 1-1). The crest elevations of these shoals reach elevations of -45 to -52 ft with respect to local mean sea level. All shoals in this area are in federal waters beyond the three-nautical-mile offshore limit of Florida state waters. There are no detailed sub-bottom seismic survey data available from these shoals. However, the crest of A9 contains at least 10 ft (3m) of medium to coarse carbonate-rich sand. Figure 2-17 is a log description of an ICONS core obtained from the crest of Shoal A9.

As previously stated, the B-shoals were identified as areas of high potential but sand resources were not verified with core sampling. Shoals B12 and B11 are being considered by Volusia County as sources of beach-quality sand to maintain eroding county beaches. Core borings acquired by Volusia County were used to verify the textural properties and volume of beach-quality sand that might be available in the B-shoal areas (Coastal Technology Corp. 2006). Figure 2-18 is a cross-section over the crest of the B12 shoal, showing a clean, medium to fine sand below the crest areas that reach 50 ft below sea level. According to the results of sub-surface sampling, silty sands are present beyond Shoals B12 and B22 in water depths of about 60 ft and greater.

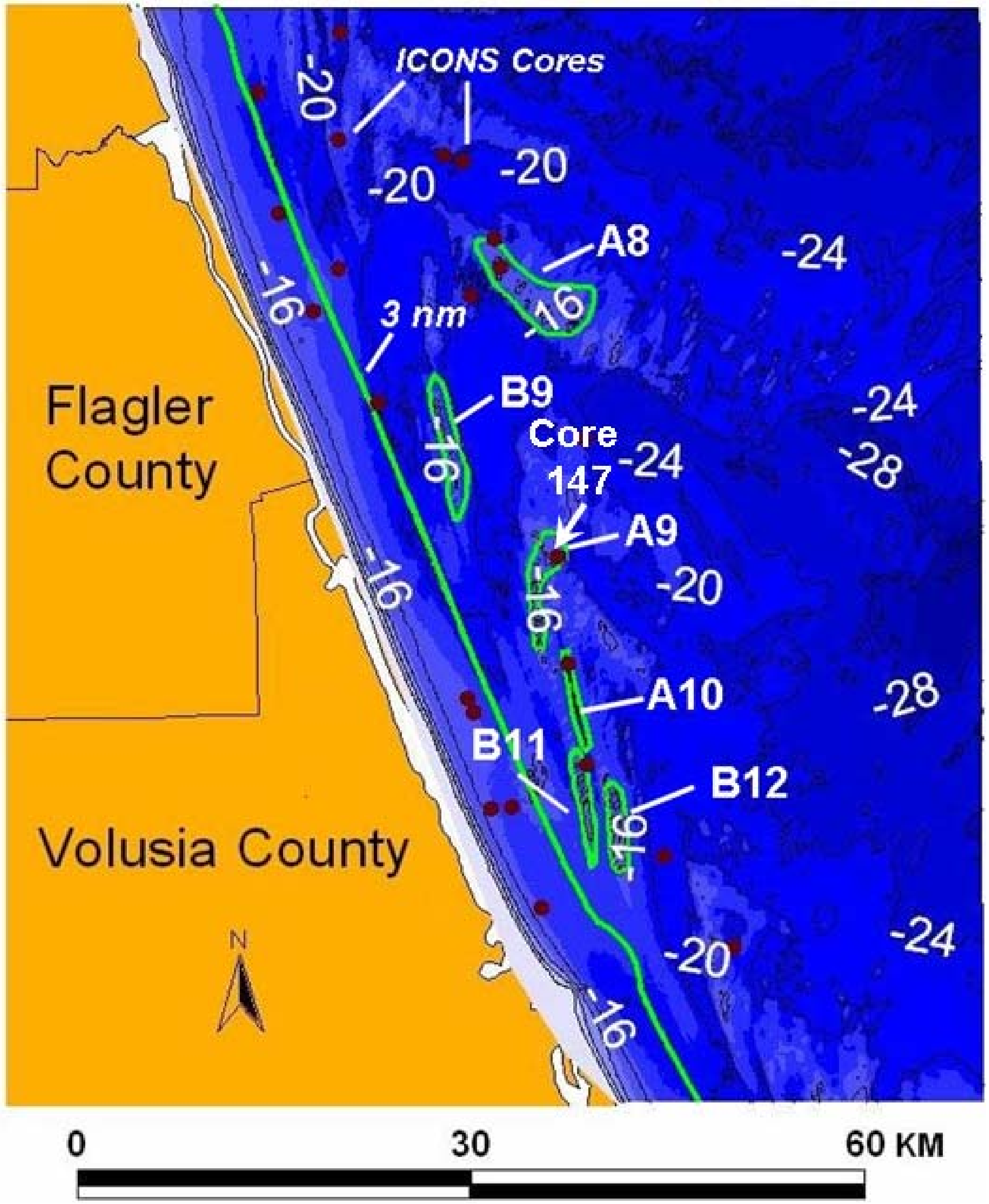
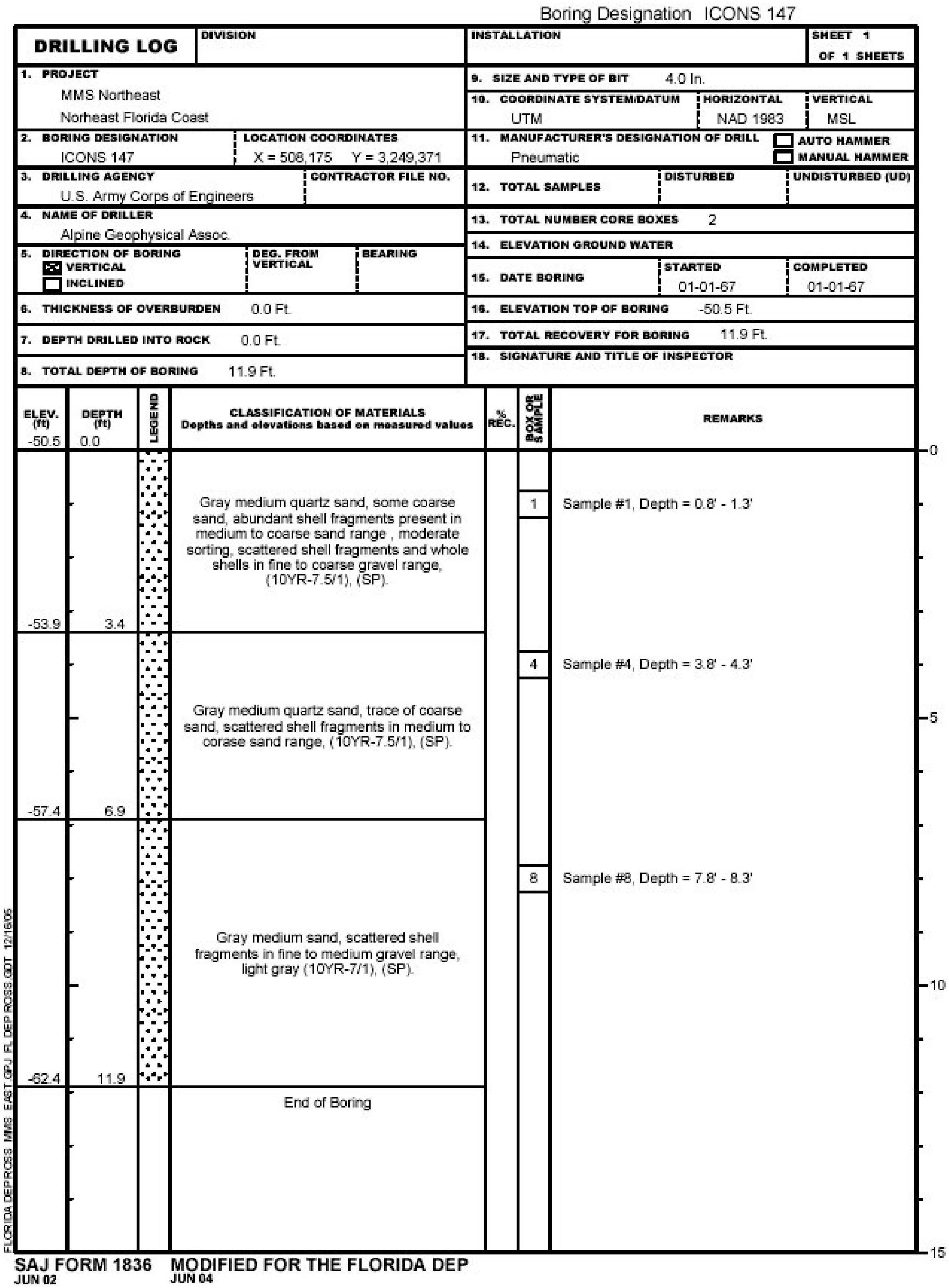


Figure 2-16. Inner shelf sand ridges of Volusia and Flagler counties, Florida. The limit of federal waters is also shown at three nautical miles. Black solid circles indicate location of ICONS cores.



Boring Designation ICONS 147

DRILLING LOG

DIVISION

INSTALLATION

SHEET 1 OF 1 SHEETS

1. PROJECT
MMS Northeast
Norheast Florida Coast

2. BORING DESIGNATION: ICONS 147
LOCATION COORDINATES: X = 508,175 Y = 3,249,371

3. DRILLING AGENCY: U.S. Army Corps of Engineers
CONTRACTOR FILE NO.

4. NAME OF DRILLER: Alpine Geophysical Assoc.

5. DIRECTION OF BORING
☒ VERTICAL
☐ INCLINED
DEG. FROM VERTICAL
BEARING

6. THICKNESS OF OVERBURDEN 0.0 Ft.

7. DEPTH DRILLED INTO ROCK 0.0 Ft.

8. TOTAL DEPTH OF BORING 11.9 Ft.

9. SIZE AND TYPE OF BIT 4.0 In.

10. COORDINATE SYSTEM/DATUM: UTM
HORIZONTAL: NAD 1983
VERTICAL: MSL

11. MANUFACTURER'S DESIGNATION OF DRILL: Pneumatic
☐ AUTO HAMMER
☐ MANUAL HAMMER

12. TOTAL SAMPLES
DISTURBED
UNDISTURBED (UD)

13. TOTAL NUMBER CORE BOXES 2

14. ELEVATION GROUND WATER

15. DATE BORING
STARTED: 01-01-67
COMPLETED: 01-01-67

16. ELEVATION TOP OF BORING -50.5 Ft.

17. TOTAL RECOVERY FOR BORING 11.9 Ft.

18. SIGNATURE AND TITLE OF INSPECTOR

ELEV. (ft)	DEPTH (ft)	LEGEND	CLASSIFICATION OF MATERIALS Depths and elevations based on measured values	% REC.	BOX OR SAMPLE	REMARKS
-50.5	0.0					
-53.9	3.4		Gray medium quartz sand, some coarse sand, abundant shell fragments present in medium to coarse sand range , moderate sorting, scattered shell fragments and whole shells in fine to coarse gravel range, (10YR-7.5/1), (SP).		1	Sample #1, Depth = 0.8' - 1.3'
-57.4	6.9		Gray medium quartz sand, trace of coarse sand, scattered shell fragments in medium to corase sand range, (10YR-7.5/1), (SP).		4	Sample #4, Depth = 3.8' - 4.3'
-62.4	11.9		Gray medium sand, scattered shell fragments in fine to medium gravel range, light gray (10YR-7/1), (SP).		8	Sample #8, Depth = 7.8' - 8.3'
			End of Boring			

FLORIDA DEP ROSS MMS EAST.GPJ FL DEP ROSS.GDT 12/16/05

SAJ FORM 1836 JUN 02 MODIFIED FOR THE FLORIDA DEP JUN 04

Figure 2-17. Geologic log of ICONS Core 147 obtained from the crest of Shoal A9 in 1967. Core location is shown in Figure 2-16.

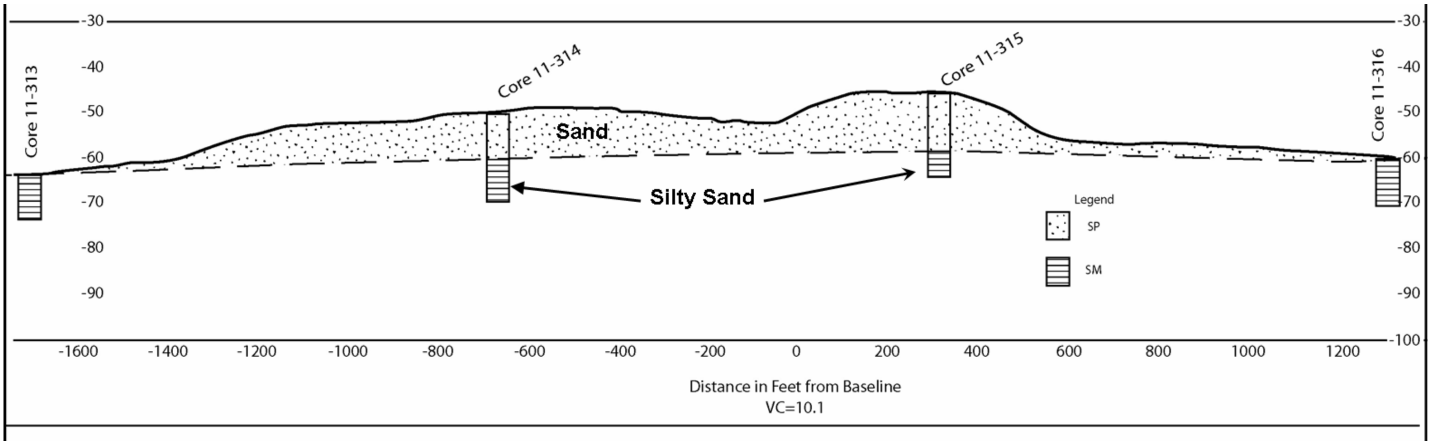


Figure 2-18. Interpretation of sub-surface sediments in a west-east section across the B11 Shoal. The unified soils classification SP indicates clean, well-sorted sand, whereas the SM designation indicates silty sand (from Coastal Tech. Corp. 2006).

2.2.2 Sand Ridge Genesis and Structural Indices

In the original ICONS publications, the term “sand ridge” was not used to describe the sand-rich shoals of the Florida inner continental shelf or from other areas of the U.S. East Coast inner continental shelf. Shoals described by Meisburger and Field (1975) on the northeastern Florida shelf were consistent in scale and orientation to the sand ridges discussed in notable papers by Duane et al. (1972), Swift et al. (1972), Stubblefield et al. (1984), McBride and Moslow (1991), and Snedden et al. (1994, 1999). Most of these investigations focused on the Eastern U.S. Atlantic continental shelf and emphasized barrier island retreat and inlet-related models for the origin of sand ridges attributed to shoreline retreat mechanisms, including shoreface-attached ridges and ebb shoal retreat paths. McBride and Moslow (1991) provided a conceptual model showing the possible relationship among sea level rise, the related shoreface transgressive process, and associated evolution of tidal inlet shoals. Figure 2-19 from McBride and Moslow (1991) shows the possible evolutionary steps in the development of linear sand shoals first attached to the shoreface and later isolated on the inner continental shelf. In this model, inlets breached barrier island systems undergoing transgression with rising sea level. As the inlets migrated alongshore, the ebb shoal systems were extended both alongshore due to inlet migration and cross-shore due to shoreface transgression.

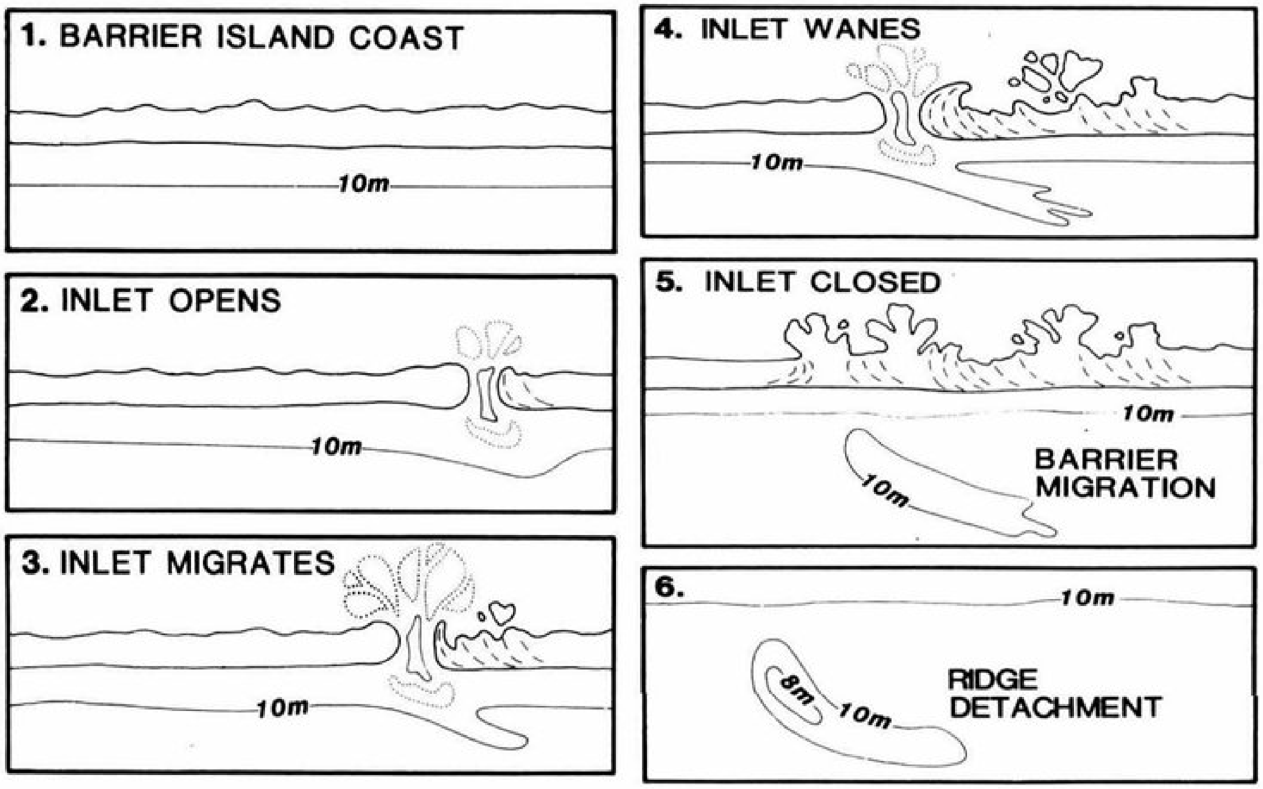


Figure 2-19. Idealized model of sand ridge genesis from the evolution of a transgressive barrier island system and associated tidal inlet migration (from McBride and Moslow 1991).

Other studies consider the formation of linear shoals on the open continental shelf unrelated to shoreline retreat (Stubblefield et al. 1984, Swift and Rice 1984, Tillman and Martinsen 1984). Once the sand ridges are generated, the open-shelf hydraulic regime is considered important for continuing to maintain sand ridge systems (Huthnance 1982, Trowbridge 1995). Hayes and Nairn (2004) used observations and predictions from coupled wave, circulation, and transport models to hypothesize how modern sand ridges can be maintained by wave-driven sand transport. For sand resource evaluation, it is important to understand the structure and sedimentologic indices of sand ridges. Because these features are found in both modern and ancient environments as porous sandstone petroleum reservoir rocks, facies models of sand ridge deposits are used to identify the shallow marine environment from well logs. Figure 2-20 shows the idealized ridge and inter-ridge sediment facies common to inner shelf environments. This idealized model of a coarsening upward sequence rests on a pre-Holocene surface and begins with mixtures of organic-rich sediments or silts and clays typical of the restricted back barrier environment, followed by the typical inter-ridge sediments that can be mixtures of sand and fine-grained sediments. The upper two units are characteristic of post-transgressive sands that have been reworked from inlet shoals and shoreface sands into discrete linear sand bodies composed of clean, silt-free sand. The crossbedding and lack of biogenic structures in the top unit of the idealized model represents the continued reworking of the modern sand ridges by inner-shelf physical processes including waves and storm- or tide-generated currents.

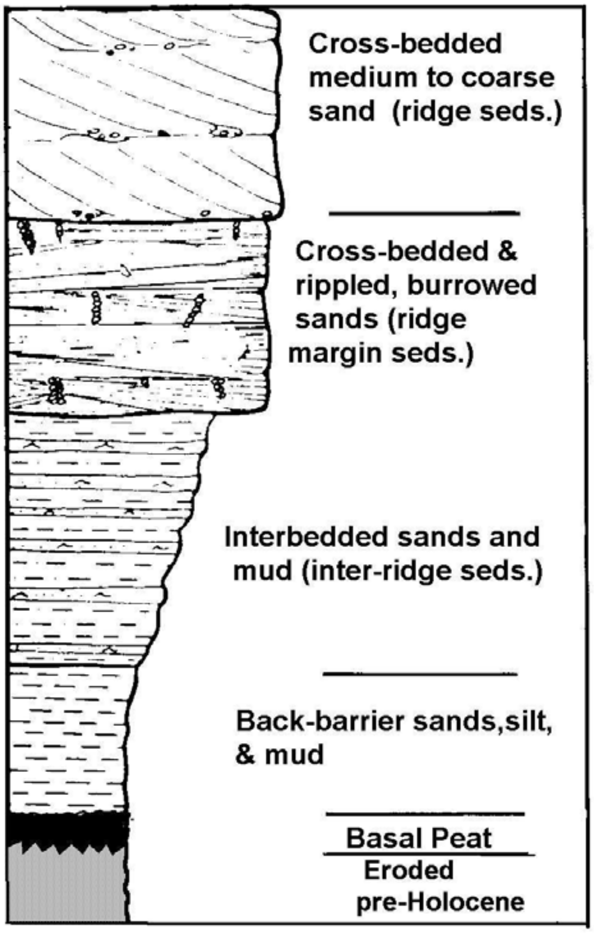


Figure 2-20. Facies model of a coarsening upward sequence capped by clean sand deposits of a linear sand ridge (from Tillman 1985).

2.3 Physical Oceanography

2.3.1 Overview and Physical Setting

The southeast coastal ocean extends from the Florida Keys to the North Carolina continental shelf. The northeast Florida continental shelf is considered part of the South Atlantic Bight (SAB), bounded on the south by Cape Canaveral, Florida, and on the north by Cape Hatteras, North Carolina. Key oceanographic characteristics of the southeast (SE) coastal ocean are related to the regional geomorphology of the SE United States. The coastal areas of Florida, Georgia, and the Carolinas have relatively low relief topography and have relatively broad continental shelves north of Cape Canaveral. The northeast Florida shelf widens to approximately 100 miles to the shelf break at the Florida–Georgia border and increases in width to the north reaching 120 miles off the coast of Georgia. In contrast, the southeast Florida shelf is narrow and reaches only about one mile in width or less in South Florida, beyond which the continental slope drops off into deep water within a few miles of the coast.

The sharp latitudinal change in the width of the continental shelf influences the interplay between local and deep-ocean forcing with respect to the distribution of physical characteristics, such as sea level, water velocity, temperature, and salinity. The distribution of chemical and biological constituents, including nutrients, non-living particulate, and dissolved organic matter; inorganic materials, such as suspended clay particles; and organisms of various trophic levels can also be considered with respect to local and deep-ocean forcing. A simplified schematic view of the key local and deep-ocean forcing is shown in Figure 2-21. Local forcing includes inputs of momentum through winds and pressure gradients, inputs of buoyancy resulting from river discharges at the coast, local precipitation/evaporation differences, and through surface heat flux. Deep-ocean effects include the influence of the ocean boundary current and associated frontal eddies on the shelf circulation and material exchange, and through tides.

Starting with the deep-ocean forcing, one of the defining characteristics of the SE coastal ocean is the presence of a major western boundary current system. The Loop Current/Florida Current/Gulf Stream complex provides a mechanism of rapid transport of materials along the ocean margin throughout the region. It also strongly influences outer shelf circulation and material exchange processes along the shelf margins through formation and dissipation of meanders, fronts, eddies, and sub-mesoscale vortices. An overview of the Florida Current/Gulf Stream influence on shelf waters is provided in Section 2.3.2 of this report. Another deep-ocean forcing is from tides. The largest tides in the SE coastal ocean are found in the central portion of the SAB, with tidal ranges of about 8–10 ft near Savannah, Georgia, and peak mid-shelf tidal currents of 1.3–1.6 ft/s. Tidal ranges are of the order of 3 ft or less over much of the rest of the domain. More detail on tides in Northeast Florida is provided in Section 2.3.4.

On the more local scale, variability in winds is one of the major factors driving shelf circulation patterns. An overview of seasonal and synoptic scale patterns of local wind and the influence of storms is summarized in Section 2.3.3. The coastal waters are linked by the Loop Current/Florida Current/Gulf Stream complex, which runs along the shelf margin. Shelf waters respond strongly to atmospheric forcing by winds and air–sea fluxes. Freshwater input occurs along the coast from a number of rivers fed by the regional drainage basins.

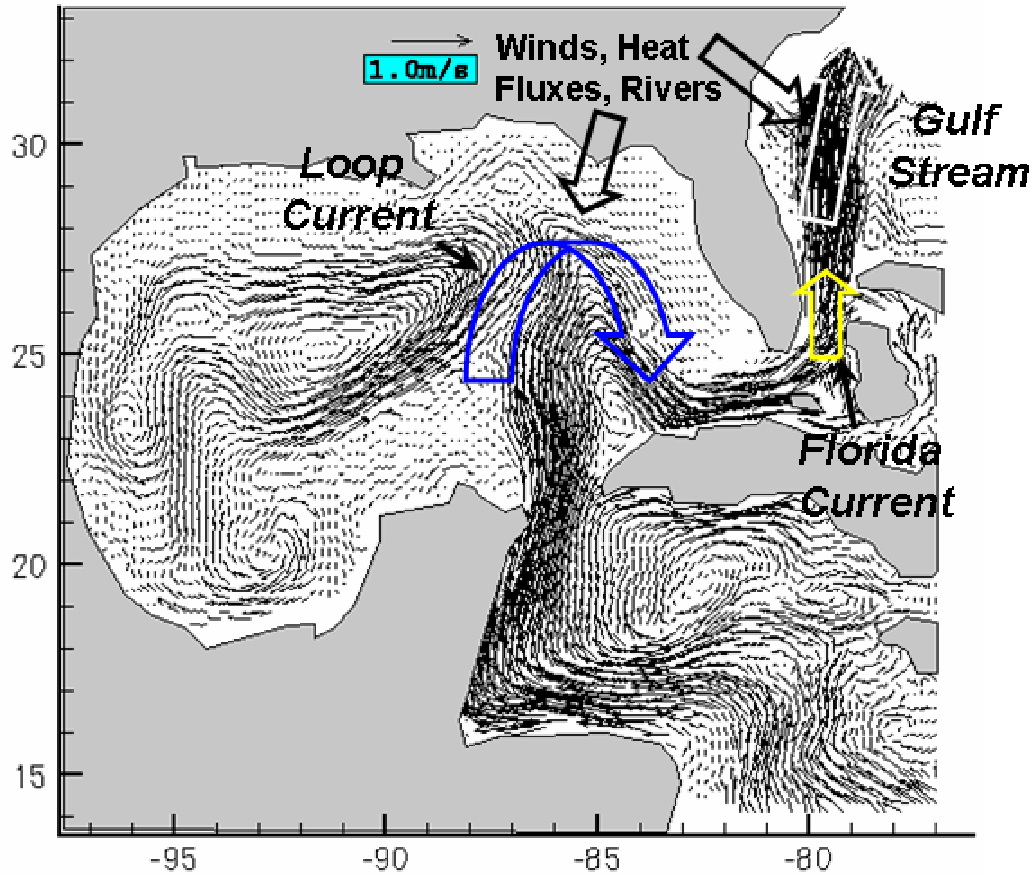


Figure 2-21. A simplified representation of some key local and deep-ocean forcing that drives water motions and determines material property distributions in the SE coastal ocean (adapted from Zarillo and Yuk 2001).

2.3.2 The Florida Current and Gulf Stream

The Florida Current can be considered the "official" beginning of the Gulf Stream system. It is defined here as that section of the system that stretches from the Florida Straits north to Cape Hatteras. The Florida Current receives its water from two main sources—the Loop Current and the Antilles Current. The Loop Current is the most significant of these sources and can be considered the upstream extension of the Gulf Stream system. Historically, the Florida Current has a mean transport of about 30 Sverdrups (Sv) (Schmitz and Richardson 1968, Niiler and Richardson 1973). This value has been confirmed in numerous studies, including the Subtropical Atlantic Climate Study (STACS) study, which verified a mean transport value of 31.5 Sv at 27°N in the Straits of Florida (Molinari et al. 1985, Lee et al. 1985, Leaman et al. 1987, Larsen and Sanford 1985, Schott et al. 1988). Measured transport values of the Florida Current have been used in model simulations to reproduce the major features of the Gulf Stream as it moves along the western boundary of the North Atlantic (Zarillo and Yuk 2001). Figure 2-22 shows a prediction of the Gulf Stream surface velocity and temperature using the Florida Ocean Model (Zarillo and Yuk 2001) in which mean transport rates were applied to the model boundaries along with monthly average wind stress and sea surface temperatures to drive the simulation.

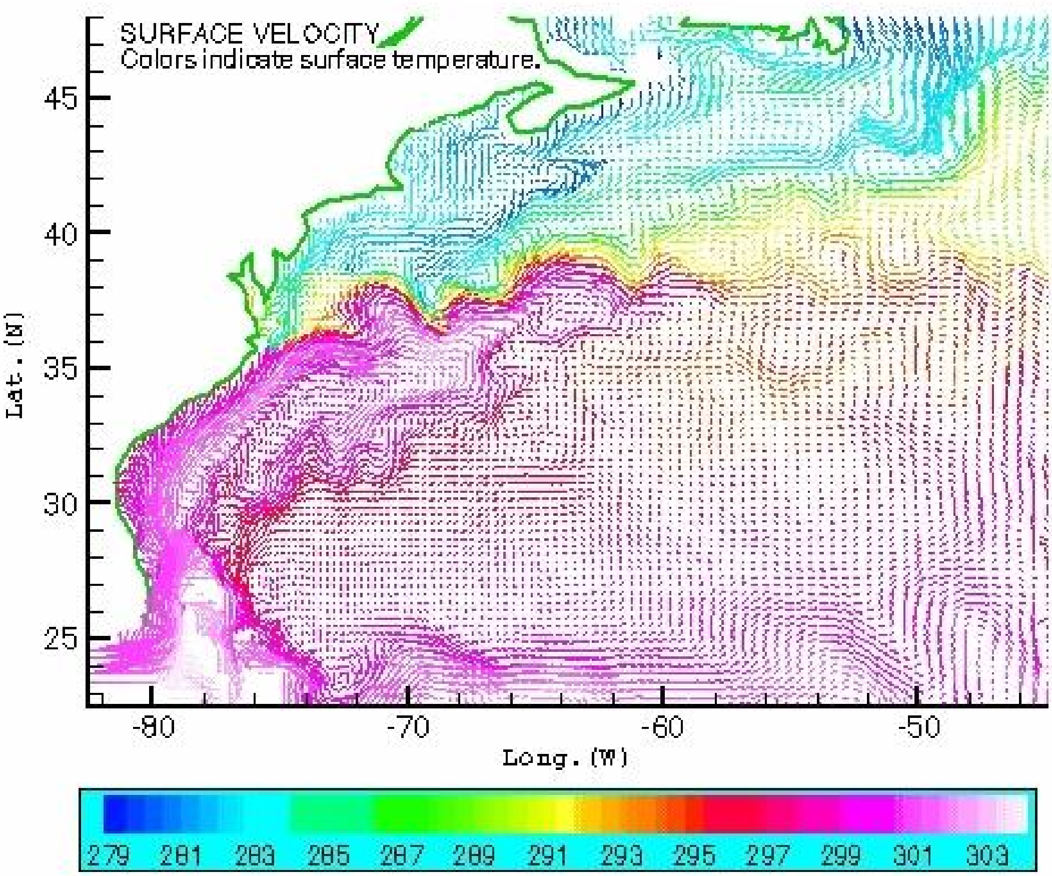


Figure 2-22. Prediction of Gulf Stream surface current and temperature from the Florida Ocean Model (from Zarillo and Yuk 2001).

The Florida Current is subject to both seasonal and inter-annual variability. These changes are significant and can amount to as much as a 10 Sv difference between high and low values along the eastern Florida coast (Schott et al. 1988). Most of this water may originate in the Gulf of Mexico. Early estimates of inflow through island passages in the Florida Straits are only about 3.5 Sv (Schmitz and Richardson 1968). Later estimates are much larger with Schmitz and Richardson (1991) reporting a total of 28.8 Sv for five key passages: Grenada, St. Vincent, St. Lucia, Dominica, and Windward. Wilson and Johns (1997) found an influx of 17.5 Sv and noted the presence of strong outflows in these passages as well. Flow through these passages is highly variable and may, in part, account for the considerable variability of the Florida Current.

The transport of the Florida Current has been shown to increase substantially between the Straits of Florida and Cape Hatteras, where transport increases three-fold from 29 Sv at 27° N to 93.7 Sv to bottom at 73° W and 86.8 Sv to 2000 m. The transport increases downstream to a maximum of about 86 Sv near Cape Hatteras (Worthington and Kawai 1972) as a result of input from recirculation gyres. The width of the Florida Current is approximately 80 km at 27° N, 120 km at 29° N, and slowly increases to a width of 145 km for the Gulf Stream at 73° W.

The dominant meanders, determined from current meter data in the Florida Current, have wavelengths of 340 km and 170 km, periods of 12 days and 5 days, and propagate at 28 km/d and 36 km/d, respectively

(Johns and Schott 1987). The amplitude of the meanders increases outside of the constraint of the Straits of Florida. Meanders and eddies serve as the principal form of mesoscale variability along the path of the Florida Current within the Mid Atlantic Bight (between Cape Canaveral and Cape Hatteras). The Florida Current is deflected offshore near 32° N, and its eddy variability decreases downstream of this deflection (Vukovich and Crissman 1978, Olson et al. 1983). This deflection is caused by the presence of a topographic irregularity known as the Charleston Bump near 31° N. This deflection has been shown to be bimodal in character with the Florida Current, assuming either a weak or strongly deflected state. Bane and Dewar (1988) observed that the transition between weak and strongly deflected modes can occur rapidly, within a few days.

2.3.3 Climate and Storms

The climatic regime and episodic occurrence of storms in the SAB region of the U.S. has an important influence on continental shelf dynamics. Climatic and storm signals are particularly amplified over the inner continental shelf and at the shoreline where tides, waves, and storm surge are amplified by the shallow depths. Five seasonal wind regimes are associated with the SAB and East Florida Shelf regions (Weber and Blanton, 1980).

In winter (November to February/March), winds are persistently southeastward in North Carolina and turn more southward over Florida. During the winter months, frequent extra tropical cyclones across the southeastern states and out over the Atlantic Ocean. These storms frequently produce gale-force winds that can cause property damage and beach erosion. During spring transition (March to May), winds shift westward from Florida to South Carolina, with the winds elsewhere in the region being more variable. In the summer (June and July), westward winds dominate the southern reaches of the domain, and northward flow sets in for the central to northern portions of the SAB from Georgia to North Carolina. During August, the summer wind pattern breaks down and becomes generally disorganized. However, Florida can experience westward and southwestward winds during this period. During the "Mariner's fall" (September and October), strong southwestward winds occur over the domain, with westward winds at times over Florida.

The Southeast U.S. region typically experiences weekly easterly tropical waves and several tropical cyclones and hurricanes each year. Neumann et al. (1993) quantified the mean direction of the tropical cyclone tracks from 1886–1989 (Figure 2-23). Generally, if storms do not recurve east of 60^{o} W, they will make landfall along the U.S. coast. The official Atlantic hurricane season runs from June 1 through November 30, with a peak from mid-August through mid-October. For 2004, NOAA estimated 12 to 15 tropical storms would form, with 6 to 8 becoming major hurricanes of Category 3 or higher on the Saffir–Simpson Hurricane Scale.

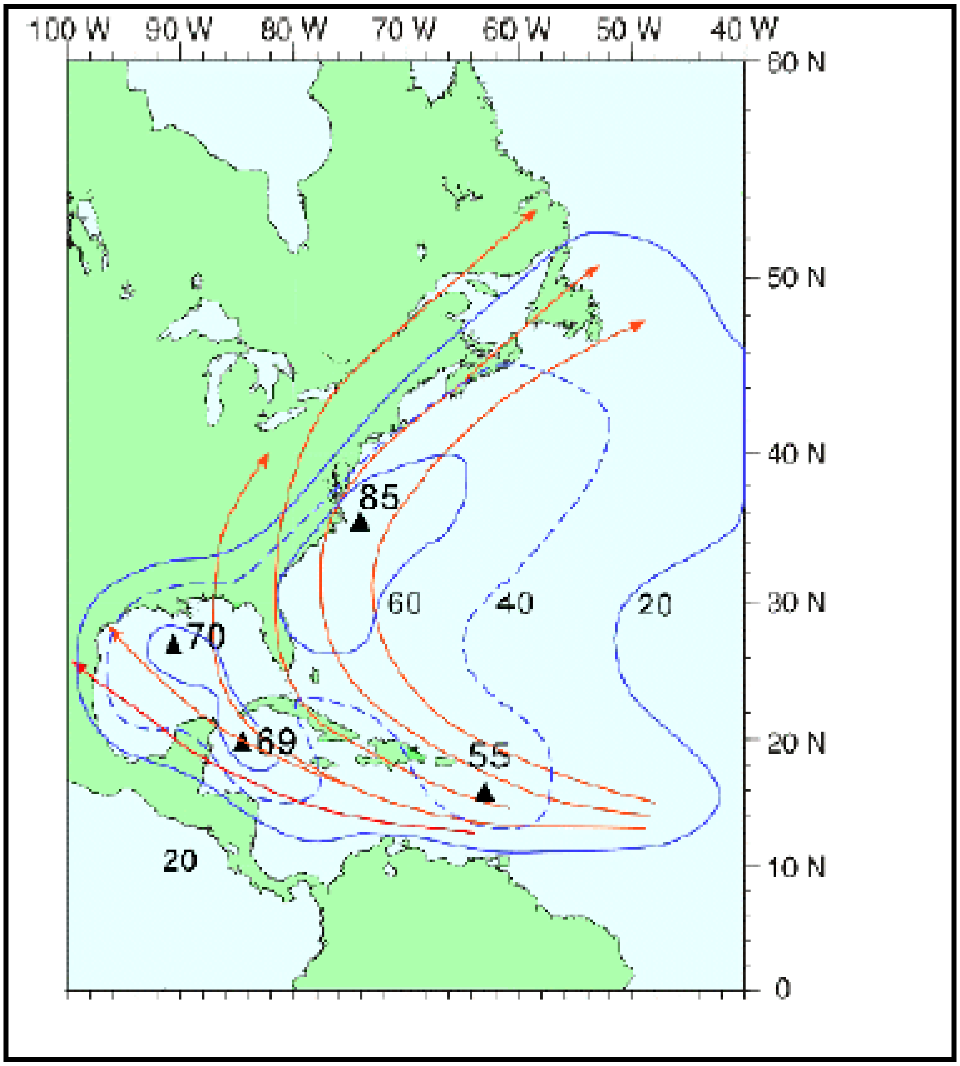


Figure 2-23. Tropical cyclone tracks (red) and number of cyclone occurrences (blue contours) over a 103-year period (from Neumann et al. 1993).

2.3.4 Tidal Regime and Sea Levels

The tides of the Florida inner continental shelf are strongly dominated by the semidiurnal forcing of the M2 (Lunar) and S2 (Solar) constituents. In the current MMS project area, tides at the shoreline are monitored continuously at three National Ocean Survey (NOS) stations. Real-time and historical water level data can be obtained from the NOAA Center for Operational Center for Oceanographic Products and Services (CO_OPS: http://140.90.121.76).

The south end of the project area is bounded by the Trident Pier Station 8721604 at Cape Canaveral in Brevard County and on the north boundary by NOS Station 8720030 located at Fernandina Beach in Duval County. There is a major shift from a microtidal regime at the south end of the project area, where the mean tidal range is approximately 1 m, to a near mesotidal regime at the Florida–Georgia border, where the mean tidal range is nearly 6 ft and can exceed 7 ft during spring tide conditions. The increase in tidal range corresponds with tidal amplification over the widening continental shelf north of Cape Canaveral to a maximum offshore of Savannah, Georgia, at the apex of the Georgia Bight. Figure 2-24 compares recorded water levels from the Fernandina Beach and Trident Pier gages for a 2-week period in late 2005. The tides at both stations are very close in phase but the tidal range at the Fernandina Beach station is distinctly larger. A relatively weak diurnal inequality is apparent in both records. McBride (1987) noted the inverse relationship between tide and wave regime along the Florida coast, classifying the northeast Florida coast as mostly tide-dominated, which is similar to the conceptual model described by Hayes (1980).

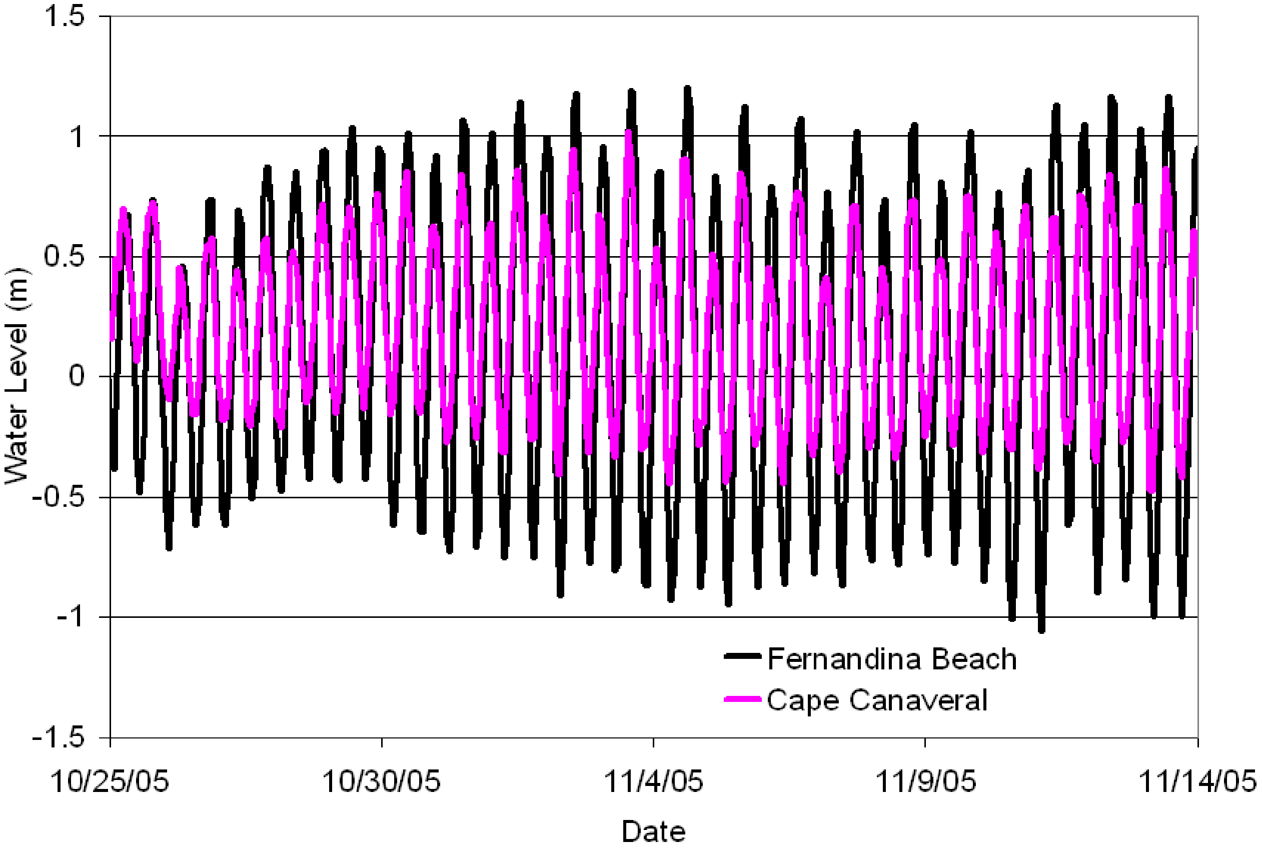


Figure 2-24. Comparison of 20-day water level records from Fernandina Beach (NOS Station 8720030) and Cape Canaveral (NOS Station 8721604).

Barrier island morphology reflects the transition from the microtidal to mesotidal regime from East Central to Northeast Florida. Barrier islands from approximately Flagler County and north are predominantly beach ridge barriers composed of a series of coalescing beach ridges added progressively to the seaward side of these features by sand from tide-generated inlet shoal deposits (Hayes 1979). In contrast, the barrier along the southern half of Volusia County is a single-ridge barrier bordering the Mosquito Lagoon until it merges with the relic beach ridge system that forms the False Cape just north of Cape Canaveral. Microtidal barrier islands are more likely to be storm- and wave-dominated and backed by open-water lagoons rather than the marshy back-barrier areas of a mesotidal barrier system.

In addition to strong tidal influence, the inner shelf of Northeast Florida is also influenced by large changes in sea level at the subtidal frequencies. Figure 2-25 compares water level records along the coast of Florida with the tidal signal removed. It can be seen that the records are coherent in phase along the entire coast of East Florida but can differ in the magnitude of sea level oscillation from place to place.

While the annual range of sea level along east Florida has been as great as 3.3 ft in some years, the annual low stand of sea level is most often in late July, whereas the annual high stand is usually in late October to early November of each year. Figure 2-26 plots the mean annual non-tidal range of sea level for the Fernandina Beach station and clearly shows the annual sea level cycle**.**

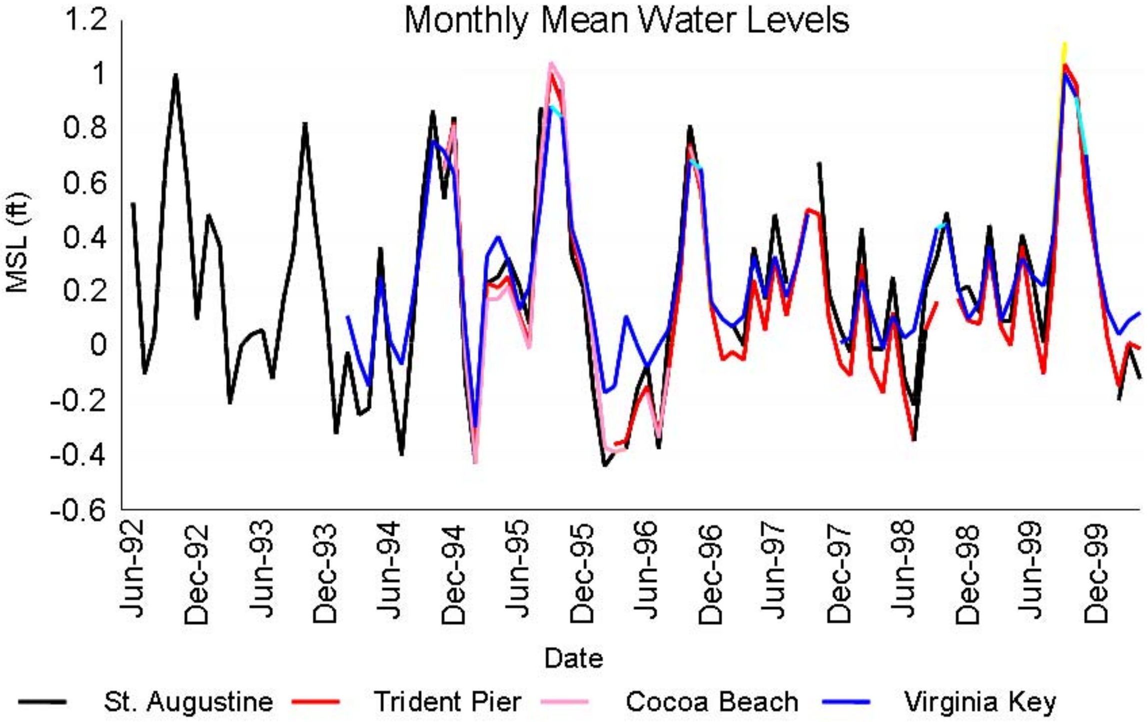


Figure 2-25. Non-tidal sea level records at four NOS water level stations on the east Florida coast.

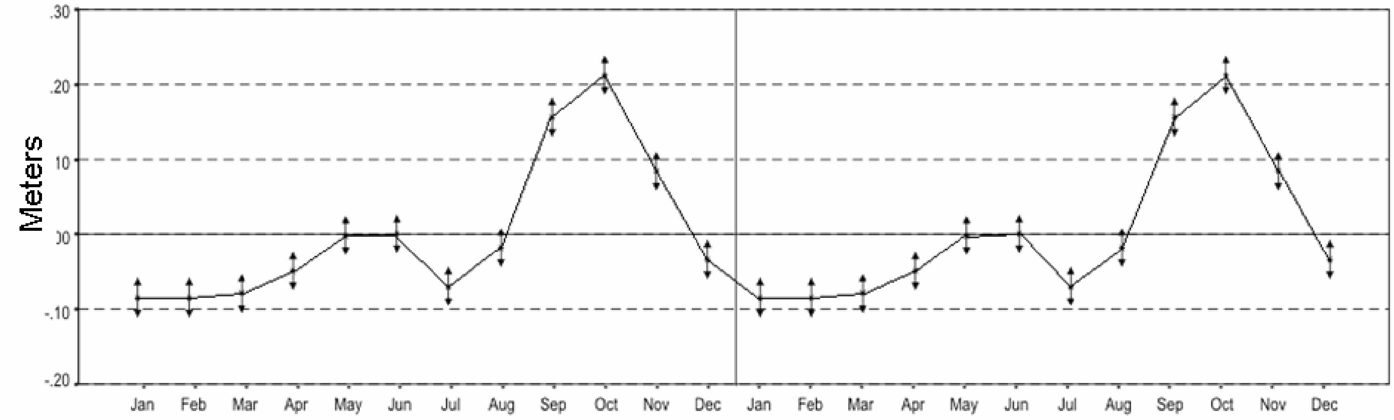


Figure 2-26. Two years of seasonal variation in non-tidal sea level at NOS Station 8720030 located at Fernandina Beach in Nassau County, Florida (from the NOAA Center for Operational Oceanographic Products and Services).

2.3.5 Physical Monitoring Resources along the Northeast Florida shoreline and Continental Shelf

Operational NOS water level stations are located at Cape Canaveral in Brevard County, Fernandina Beach in Nassau County, and Mayport in Duval County, Florida. An NOS C-Man station is located in St. Augustine Beach and records water level and meteorological data. In additional to these onshore stations, the National Data Buoy Center operates Buoy 41012, which is situated about 50 miles offshore over water depths of 150 ft. These federally operated monitoring stations are supplemented by resources from and maintained by the Southeast Atlantic Coastal Ocean Observing System (SEACOOS, http://www.seacoos.org) and Southeast Coastal Ocean Observing Regional Association (SECOORA, http://secoora.org). They are regional partnerships that integrate coastal ocean observing systems for a four-state region (North Carolina, South Carolina, Georgia, and Florida) of the southeastern coastal U.S. Currently, SEACOOS is transitioning its data products and mapping services to SECOORA. The long-term intent of the monitoring programs is to establish a regional, coastal ocean observing system as part of the coastal component of the national Integrated Ocean Observing System envisioned by the national-level Ocean U.S. Project.

2.3.6 Wave Regime and Shoreline Changes

Long-term observations of the spectral wave field in either shallow or deep water are limited the coastal ocean of Northeast Florida. Long-term hind casts of swell and wind wave conditions across the continental shelf are available from Wave Information Study (WIS). The hind cast databases are periodically updated by the Coastal Hydraulics Laboratory (CHL) at the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, Mississippi. WIS hind cast data are generated from numerical models driven by climatological wind fields overlain on grids containing bathymetric data. The WIS numerical hind casts provide long-term wave climate information at nearshore locations (numerical recording stations) of U.S. coastal oceans. The spectral wave characteristics provided at selected numerical wave stations on the northeast Florida inner continental shelf supply offshore boundary conditions for simulation of wave propagation over the MMS characterization sites. Figure 2-27 shows the position of WIS hind cast Stations 415 and 425 among other WIS stations on the northeast Florida shelf. These numerical stations provided hind cast spectral wave data for model simulations in this project. Station 415 is located approximately 9 miles offshore where waters depths are about 57 ft, just seaward of ICONS borrow site A6. WIS Station 425 is located nearly 10 miles offshore and 2 miles north of ICONS borrow site A9, where the maximum water depth is approximately 60 ft. The locations of ICONS sites A6 and A9 are shown in Figure 1-1.

Hind cast wave information indicates that the dominant or most energetic waves approach from the east to northeasterly directions, although distinctive seasonal differences occur in both direction and energy. Figure 2-28 shows the joint probability between significant wave height and peak direction for hind cast wave data for the months of October through March at WIS Station 415 between 1995 and 1999. The joint probability analysis for these records reveals peaks of energy arriving from approximately 83^o and from approximately 70^o. The modal significant wave height for the peak energy from 83^o is approximately 4 ft, whereas the modal significant wave height at the 70^o peak is about 0.9 m. During spring and summer (April through September), dominant energy approach is from approximately 115^o, corresponding with a model significant wave height of approximately 1.5 ft (see Figure 2-29). Seasonal variation in significant wave height at the peak period is demonstrated by Figure 2-30, which shows the hind cast wave heights, along with a 30-day moving average. Monthly average wave heights are well above 3 ft at this station and wave heights often exceed 9 feet on a daily basis. In contrast, average monthly summer energy peaks are usually below 3 ft.

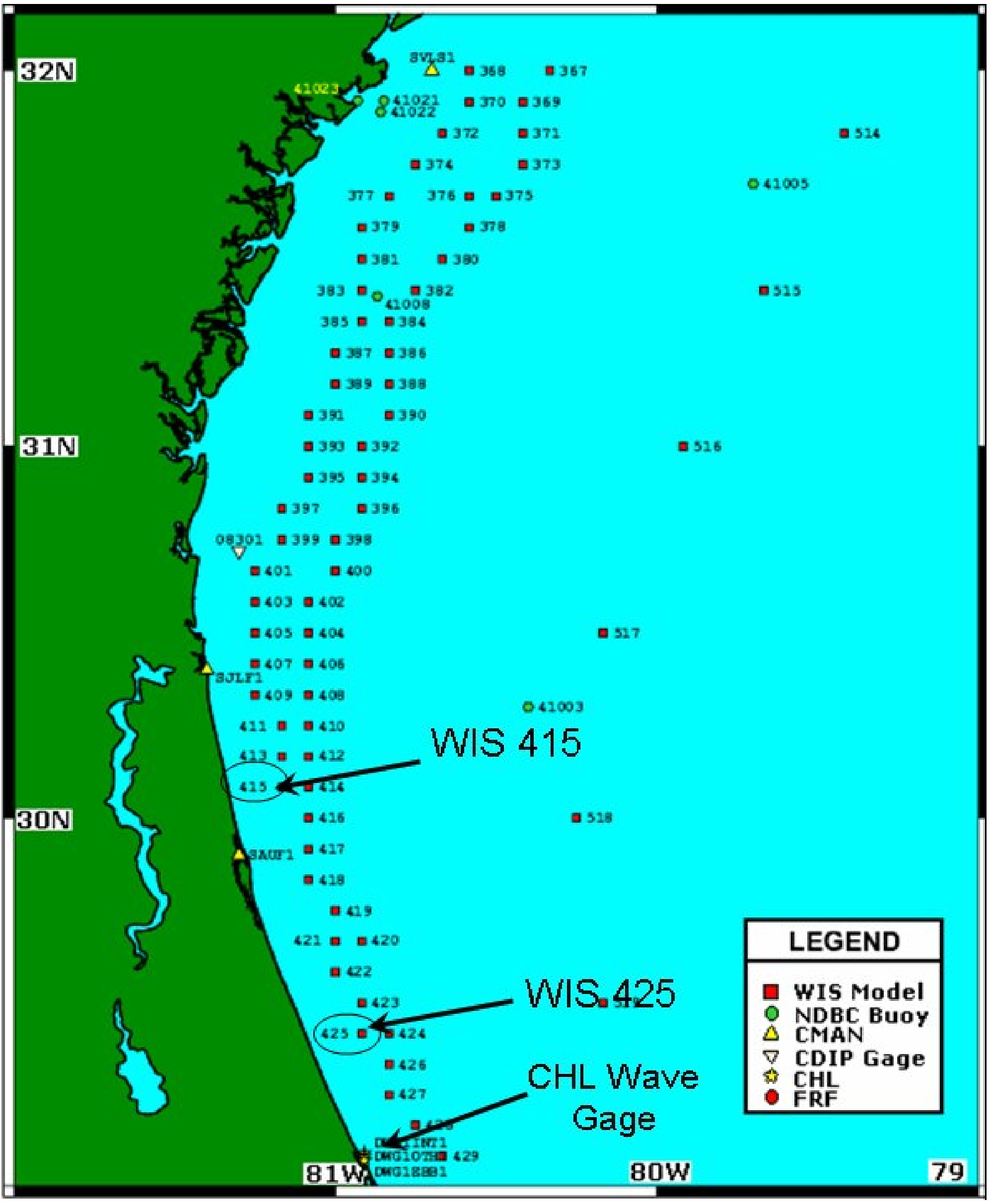


Figure 2-27. Location of WIS hind cast stations and the Ponce Inlet CHL directional wave monitoring station on the inner continental shelf of Northeast Florida.

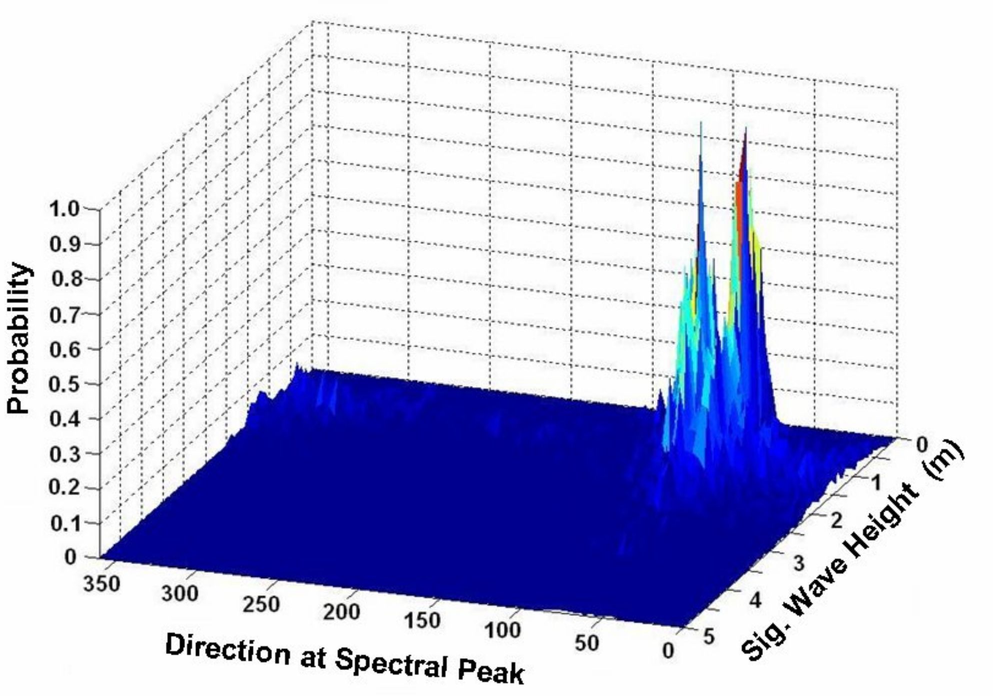


Figure 2-28. Joint probability between significant wave height and peak direction at WIS Station 415 from October to March (hind cast time period is 1995–1999). The location of WIS 415 is shown in Figure 2-27.

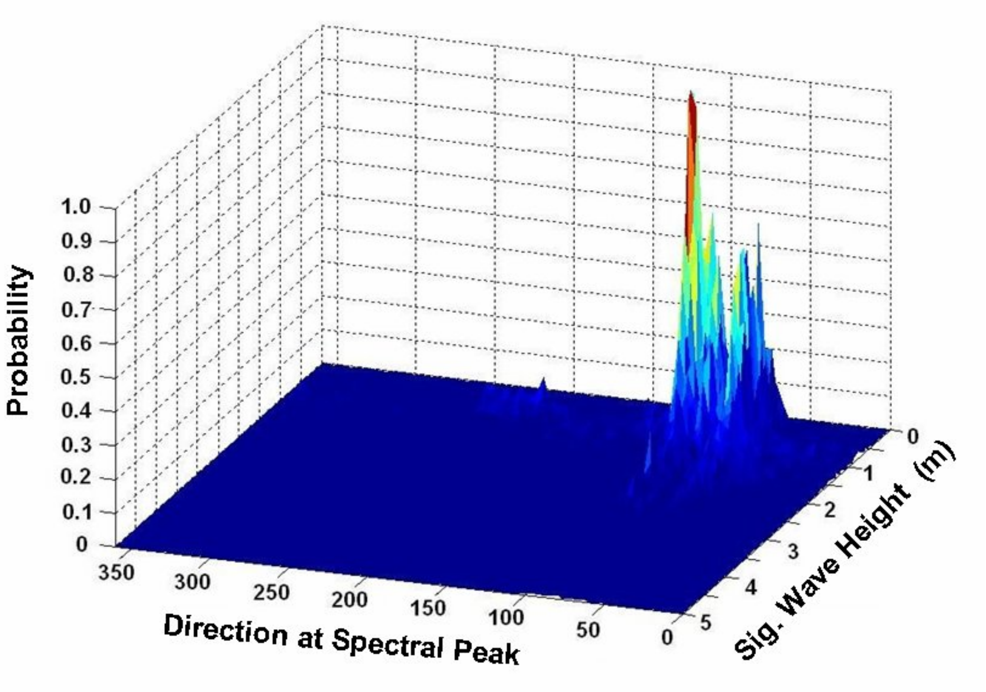


Figure 2-29. Joint probability between significant wave height and peak direction at WIS Station 415 from April to September (hind cast time period is 1995–1999). The location of WIS 415 is shown in Figure 2-27.

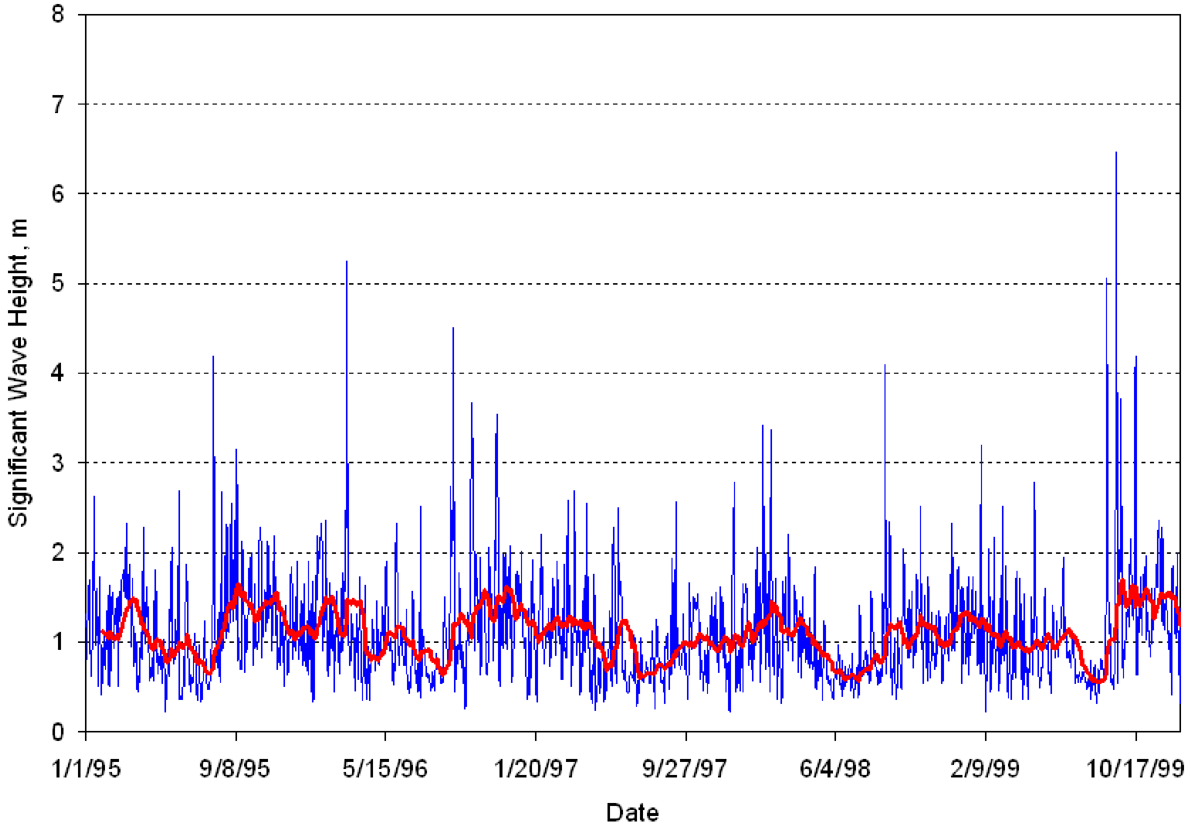


Figure 2-30. Hind cast of significant wave heights at WIS Station 415, 1995–1999. The trend line is a 30-day moving average. The location of WIS 415 is shown in Figure 2-27.

Between the WIS hind cast stations and the shoreline, the shallow inner shelf and irregular topography modify waves that approach the coast. The result of nearshore wave transformation is usually a decrease in overall energy and the focusing of waves to a more shore perpendicular path.

There have been very few long-term directional wave gage deployments in shallow water along the northeast Florida coast. Several directional wave gages were deployed at Ponce Inlet from October 1995 through March 1997. The deployment was part of the Coastal Inlets Research program of the CHL. The position of the CHL directional wave monitoring station DWG1INT1 is shown in Figure 2-27 along with the nearby WIS hind cast stations. The CHL gage was located 2 miles offshore to the northeast of Ponce Inlet in a water depth of 48 ft. Figure 2-31 shows the joint probability between significant wave height and direction of data collected at this station. Comparison with the WIS data (Figure 2-32) predicted at a depth of 60 ft shows that the directional spectrum and energy spectrum changes as waves approach the shoreline. The nearshore measured wave spectrum has a joint probability maximum at an approach of 75^o and significant wave height of 1.6 ft for data recorded during the October to March period. For spring and summer, energy peak at this station shifted to approximately 80^o at a significant wave height of 1 ft.

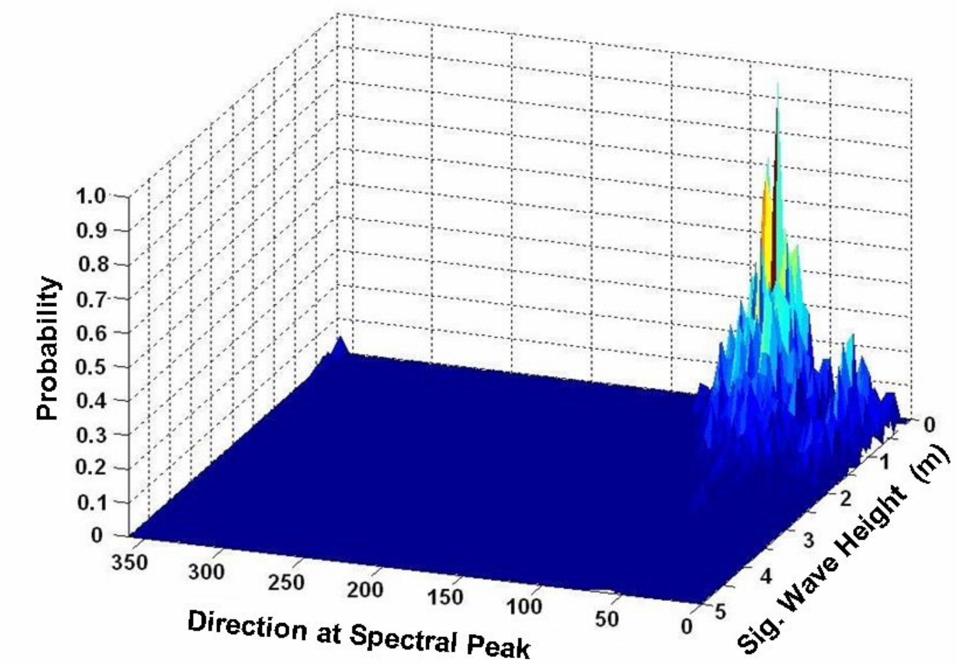


Figure 2-31. Joint probability between significant wave height and peak direction at Ponce Inlet Station DWG1INT1 from October to March. Monitoring Period is 1995–1997. Station location is shown in Figure 2-27.

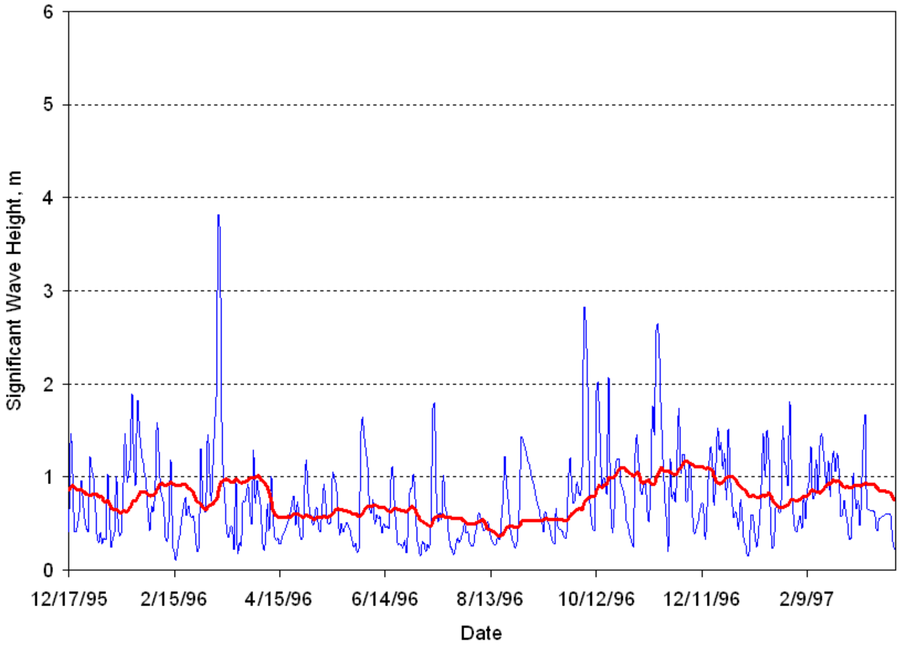


Figure 2-32. Significant wave height record at CHL gage DWG1INT1 located 2 miles offshore Ponce Inlet (see Figure 2-27 for approximate gage location).

The period of record at the Ponce Inlet gage is not long enough to resolve seasonal variations in wave energy. Wave records show distinct variations in the mean wave height over several months as well as maximum significant wave heights of 9 and 12 ft during the period of record (Figure 2-32).

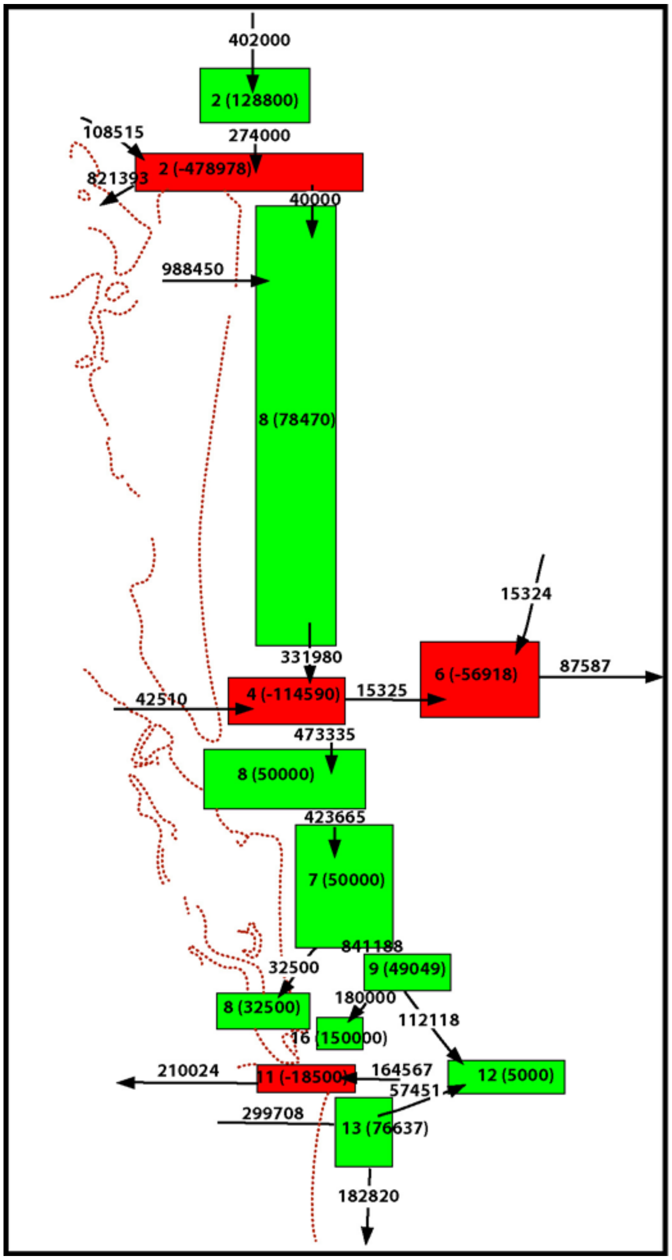


Figure 2-33. Littoral sand budget calculations for Northeast Florida (from Taylor Engineering, Inc. 2001).

Analysis of the wave regime along Northeast Florida indicates that the net longshore drift of sand driven by breaking waves in the littoral zone should be from north to south. Estimated longshore drift rates by O'Brien and Dean (1987) indicate that net rates are between 500,000 and 600,000 cubic yards per year in Northeast Florida. Regional estimates, as shown in Figure 2-33, can be used as a guide and are consistent with the approach of dominant wave energy from the east to east–northeast direction across the inner continental shelf (see Figures 2-29 and 2-30). To date, however, regional estimates are based on limited observations of nearshore spectral wave energy and temporally and spatially sparse beach profile data.

More detailed calculations of sub-regional and local sand budgets in Northeast Florida are based on a combination of morphology, topographic surveys, dredging records, and knowledge of local wave regime. For instance, a sediment budget was calculated for the coastal segment between the St. Mary's River entrance on the Florida–Georgia border to Atlantic Beach just south of the mouth of the St. Johns River (Taylor Engineering 2001). The sand budget was set up in the Sediment Budget Analysis System developed by the WES Coastal and Hydraulics Laboratory (Rosati and Kraus 2001). Input data for this system is arranged in a series of littoral cells in which net losses and gains of sand volume from various sources are specified on an annualized basis. Figure 2-33 shows the results of the calculation for northeast Florida. Very often the volume change in the shoreline cells is estimated from beach profile data or simply shoreline change data. A large component of the budget can be found at inlet and bay entrances, which can function as sources or sinks of sand. The exchanges across the cells running along the coast indicates that net annualized littoral drift in this area is in the range of 200,000 to 400,000 cubic yards, with lesser exchanges between tidal inlet shoals and losses to offshore transport.

2.3.7 Influence of Physical Processes on Sand Ridge Topography

The sand ridge and sand banks formed from grouping of linear sand ridges were described from a geologic point of view under Section 2.2.2. A question that remains unanswered with a degree of uncertainty is whether linear sand ridges remain dynamic and morphologically evolve over time. Analysis of physical processes by Huthnance (1982) and Trowbridge (1995) indicate it is possible these features remain active at depths typical of the inner continental shelf. Geologic studies (Rine et al. 1991) present stratigraphic and paleontologic evidence that modern shelf ridges can regenerate over long periods of time and incorporate benthic fauna that represent mid-shelf environments rather than nearshore and littoral environments where the features are formed. Field observations designed to evaluate sand ridge dynamics have not been made over a long enough period of time to document their evolution. A comparison of available historic bathymetric data from a variety of sources compiled by the National Geophysical Data Center shows that the crest of some ridges may experience several feet of vertical change at the decadal time scale and longer. Figure 2-34 shows several linear sand ridges on the inner continental shelf offshore of Volusia County. Two of the ridges, B12 and B11 are discussed in greater detail in other sections of this report. Topographic surveys over the crest of shoal B15 are available from 1966 and 1974. These survey data were compared for topographic differences in the eight-year interval between 1966 and 1974 as shown in Figure 2-35. Over this time period, changes of +/- 4 ft were calculated from the surveys.

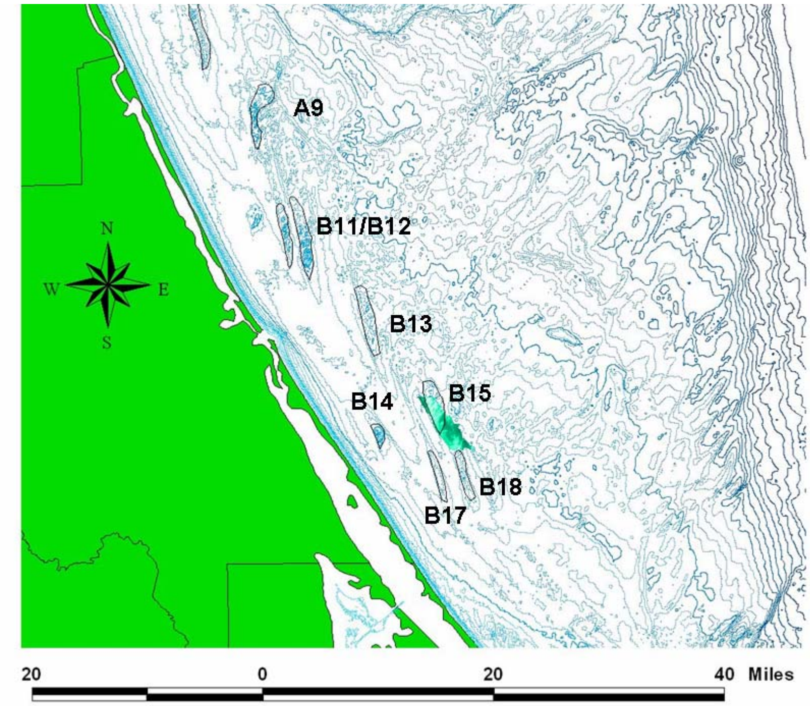


Figure 2-34. Distribution of linear sand ridges offshore of Volusia County, Florida. Survey data are available from the vicinity of the B15 shoal for years 1966 and 1974, an eight-year interval.

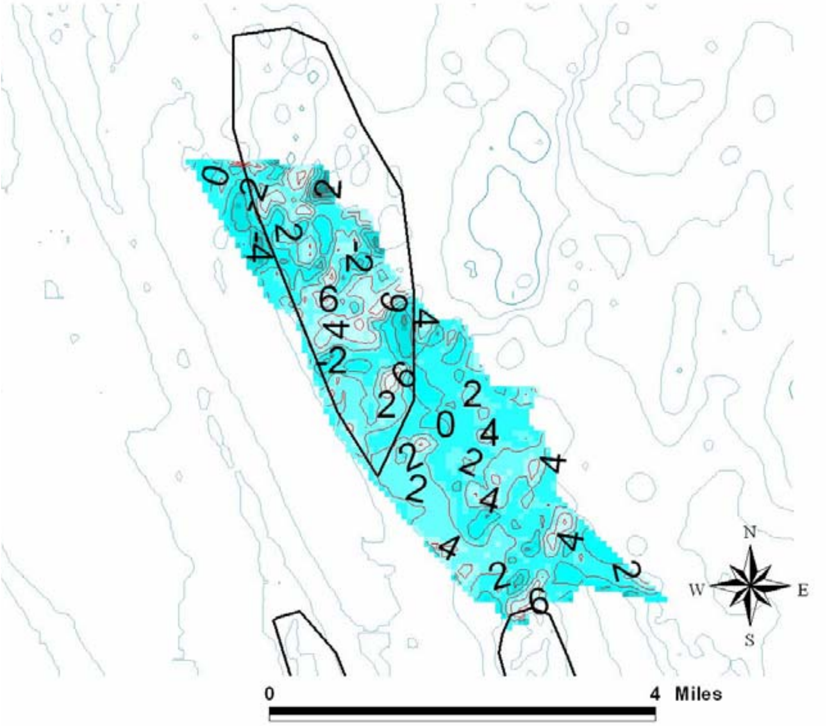


Figure 2-35. Topographic changes (in ft) over the crest of the B15 shoal between 1966 and 1977.

Assuming the surveys are accurate, it can be concluded that at least the crest of the B15 shoal and other similar sand ridges may be reworked by occasional strong currents and large waves generated by passing storms. The influence of these processes may be cumulative over time and depend on the frequency of storms and the movements of large waves across the northeast Florida shelf. The magnitude of the measured changes over long time scales can be compared with model predicted changes discussed later in this report under Section 4.3.3.

Only a very few local areas of the northeast Florida inner continental shelf have bathymetric records that can be compared at the decadal time scale and longer. In addition to the B15 area, the base of the shoreface and inner shelf just seaward of the mouth of the St. Johns River at Mayport, Florida, can be compared over 40 years between 1958 and 1998. This area includes the A5 and A4 shoals analyzed later in this report. Large vertical changes can be seen directly at the entrance of the St. Johns River, which are due to dredging for navigation through the entrance of the Port and natural scour through the throat of the inlet. Further offshore, 8 ft of deposition occurred on the crest of A5 as shown in Figure 2-36. A check of dredging records reveals that this area has been used for the disposal of dredge spoils since the early 1950s. The source of the material is from dredging of the entrance to Mayport Harbor and the Naval Air Station to maintain navigation. Thus, major changes that can be resolved in this area have an anthropogenic origin.

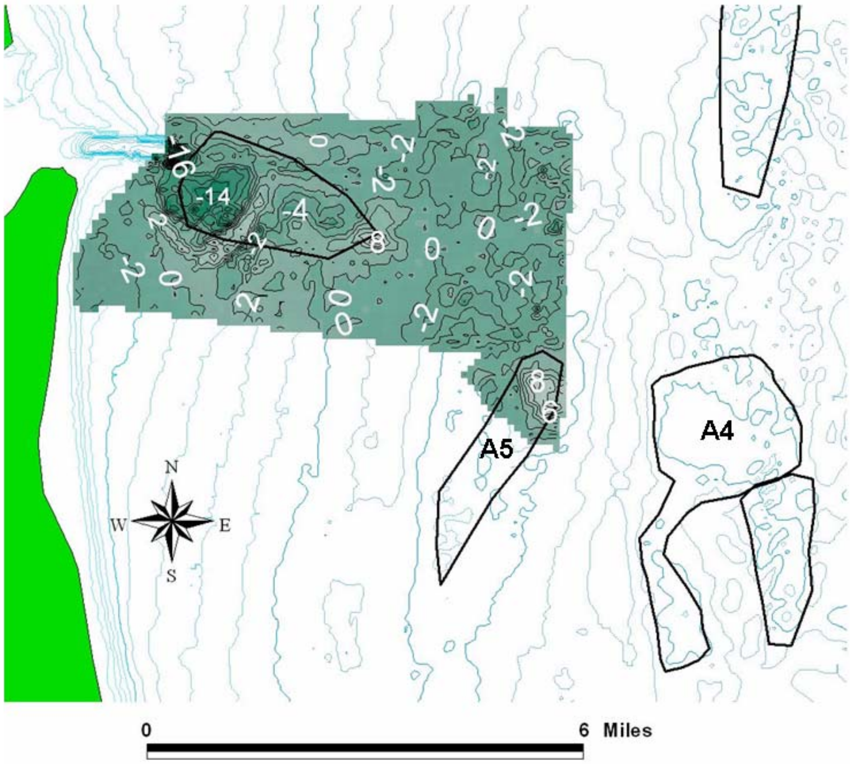


Figure 2-36. Topographic changes seaward of the St. Johns River entrance at Mayport, Florida.

The only other area with long-term records is over the ebb shoal of St. Augustine inlet to the south of the A5 and A4 shoals and in the immediate vicinity of the A6 shoal. Although this shoal is active and in Florida state waters, it is worth considering because topographic records exist and it may be an example of the genesis of a linear shoal as described in Section 2.2.2 of this report. In Figure 2-37, it can be seen that over the 50-year period between 1924 and 1974 notable evolution of the inlet shoal has taken place. Growth of the modern ebb shoal has taken place as indicated by the 6- to 12-ft accretions at the toe of the shoal just beyond the inlet entrance. To the south of the inlet, two areas of erosion are probably due to the collapse of an earlier version of the ebb shoal when the inlet entrance was located to the south of the current position. Within the past decade, a portion of the St. Augustine ebb shoal containing the largest volume of beach sand was dredged. Approximately 3.7 million cubic yards of sand was removed for the St. Augustine Beach fill project south of the inlet.

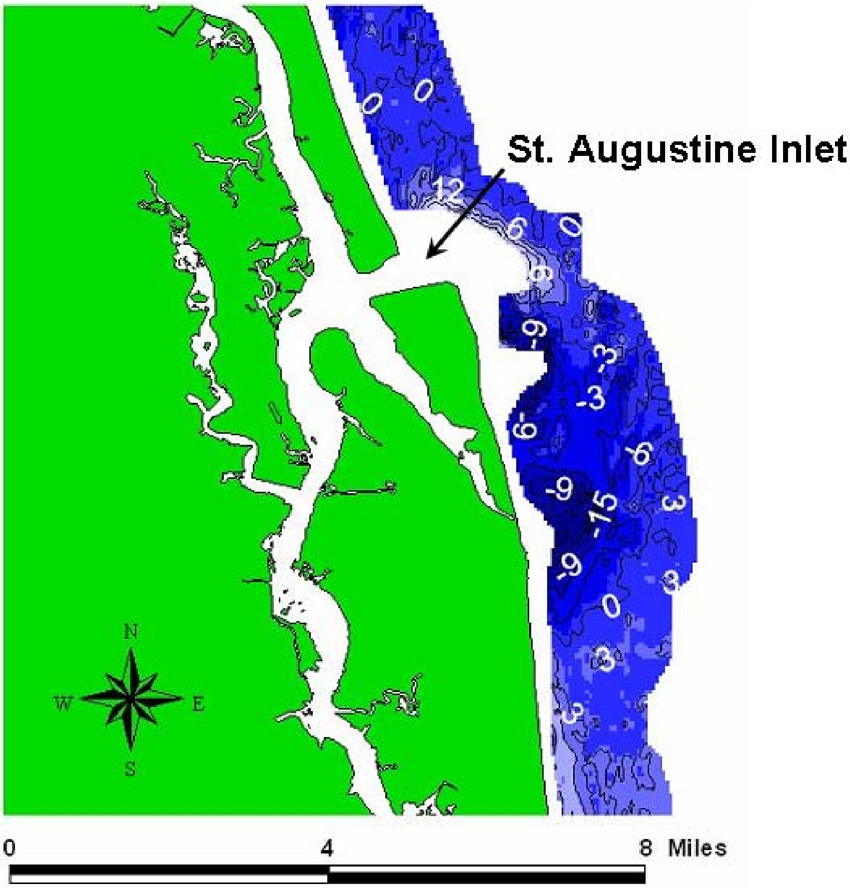


Figure 2-37. Topographic changes in the vicinity of St. Augustine Inlet in St. Johns County between 1924 and 1974.

2.4 Biological Resources

2.4.1 Benthos

Previous Studies

The study area falls within the SAB, which extends from Cape Hatteras, North Carolina, to Cape Canaveral, Florida. The benthic habitat features of the nearshore northeast Florida shelf, within the region of the study area, primarily consist of topographically high sand ridges. A description of the sedimentary environment of the study areas and region is provided in Section 2..2.1 Geology of the Continental Shelf As described in that section, the sediment in the nearshore shelf of the SAB, including the area adjacent to

Northeast Florida, receives occasionally strong scour generated by waves and currents from storm activity. This dynamic environment underpins the conditions in which the benthos exists.

Relatively few open-shelf benthic studies have been conducted off the northeast Florida coast. Studies of a dredged material disposal site offshore of Jacksonville and sand borrow areas provide the only information. Barry Vittor and Associates (BVA 1996a), for example, surveyed benthic communities in and around the Jacksonville Ocean Dredged Material Disposal Site (ODMDS) in 1995 and 1998. The Jacksonville ODMDS is located just inshore of shoal A4. In addition, Lotspeich and Associates, Inc. (1997) performed benthic community surveys in an area adjacent to the present A4-shoal study area. This study is of particular interest because sampling was undertaken before and after dredging occurred, as well as during different seasons. The benthic sampling component of these studies was limited to hand-coring conducted by divers. Other benthic community studies have been conducted in the SAB that cover larger areas of the shelf off North Carolina to Florida (Tenore 1985) and off North Carolina (Day et al. 1971, Weston 1988). Most notably, Hammer et al. (2005) conducted a study of potential sand areas off the east central coast, south of Cape Canaveral, Florida, for MMS.

Overview

Recent studies have concluded that softbottom community complexity does not fit a simple paradigm and is not related to a single parameter (Snelgrove and Butman 1994, Newell et al. 1998). They suggest, instead, that the organism distribution patterns can be understood in terms of a dynamic relationship between the sediments and their hydrodynamic environment. For example, shear forces at the sediment–water interface play a dominant role in controlling food availability, larval settlement, pore water flow, and other parameters that affect benthic organisms (Newell et al. 1998). Environmental factors, such as productivity, temperature, and sediment grain size, determine patterns of regional and local-scale species richness and turnover in species (Gray 2002).

Sedimentary characteristics, such as grain size, sorting, and organic content, are important in determining the composition of benthic communities (e.g., Sanders 1958, Gray 1974) in estuaries (Young and Rhoads 1971) as well as in the open continental shelf (Dames and Moore 1979, Weston 1988, Theroux and Wigley 1998). However, for the continental shelf benthos, depth also plays a major role in determining benthic community structure (Buchanan et al. 1978, Theroux and Wigley 1998).

The distribution of sediment grain size plays an important role in determining substrate stability and food availability which affect benthic community structure and trophic groups (e.g., suspension or deposit-feeding taxa) that are present (Rhoads 1974, Fauchald and Jumars 1979). Although many infaunal species occur across a range of sediment types, the distribution of many infaunal taxa tends to be correlated with specific sedimentary habitats. Gaston (1987) analyzed the feeding and distribution of the polychaetes of the Mid Atlantic Bight. Surface-deposit feeders numerically dominated most habitats and were proportionately more abundant in fine-sediment habitats. Carnivorous polychaetes were proportionately more abundant in coarser sediments, while sessile polychaetes generally inhabited physically stable habitats.

Hydrodynamic processes also affect benthic community structure (e.g., Eckman 1983, Hall 1994). These processes affect both macro- and meiofaunal larval transport and sedimentary and food resources at several scales (Butman 1987, Zajac et al. 1998, Palmer 1988). Storms may affect benthic community composition, especially in shallower waters (Hall 1994, Posey et al. 1996, Posey and Alphin 2002). Diaz et al. (2004) stated that storms are important in structuring benthic communities, and even though individual storm events are unpredictable, their seasonality and frequency have a relatively narrow range over the course of a year. Dobbs and Vozarik (1983) examined the effects of a single storm at a site in 5 m of water and reported no before and after differences in individual benthic species densities. However, they noted that there were many non-reproductive fauna in the water column immediately after the storm. Oliver et al. (1980) examined the effects of wave-induced bottom disturbance on the benthic fauna off the California coast. They found that in depths of less than 14 m, few organisms lived in permanent tubes or burrows, and the abundant fauna were small, mobile, deposit-feeding crustaceans. In deeper water, the community was dominated by polychaete taxa that occupied permanent or semi-permanent tubes or burrows. Niedoroda et al. (1989) explored how laminae are laid down in sediment through erosion and redeposition. They concluded that a major storm can deposit a bed several centimeters thick in 20 m water depths and several millimeters thick in 40 m water depths.

Local bottom topographic features, such as ridges and troughs, may also play a role in determining shallow continental shelf macrobenthic communities (Diaz et al. 2004). On Fenwick and Weaver Shoals offshore of Ocean City, Maryland, Diaz et al. (2004) reported that shoal-ridge communities are different from the mid-shoal and trough communities. They noted relatively abrupt changes in habitat and substrate types within a few tens of meters due to changes in topography.

Ecological patterns and processes operating at one spatial scale may differ from those at another spatial scale for benthos (Whitlatch et al. 1998). Continental shelf softbottom benthic community attributes vary from small (cm) to regional (km) scales similar to physical parameters (e.g., sediment characteristics, water depth) (Zajac et al. 1998, Ellingsen 2001, Diaz et al. 2004). Thus, benthic community responses to disturbances vary as the spatial scales of disturbance vary. In addition to spatial scale distinctions, benthic communities differ on a range of temporal scales. Gray and Christie (1983) reported that a number of benthic species respond to long-term hydrographic cycles.

Macro- and meiofaunal benthic communities provide an important food or energy resource for higher trophic levels, including demersal fish and large epifaunal organisms. For example, meiofauna are important food sources for fish (Feller and Kaczynski 1975, Elmgren 1976, Alheit and Scheibel 1982). As a result, changes in benthic community structure may result in changes in other trophic levels dependent upon the benthos.

The following terminology is used in subsequent sections of the report. Infauna are those organisms that live within the sediment. Epifauna are those organisms that live on the surface of the sediment. Macrofauna are those organisms retained on a 0.5 mm sieve (some researchers use a 1.0 mm sieve). Typical representatives of the macrofauna include annelids (i.e., polychaetes and oligochaetes) and crustaceans (i.e., decapods, panaeids, amphipods, isopods, tanaids, and cumaceans). Meiofauna are those organisms passing thru a 0.5 mm sieve but retained on a 0.063 mm sieve. Typical representatives of the meiofauna include harpacticoid copepods, nematodes, turbellarians, kinorynchs, and gastrotrichs. Newly settled macrofauna may be contained in the meiofauna component of the benthos.

Infauna

The predominant infaunal macroinvertebrates inhabiting the sand-bottom habitats of the nearshore east Florida shelf include polychaetes, crustaceans, echinoderms, and mollusks. Infaunal assemblages that inhabit this area include taxa common throughout the SAB (e.g., Wenner and Read 1982, Tenore 1985). Tenore (1985) reported that there was no clear dominance by one or more species that persisted seasonally either throughout or over part of the shelf of the SAB. The fauna was dominated by semi-mobile, non-tube-dwelling polychaetes. The inner shelf faunal assemblage included dominant magelonid, prionospionid, and nereid polychaetes, and both burrowing and surface brittlestars. Other more recent studies by Lotspeich and Associates (1997) and BVA (1999b) also reported that the inner shelf infaunal assemblages in the study area are dominated by polychaetes in terms of overall numerical abundance and species richness. Amphipods, gastropods, and bivalves are also well represented. Infaunal assemblages that inhabit the study area are similar to those of sand-bottom habitats of other regions in that they exhibit spatial and seasonal variability in their distributions.

Tenore (1985) found that polychaetes were numerical dominants over a wide area of the SAB, accounting for more than half of the total overall abundance. There was no obvious numerical dominance of any taxon that persisted seasonally. Of the most abundant species, 18 taxa comprised more than 0.2% of the total infaunal density at all stations in at least one season during the study. No latitudinal gradient of infaunal assemblage change was found on the inner continental shelf of the SAB between Cape Fear, North Carolina, and Daytona Beach, Florida, indicating an absence of a geographically persistent transition area between faunal provinces across the region. Many of the numerically dominant taxa found during the study, such as the polychaetes *Spiophanes bombyx*, *Spio pettiboneae*, and *Prionospio cristata* are also common in the Caribbean (Foster 1971).

Lotspeich and Associates (1997), whose study area overlaps part of the A4 shoal examined in the present study, performed pre- and post-mining benthic faunal and sediment studies at a borrow site approximately seven miles off Atlantic Beach, Florida, between 1995 and 1997. Benthic samples were collected from 11 stations at water depths of 12–15 m. Again, polychaetes were the most numerous organisms present, representing 35.3% of the total assemblage, followed in abundance by molluscs (33.6%) and arthropods (18.8%). Polychaetes represented 51.6% of the total number of taxa, followed by arthropods (23.4%), and mollusks (16.1%). The five most abundant species were the gastropod *Caecum bipartitum,* the polychaetes *Apoprionospio dayi* and *Spio pettiboneae*, the gastropod *Cylichnella bidentata*, and the bivalve *Ervilia concentrica*, which collectively accounted for 27.1% of the total abundance although they represented only 2.0% of the total taxa collected.

The Lotspeich and Associates (1997) study results indicated that seasonal changes in species richness, abundance, and community structure within the borrow and control areas were pronounced and greater than measured spatial variation. Species richness and abundance were much greater in June 1995 than either February or September 1996 for both the control and borrow sites.

The composition of the borrow area benthic community changed following dredging; as compared to nearby control stations, gastropods disappeared, bivalves and annelids declined, and crustaceans increased. Species richness and abundance at both dredged and control stations declined dramatically after dredging. Two years after dredging, species richness and abundance had returned to pre-dredging levels, and there were no observable differences in substratum conditions. The decline of both borrow area and control station macroinvertebrate populations following dredging was attributed to a series of hurricanes crossing the area during 1996, making identification of dredging effects on benthic communities difficult to detect.

BVA (1999b) conducted benthic sampling at and around the Jacksonville ODMDS in 1998 as part of a monitoring study. The ODMDS site is approximately one mile west of the most northern shoal (A4) in this study area. In July 1998, benthic samples were collected by divers using hand-held coring devices from 12 stations at water depths of 10–15 m. Sediment at all stations was predominantly sand. A total of 434 taxa were identified. Polychaetes were the most numerically dominant group present, representing 33.8% of the total assemblage, followed by bivalves (26.9%), gastropods (15.0%), and malacostracans (14.7%). Polychaetes represented 34.3% of the total number of taxa, followed by malacostracans (28.8%), bivalves (14.3%), and gastropods (11.3%). Dominant taxa included the polychaetes *Mediomastus* spp. and *Prionospio cristata,* the bivalve *Tellina* spp., and the gastropods *Acteocina bidentata* and *Caecum pulchellum.* The macroinvertebrate taxa collected represented a homogeneous assemblage, lacking a clear family dominance. Differences in dominant taxa present at the same stations in 1995 were attributed to natural variations in the benthic macroinvertebrate assemblage (BVA 1996).

Hammer et al. (2005) reported on the benthic infauna of potential sand borrow sites of the East Central Florida coast collected during field studies conducted in September 2000 and June 2001. Grab samples were collected using a Shipek grab. Hammer et al. (2005) reported that the polychaete *Goniadides carolinae* was numerically dominant, particularly during September, and represented 6.2% of all infauna noted during both surveys. Other than *G. carolinae*, taxa among the top ten numerical dominants during both the September and June surveys were the bivalve *Crassinella lunulata*, unidentified rhynchocoels, and the polychaete *Exogone lourei*. Polychaetes and bivalves contributed most to overall abundance, although amphipods were a conspicuous infaunal component at sand-bottom stations. During September, numerically dominant taxa included the polychaete *Mediomastus* (4.57% of all collected individuals), bivalve *Crassinella lunulata* (3.9%), polychaete *G. carolinae* (3.7%), and unidentified ophiuroids (2.9%). The ten most abundant taxa comprised 27.5% of all infaunal individuals during September. Numerically dominant taxa collected during June included *G. carolinae* (10.4% of all individuals collected), *C. lunulata* (7.0%), and unidentified tubificid oligochaetes (4.7%). The ten most abundant taxa comprised 37.5% of all infaunal individuals during June.

Epifauna

Dominant conspicuous epifauna observed at the borrow site seven miles off Atlantic Beach in Jacksonville, Florida, by Lotspeich and Associates (1997) consisted of several species of echinoderms, including the arrow sand dollar and sea stars *Luidia clathrata* and *Astropecten* spp. The arrow sand dollar occurs from Cape Hatteras, North Carolina, to the southern tip of Florida and throughout the Gulf of Mexico (Hendler et al. 1995). The striped sea star, *L. clathrata*, occurs in Atlantic waters from New Jersey coastal waters to Brazil, and *Astropecten articulatus* occurs from the Chesapeake Bay to Columbia (Downey 1973). Two species of sea urchins and a sea cucumber were also observed.

Wenner and Read (1982), who reported on decapod crustaceans collected by trawl over a wide area of the SAB between Cape Fear, North Carolina, and Cape Canaveral, Florida, suggested that site and species group distributions were related to depth and depth-related changes in groups and that seasonal variation was minimal. Species groups consisted of an inner shelf assemblage, an open shelf assemblage, and an upper slope assemblage. Epifaunal populations have distributions limited by depth-related temperature variability and sedimentary habitat (Cerame-Vivas and Gray 1966, Wenner and Read 1982). Wenner and Read found an inner shelf assemblage that was numerically dominated by roughneck shrimp, *Rimapenaeus constrictus*; iridescent and blotched swimming crabs, *Portunus gibbesii* and *P. spinimanus*, respectively; and coarsehand lady crab, *Ovalipes stephensoni*.

Some epifaunal groups are associated primarily with a particular sediment type. For example, Theroux and Wigley (1998) reported that gastropods occurred in particularly high densities in shelly sediments. They speculated that the gastropods were predators on the bivalves, the shells of which comprised the substrate. In addition, coarse sediments are more suitable for locomotion by broad-footed benthic mollusks than are fine sediments, which are relatively unstable. Lyons (1989) reported some mollusk species were most abundant in an offshore trough feature with poorly sorted sediments, whereas other mollusks were abundant on an offshore shoal with well-sorted, coarse sediments. Other members of the epifauna, such as crabs, are generally found in areas of gravel and shell. However, some crab species such as *Crangon septemspinosa* may occur in areas of sand, whereas the crab *Cancer irroratus* inhabits a variety of sediment types (Hammer et al. 2005). Wenner and Read (1982) suggested that the combination of extremely variable sediments and temperatures may be sufficient to cause marked zonation between decapod assemblages on the outer shelf.

2.4.2 Fishes

The continental shelf of the southeastern United States from Cape Fear, North Carolina, to Cape Canaveral, Florida, out to the shelf break or SAB, harbors a diverse marine fauna and supports large commercial and recreational fisheries. Although many fish and invertebrate species are widely distributed throughout the SAB, abundance and community diversity is quite heterogeneous, dictated by (often considerable) spatial variability in hydrographic conditions and habitat availability (Sedberry and Van Dolan 1984, Wenner and Sedberry, 1989, Rowe and Sedberry, 2006). In recent years, increased awareness of the value and vulnerability of coastal fisheries, along with Essential Fish Habitat provisions of the Magnuson–Stevens Fisheries Conservation and Management Act, have spurred investigations of the environmental factors that structure SAB macrofaunal assemblages as well as numerous species-specific life history studies of economically important fish and macrocrustaceans.

2.4.2.1 Factors Structuring the Northeast Florida Fish Fauna

Hydrography

Along the northeast Florida shelf, the southernmost extent of the SAB, fish assemblages are strongly influenced by both latitudinal and longitudinal gradients in water temperature. As the warm northward-flowing Florida Current diverges from the Florida peninsula (less than 20 km at Jupiter Inlet to over 120 km at the Florida–Georgia border), its ability to moderate inner shelf water temperature progressively wanes. Consequently, although winter water temperatures south of Cape Canaveral rarely fall below 20°C (Gilmore et al. 1981), temperatures across the northeast Florida shelf are largely driven by seasonal changes in ambient air temperature with cold fronts and episodic upwellings, resulting in more extreme seasonal temperature fluctuations. Populations of tropical coastal species may not persist year-round north of Cape Canaveral except near the western edge of the Florida Current. As such, the Florida central east coast is often identified as a broad area of faunal transition where assemblages derived from the Caribbean Province to the south and the Carolinian Province to the north commonly intermingle (Briggs 1974, Gilmore 1995), resulting in one of the richest faunas of the western Atlantic Ocean.

Salinity can also directly affect the distribution of fish (and invertebrates), although its influence is greatest near the coast (Able and Fahay 1998). Numerous rivers discharge into the SAB, resulting in considerable salinity fluctuations within coastal tributaries, estuaries, and nearshore waters in the vicinity of tidal inlets. Precipitous salinity reductions are known to displace marine species seaward. Salinity fluctuations in nearshore waters may also indirectly influence population structure along the outer continental shelf by mediating recruitment and survival of fishes that use estuaries temporarily as juvenile nurseries.

Habitats

Open sand–mud substrates: Habitat distribution also influences the composition of the marine fauna over the northeast Florida shelf. The majority of the open shelf in this region is comprised of a sand-shell bottom with only widely dispersed hardbottom substrates. The fish fauna inhabiting SAB softbottom habitats often the product of bycatch assessments in the penaeid shrimp fishery received some scrutiny with early descriptions (e.g., Anderson and Gehringer 1965, Struhsaker 1969, Knowlton 1972). Such efforts provided information about species distribution and relative abundance in specific locations but were not easily comparable across wide areas (Wenner and Sedberry 1989). To promote uniformity in fisheries data, the South Carolina Department of Natural Resources (SCDNR), in partnership with the National Marine Fisheries Service (NMFS), began conducting annual standardized fishery-independent trawl surveys to monitor the abundance, habitat requirements, and life history attributes of coastal fishes and macroinvertebrates from Cape Hatteras to Cape Canaveral (encompassing all proposed sand resource areas) in 1973. In a comprehensive ten-year (1990–1999) summary of this effort (now called the Southeast Area Monitoring and Assessment Program—South Atlantic [SEAMAP–SA]), 195 finfish taxa, 30 elasmobranchs, and 90 decapod crustaceans were collected (ASMFC 2000). Fish captures were numerically dominated by two species: spot, *Leiostomus xanthurus*, and Atlantic croaker, *Micropogonias undulatus*. These two species accounted for 36% of all fish and invertebrates taken. Other abundant taxa included Atlantic bumper, *Chloroscombrus chrysurus*; porgies, *Stenotomus* spp.; and striped anchovy, *Anchoa hepsetus*. The most common decapod crustacean included white shrimp, *Litopenaeus setiferus*; coarsehand lady crab, *Ovalipes stephensoni*; brown shrimp, *Farfantepenaeus aztecus*; iridescent swimming crab, *Portunus gibbesi*; and the lesser blue crab, *Callinectes similis*. Elasmobranchs, particularly carcharhinid sharks and pelagic and demersal rays, were collected less frequently but constituted a large percentage of overall biomass due to their generally large sizes. Combined densities of fish and selected macroinvertebrates averaged 345 individuals per hectare in nearshore waters but varied considerably among years. Results of this survey also suggested that the resident macrofaunal assemblage between Cape Canaveral and the St. Johns River was most dissimilar to that of any other section of coastline surveyed. Rowe and Sedberry (2006), in a synthesis of earlier SAB groundfish trawl data of the region (1973–1980), also noted relatively high diversity and richness in this region—a pattern they attributed to less dramatic temperature fluctuations compared to the rest of the SAB.

Sand shoals: Shore-connected and offshore sand shoals also likely support a somewhat distinctive species assemblage due to unique sediment composition and bathymetric profiles. For fish, shoals may offer foraging opportunities, physical landmarks on which to assemble, and in some cases, depth refugia from predation. East Central Florida possesses the most expansive sand shoals on the Florida Atlantic coast. In a relevant MMS study, nine low relief shoal sites (mean 2–3 m high) were trawled on two dates (September 2000 and June 2001) offshore of Brevard, Indian River, St. Lucie, and Martin counties (18 total collections), producing 63 fish taxa with dusky anchovy, *Anchoa lyolepis*, and silver seatrout, *Cynoscion nothus*, comprising 69% of all fish caught (Hammer et al. 2005). Macroinvertebrate catches included 32 taxa of stomatopods, decapod crustaceans, echinoderms, and squid. Similar studies have occurred at shoals off Alabama (Byrnes et al. 1999) and North Carolina (Byrnes et al. 2003), but in each case, sampling protocols were not designed to provide robust comparisons of the macrofauna with adjacent open sand-shell areas. However, Slacum et al. (2006), in an MMS-funded trawl, gill net, and bioacoustics survey of shoal fish communities of the Mid Atlantic Bight, found generally higher abundance and diversity of fishes away from shoals during daylight hours but suggested these bathymetric highs may serve as valuable foraging habitat at night.

The fauna of the most prominent shoals in the region, namely the Southeast Shoal, Chester Shoal, and Ohio–Hetzel Shoals at Cape Canaveral (75 km south of current study area), have not been thoroughly inventoried. However, Reyier et al. (2008) provide an account of recurring high-density aggregations of juvenile lemon sharks, *Negaprion brevirostris*, amassing here each winter, suggesting these features support one of the most important nurseries yet described for this species.

Hardbottom substrates: Reef substrates offer attachments sites for algae, sponges, corals, ascidians, and other sessile invertebrates and serve as critical habitat for a multitude of fish taxa, many of which maintain near obligate reliance on hardbottom habitats for spawning, recruitment, and foraging. Estimates of SAB hardbottom distribution vary considerably with values ranging from 10% to 23% of total aerial coverage (Rowe and Sedberry 2006). The Marine Resources Monitoring, Assessment and Prediction (MARMAP) program (another SCDNR–NMFS partnership) has been assessing SAB reef habitats and associated fisheries since 1973. Trawling has proven an ineffective and destructive means of determining the community composition and relative abundance of fishes associated with regional reefs. As a result, data collection in recent years has relied primarily on fish traps, submersible and remotely operated vehicle (ROV) video, longlines, and rod and reel. MARMAP efforts have determined that SAB hardbottom substrates have higher levels of fish diversity and biomass than open sand-shell substrates and also support demersal species of greatest fishery value to the region (e.g., grouper and snapper; Sedberry and Van Dolan 1984, Coleman et al. 2000, Rowe and Sedberry 2006). Unfortunately, the associated cryptic fauna remains largely unstudied, so patterns of diversity are still not fully resolved.

Along the northeast Florida continental shelf, natural hardbottom substrate generally consists of low- to moderate-relief limestone pavement, ledges, and escarpments, which are apparently relic Pleistocene dune formations. A comprehensive survey of limestone reefs and their associate fauna in the vicinity of proposed borrow sites has not been undertaken, although Perkins et al. (1997) compiled all available location data of hardbottom substrates along the entire Florida Atlantic coast. Their results determined that although this habitat type was generally more common south of Cape Canaveral, locally high estimates of hardbottom and/or suspected hardbottom substrate (~15% coverage) occurred in coastal waters off Fernandina Beach. This estimate does not include artificial reefs, which continue to be established on a regular basis throughout the region.

Fish populations inhabiting inshore reefs of the northeast Florida shelf are likely linked to other substantive reef areas of the southeastern United States either through migration of adult fish or recruitment of planktonic fish larvae. Sedberry et al. (1998) documented movement of black sea bass, *Centropristis striata*, from Gray's Reef, Georgia, to Northeast Florida. More recently, McGovern et al. (2005) demonstrated that many adult gag grouper, *Mycteroperca microlepis*, tagged off the Carolinas were recaptured at multiple locations along the Florida Atlantic coast. Further, the Florida Current undoubtedly carries larval recruits spawned on shelf edge coral reefs of East Central Florida (e.g., *Oculina* ivory tree coral) as well as shallow water coral reefs of South Florida and the Caribbean (although this has not been empirically examined). Recruitment of tropical fish larvae to the north Florida inner shelf may be inhibited by the greater shelf width that larvae must traverse. Therefore, the supply of many reef fishes may be linked to ephemeral gyres and warm water filaments spinning off the western boundary of the Florida Current.

2.4.2.2 Commercial and Recreational Fisheries

A review of northeast Florida fishery landings data provided a means for identifying species that may cause economic harm to northeast Florida coastal communities if disturbed by sand dredging (or other anthropogenic actions). The fisheries data included here were derived from the Florida Fish and Wildlife Research Institute (FWRI) for commercial landings and from the Marine Recreational Fishery Statistics Survey (MRFSS) for recreational fisheries landings. Commercial landings data are available from FWRI at www.floridamarine.org for all Florida coastal counties and include total poundage of each species landed annually, as well as the number of fishing trips made to acquire those landings. For this report, the most recent set of commercial landing data (2005) were compiled from Brevard, Volusia, Flagler, St. Johns, Duval, and Nassau counties, which are the coastal counties nearest to the sand borrow sites currently under study. Recreational fisheries landings are jointly monitored by the FWRI and the NMFS. Queries of the MRFSS database (www.st.nmfs.gov/st1/ recreational/ index.html) provided estimates of the total number of individuals landed for each species taken in the recreational fishery during 2005. The smallest geographic region available in the MRFSS database is East Florida, which includes catches from the Florida–Georgia border to the Florida Keys. Thus, these data do not provide precise capture location but, as with commercial landings, will help identify primary species of concern when evaluating potential dredging impacts.

Commercial and recreational landings data for the northeast Florida region are available for 54 individual species of fish and 19 mixed-species categories (e.g., sharks, flounders, triggerfish, and mixed grouper). The dominant commercial finfish species in terms of pounds landed regionally are sharks, kingfish (whiting), Spanish mackerel, striped mullet, and king mackerel (Appendix A). Recreational catches are numerically dominated by spotted seatrout, jack crevalle, kingfish (whiting), gray snapper, and red drum. Pinfish are also recorded as a large component of the recreational fishery, but this small-bodied species is utilized largely as bait. Decapod crustaceans sustain the largest commercial and recreational fisheries by weight in Northeast Florida, with landings dominated by white shrimp and blue crabs and other species comprising less than 1 % of the catch (Appendix A).

The life history summaries of select economically valuable northeast Florida fish and invertebrate species are discussed. Habitats utilized by the different life stages for these species are summarized in Table 2.2, and their spawning seasons are listed in Table 2.3. Additionally, the life history of other species that fill important ecological roles in the coastal ecosystem, as prey for larger fishes and as predators on benthic fauna, are also discussed.

Table 2.2. Summary of habitats used by different life stages of economically and ecologically important fish and epibenthic invertebrate species of the study area. C = Coastal/Offshore, E = Estuary/Seagrass, R = Rock/Reef Substrate, S = Sand/Mud Substrate, P = Pelagic.

Common Name	**Spawning Habitat**	**Juvenile Habitat**	**Adult Habitat**
Sharks	E,C,P	E,C,P	E,C,P
Striped Mullet	C	E	E,C,P
Kingfish	E,C	E,C	E,C
King Mackerel	C	C,P	C,P
Spanish Mackerel	C	C,P	C,P
Flounders	C	C,E,S	C,E,S
Vermilion Snapper	C	C,R	C,R
Amberjack	C	C,R,P	C,R,P
Gag Grouper	C	E	C,R
Red Snapper	C	C,R,S	C,R
Sheepshead	C	C,E	C,E
Dolphin	E,C	C,P	C,P
Bluefish	P	E,C	C,P
Red Drum	E,C	E	C,E
Sea Robins	C	C,E,S	C,E,S
Rock Shrimp	C	C	C
Blue Crab	C	E	C,E
White Shrimp	C	E	C,E
Brown Shrimp	C	E	C,E
Pink Shrimp	C	E	C,E

Table 2.3. Spawning seasons of economically and ecologically important fish and invertebrate species along the study area. X = peak spawning period.

Common Name	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Sharks			X	X	X	X	X	X	X	X		
Striped Mullet	X										X	X
Kingfish				X	X	X	X	X	X	X		
King Mackerel					X	X	X	X	X	X		
Spanish Mackerel					X	X	X	X				
Flounders	X	X									X	X
Vermilion Snapper				X	X	X	X	X	X			
Amberjack			X	X	X	X	X					
Gag Grouper		X	X									
Red Snapper						X	X	X	X			
Sheepshead	X	X									X	X
Dolphin	X	X	X	X	X	X	X				X	X
Bluefish				X	X				X	X		
Pinfish	X	X									X	X
Red Drum								X	X	X		
Sea Robins				X	X	X	X	X	X			
Rock Shrimp	X										X	X
White Shrimp				X	X	X	X	X	X	X		
Blue Crab						X	X	X	X			
Brown Shrimp		X	X									

Pelagic fishery species

Pelagic fishes spend their entire lives in the water column of estuarine, coastal, and offshore habitats. Many small-bodied pelagic species (e.g., herrings, mullets) form large migratory schools that serve as important forage for larger fishes, marine mammals, and seabirds. Larger pelagic taxa generally are important predators of fish and cephalopods and may swim singly (e.g., cobia, tripletail) or in large schools (e.g., mackerels, tunas). Some pelagics are the target of intense commercial and recreational fisheries. Dominant pelagic fishery species along the coast of Northeast Florida include the following:

Sharks: The largest commercial finfish fishery in East Florida is a multi-species gill net and longline shark fishery that landed over 828,000 pounds in 2005 (Appendix A). Trent et al. (1997) reported that eight species comprised 99% of the driftnet catch in coastal waters from southern Georgia to Cape Canaveral, Florida. Blacknose, Atlantic sharpnose, blacktip, and finetooth sharks dominate catches, with scalloped hammerhead, bonnethead, spinner, and great hammerhead sharks also regularly contributing to overall landings.

Blacknose sharks, *Carcharhinus acronotus*, are one of the most abundant species in terms of catch-per-unit-effort (CPUE) taken by the regional commercial shark fishery. Trent et al. (1997) recorded landings of 41.2 kg/net/hour. Blacknose sharks reach a maximum length of 2 m, feed primarily on fishes, and give birth to live young in estuarine nursery habitats (Castro 1993a).

Atlantic sharpnose sharks, *Rhizoprionodon terraenovae*, were also very abundant along the northeast Florida coast with a CPUE of 38.6 kg/net/hour (Trent et al. 1997). They are often found in large schools and are frequently taken as shrimp trawl bycatch (Castro 1993b). The maximum size of this small coastal shark is about 1 m. A study on the diet of Atlantic sharpnose sharks in Apalachicola Bay, Florida, found that young-of-the-year individuals fed primarily on shrimp, juveniles fed on drum, and adults fed on herring (Bethea et al. 2004). Females give birth to litters of up to eight young in estuaries during May and June (Castro 1993a, Loefer and Sedberry 2003).

Blacktip sharks (*Carcharhinus limbatus*) are greatly coveted due to the high quality of their fillets. This species is found in subtropical coastal waters around the world. The high CPUE for blacktip sharks in northeast Florida commercial landings (37.9 kg/net/hour; Trent et al. 1997) indicates that it is one of the most abundant coastal sharks. Adults reach a maximum size of 1.8–2.0 m and migrate along the coast while feeding on both small fishes like menhaden as well as larger fishes, including other elasmobranchs (Castro 1996, Bethea et al. 2004). Juveniles are born in late spring and early summer within estuaries of South Carolina, Georgia (Castro 1996), and presumably northeastern Florida as well. Juveniles emigrate to open coastal waters in the fall, feeding primarily on drum.

Finetooth sharks, *Carcharhinus isodon*, are captured less frequently than blacknose, Atlantic spinner, and blacktip sharks, with a CPUE of 11.2 kg/net/hour estimated from the coastal driftnet fishery (Trent et al. 1997). Normally found in shallow water near the surf zone, finetooth sharks winter off Florida and migrate to Georgia, South Carolina, and North Carolina during summer (Castro 1993c). Females give birth to live young in estuaries in South Carolina in the spring. Juveniles are occasionally taken in shrimp trawls. Juveniles and adults are piscivorous, feeding on menhaden and other schooling fishes (Castro 1993b, c; Bethea et al. 2004).

Scalloped hammerheads, *Sphryna lewini*, are large sharks (up to 3.5 m in length) found in warm coastal and oceanic waters around the world. In Northeast Florida, they are captured in both the coastal drift net fishery and the pelagic longline fishery, primarily for their fins rather than their flesh (Castro 1993a). Parturition appears to occur in coastal waters or bays (Thorpe et al. 2004), with small individuals often taken incidentally in shrimp trawls (Castro 1993a). Juveniles feed on benthic crustaceans, and fishes and adults feed on fish and cephalopods (Smale and Cliff 1998, Bush 2003).

Bonnethead, *Sphyrna tiburo*, are small sharks, rarely exceeding 1 m in size and are observed in Florida spring through fall. They feed primarily on hard-shelled crustacean prey, such as portunid crabs, *Callinectes* spp., and shrimp, as well as small fishes (Cortes et al. 1996). Thorpe et al. (2004) suggest that bonnethead give birth to live young during fall in coastal waters of North Carolina.

Spinner sharks, *Carcharhinus brevipinna*, reach 3 m in length and have a circumtropical distribution in coastal and pelagic habitats. Juveniles and adults feed primarily on schooling fishes (Castro 1993a, Bethea et al. 2004). Thorpe et al. (2004) indicate that females give birth in North Carolina coastal waters, and Aubrey (2001) noted that nearshore waters of Cape Canaveral serve as an important spinner shark nursery.

Great hammerheads, *Sphyrna mokarran*, are one of the largest coastal shark species reaching lengths of 6–7 m. This species is captured primarily for the sharkfin market by coastal and pelagic longline fisheries along U.S. East Coast. Although circumtropical in distribution, juveniles are rarely observed in the western Atlantic (Castro 1993b).

Striped mullet, *Mugil cephalus*: Striped mullet are an extremely valuable fishery in Northeast Florida, with nearly 516,000 pounds landed in 2005 (Appendix A). The commercial fishery focused on adult stocks inhabiting estuaries and living along the coast. Seventy-three percent (73%) of the commercial landings were made in Brevard and Volusia counties. Although landings decreased following the passage of a ban on the use of gill nets in 1995, they have rebounded in recent years as the fishery was reestablished using different gears. Large numbers of mullet are also caught by recreational anglers primarily for use as bait.

Adult mullet live mainly in estuaries or nearshore coastal waters and migrate offshore to spawn. Collins and Stender (1989) determined that striped mullet spawn along the edge of the outer continental shelf from October through April, with peak activity in midwinter. Juveniles feed on zooplankton as they migrate toward estuarine nursery areas during spring (Nordlie 2000). As they grow within the estuary, their diet shifts to detritus and epiphytes.

King mackerel, *Scomberomorus cavalla*: The piscivorous king mackerel is a large coastal pelagic species, highly prized by both commercial and recreational anglers. Most common in the southern portion of the region under study, 63% of the 2005 commercial landings were made in Brevard County and 27% in Volusia County. The target of numerous fishing tournaments, nearly 390,000 fish were taken by the recreational fishery throughout eastern Florida in 2005.

King mackerel spawn from April to September, generally in waters over 120 ft deep, but move closer to the coast during the summer (Finucane et al. 1986, Collins and Stender 1987). Pelagic juveniles feed on small schooling fishes, such as anchovies, menhaden, and threadfin herring (Naughton and Saloman 1981).

Spanish mackerel, *Scomberomorus maculates*: Spanish mackerel are a pelagic species common along the east–central Florida coast. The species appears most abundant south of the study area, with 97% of total regional commercial landings (540,000 pounds) reported from Brevard County (Appendix A). Spanish mackerel spawn from May through September, generally where water depths are less than 120 ft (Collins and Stender 1987). As with the congeneric king mackerel, juvenile Spanish mackerel feed on small schooling fishes, including anchovies, menhaden, and threadfin herring (Naughton and Saloman 1981).

Amberjack, *Seriola dumerili*: Amberjack are a larger pelagic member of the jack family, Carangidae, and are often observed feeding on fish and squid around reefs. Over 116,000 pounds of amberjack were landed by the commercial fishery in Northeast Florida in 2005. Volusia, St. Johns, and Duval, counties accounted for 89% of the landings. Spawning is reported from February through July, with peak reproductive activity from February through April (Wells and Rooker 2004). Juveniles are often associated with pelagic *Sargassum* or other floating structures and feed on fish and small crustaceans (Wells and Rooker 2004).

Dolphin, *Coryphaena hippurus*: Dolphin (mahi mahi) are among the most popular pelagic recreational fishery species and also support a significant commercial fishery in Florida. Nearly 65,000 pounds were landed by the commercial fishery in Northeast Florida in 2005. Most of the landings were made in Brevard, Volusia, and Duval counties.

Dolphin are circumtropical, with populations migrating over long distances. In the western Atlantic, dolphin spawn in the Florida Current from November through July, with peak reproductive effort in March. Juveniles and adults migrate northward in spring, reaching Northeast Florida in late spring and early summer. An extremely fast-growing species, dolphin feed on fish, cephalopods, and crustaceans. They are often associated with floating mats of *Sargassum*, especially around the edges of the Gulf Stream. They normally stay in clear oceanic water and move over the continental shelf with meanders and eddies of ocean currents.

Bluefish, *Pomatomus saltatrix*: Bluefish are a migratory pelagic species that spans North American coastal waters from Nova Scotia to Florida and into the Gulf of Mexico. Nearly 95% of the 89,400 pounds of bluefish captured by the commercial fishery in Northeast Florida in 2005 was landed in Brevard County. South Atlantic populations spawn during spring months from Florida to North Carolina in waters near the Gulf Stream (Oliver et al. 1989). A secondary spawning peak in late summer has been reported by Collins and Stender (1987). Juveniles are common in estuaries, feeding primarily on small schooling fishes such as herring and silversides. Adults migrate northward in the spring, returning southward along the coast during the fall.

Demersal fishery species

The demersal fish fauna off Northeast Florida is diverse and includes dozens of species of considerable commercial and recreational value as well as a multitude of forage taxa that serve as important trophodynamic links in the coastal ecosystem. Demersal fishes are often associated with specific substrates (e.g., rock or coral reefs, oyster bars, seagrasses, sand, or mud), and many undergo predictable ontogenetic shifts in their preferred habitat. Most reproduce by spawning pelagic eggs or larvae that are dispersed in coastal currents. Juveniles settle on specific nursery substrates and transition to adult habitats as they mature. The most important commercial and recreational demersal fishery species in Northeast Florida include the following:

Kingfish, *Menticirrhus* spp.: Kingfish are small drum (family Sciaenidae) commonly caught in coastal waters and the surf zone from Florida into the Carolinas. Although several species may be present, most of the commercial catch is presumably the southern kingfish, *Menticirrhus americanus*. Over 778,000 pounds were landed by the commercial fishery along the northeast Florida coast in 2005, with 85% landed in Duval County (Appendix A). They are also commonly taken by recreational anglers.

Kingfish feed primarily on benthic organisms, including siphon tips and whole surf clams, mole crabs, polychaetes, as well as epibenthic mysids, amphipods, and cumaceans (Modde and Ross 1983, McMichael and Ross 1987). Spawning occurs in early summer in coastal waters (Smith and Wenner 1985), although Reyier and Shenker (2007) found that adult populations within the Mosquito Lagoon and northern Banana River spawn within the estuary.

Flounder, *Paralichthys* spp.: Although available landings data do not discriminate among different flounder species, three species contribute to both commercial and recreational landings along the northeastern Florida coast: Gulf flounder, *P. albigutta*; summer flounder, *P. dentatus*; and southern flounder, *P. lethostigma* (Murphy et al. 1994). Volusia County recorded 52% of the 2005 commercial landings of 157,000 pounds, and Brevard County had 19% of landings.

Adult flounder of all three species inhabit coastal waters and estuaries, while summer flounder are rare to absent in southern Florida. Murphy et al. (1994) reported that Gulf flounder prefer sand substrate, whereas, southern flounder are more abundant on soft mud, clay, or silt. Juveniles feed primarily on small crustaceans, including mysids, amphipods, and palaemonid shrimp. As they grow, flounders switch to a diet of small fishes (Murphy et al. 1994). Adults move offshore to spawn at depths of 67–200 ft in late fall and winter, with peak activity occurring in November through January.

Vermilion snapper, *Rhomboplites aurorubens*: Vermilion snapper are a small snapper that support commercial and recreational fisheries along the U.S. southeast and Gulf coasts. The largest fishery on the east coast is in the Carolinas (Cuellar et al. 1996a). The commercial fishery in Northeast Florida is centered in Duval and St. Johns counties where 72% and 27%, respectively, of the 134,000 pounds were landed in 2005. Vermilion snapper live along rocky ridges and other structures on outer shelf and upper continental slope waters. Adults spawn from April through September (Cuellar et al. 1996b).

Gag grouper, *Mycteroperca microlepis*): Gag are one of the most valuable fishes of coastal Florida and support significant commercial and recreational fisheries throughout much of the SAB and Gulf of Mexico. Although landings in Northeast Florida are generally lower than most of the Florida coast, nearly 113,000 pounds were landed by regional commercial fisheries in 2005. About 45% of the landings occurred in Duval County and 20% in Brevard County.

These protogynous hermaphrodites spawn in aggregations around structures along the outer continental shelf from December through April, with peak spawning activity in February and March (Bullock and Smith 1991, Hood and Schlieder 1992, Collins et al. 1998). The only known spawning aggregations in the central Florida region are in the reef structures of the Experimental *Oculina* Research Reserve near the edge of the continental shelf off Ft. Pierce (Koenig et al. 2000).

Gag larvae are transported across the shelf and utilize estuarine and coastal seagrass beds as their juvenile habitat (Keener et al. 1988, Ross and Moser 1995). As fish grow, they migrate progressively further offshore, inhabiting reef and hardbottom structures to depths of 150 m or more. Newly settled juveniles feed primarily on small crustaceans, with larger juveniles and adults primarily feeding on fishes.

Red snapper, *Lutjanus campechanus*: One of the most prized recreational and commercial fishes in Florida, red snapper are found on rock reef structures throughout much of Florida. Populations are most abundant along the Florida panhandle and off the northeastern counties, but they are also found in other portions of Florida. In 2005, over 69,000 pounds were taken by the commercial fishery in Northeast Florida, with 93% of landings in Brevard, Volusia, and Duval counties.

Adult red snappers are found on rock reefs and ledges along the continental shelf. They spawn from April through January, with a peak of reproductive activity in June and September (Bradley and Bryan 1975, White and Palmer 2004). Juveniles settle in coastal waters on sand, seagrass, and hardbottom habitats, and comprise a major portion of the bycatch of the trawl fishery for shrimp. Juveniles consume a variety of small crustaceans and cephalopods; adult diets expand to include many fish species.

Sheepshead, *Archosargus probatocephalus*: Sheepshead are primarily an estuarine species that uses its grinding dentition to obtain and crush hard-shell molluscan and crustacean prey (Sedberry 1987). Of the nearly 70,000 pounds taken by the commercial fishery in 2005, landings were relatively evenly distributed among Brevard, Volusia, Duval, and St. Johns counties. Adults migrate offshore to spawn in winter, and their planktivorous larvae recruit back into nursery habitats inside estuaries.

Red drum, *Sciaenops ocellatus*: The commercial fishery for red drum in Florida was eliminated in the 1990s following severe overfishing and population declines. The species now supports a thriving recreational fishery, and nearly 1.5 million fish were taken by anglers in east Florida in 2005. Adult red drum live primarily within estuaries or nearshore waters. They spawn from July through November, with peak spawning occurring near tidal inlets and the enclosed waters of the Mosquito Lagoon in September and October (Murphy and Taylor 1990, Johnson and Funicelli 1991). After drifting in the coastal waters for up to several weeks, larvae return to nursery habitats in seagrass beds in estuaries. Juveniles feed primarily on small crustaceans, and adults feed on a wide variety of crustaceans and fish.

Demersal forage species

Small-bodied demersal fishes are often extremely abundant and thus form critical links in the trophic structure of coastal regions by feeding on epibenthic and infaunal invertebrate species and by serving as prey for larger piscivores. Demersal forage species that are of special importance on the northeast Florida shelf include the following:

Grunts, Haemulidae: Grunts comprise an extremely valuable group of fishes that are prey for larger piscivores such as groupers and snappers. The diverse species of grunts inhabiting Florida's northeast coastal waters include the pigfish, *Orthopristis chrysoptera,* which is generally found in estuarine seagrass beds. White grunt (*Haemulon plumier*), tomtate (*H. aurolineatum*), and sailor's choice (*H. parra*) typify the offshore species that can be extremely abundant on rock and artificial reefs (Sedberry and Van Dolan 1984, Shenker et al. 2003). Grunts are generally associated with low-relief rock and coral structures in the daytime. They feed in and around the benthic structures, but some species migrate into adjacent sandy habitats and seagrass beds at night to forage on benthic invertebrates (Meyer and Schultz 1985, Sedberry 1985). Many grunts spawn during the spring but may have extended spawning seasons in offshore waters.

Porgies, Sparidae: Porgies are a diverse family of forage fishes, although some species such as the sheepshead, *Archosargus probatocephalus*, and jolthead porgy, *Calamus bajonado*, are targeted by the recreational fishery. Most commercial and recreational porgy landings are intended as bait for snapper, grouper, and other species. The most abundant baitfish species is the pinfish, *Lagodon rhomboides*. Adult pinfish live in estuaries or in nearshore waters, generally in seagrass or patchy hardbottom habitats. They spawn offshore in late fall and winter, and larvae recruit to estuarine nurseries (Shenker and Dean 1976, Nelson 2002). Juveniles feed primarily on crustaceans, although adults are one of the few Florida marine fishes that feed extensively on macrophytes.

Seven species of the genus *Calamus* are also commonly found in coastal waters of Northeast Florida, but their biology is poorly known. The knobbed porgy, *C. nodosus*, spawns May through June off the Carolinas (Horvath et al. 1990). Their assessment of the diet of *C. nodosus* indicated that this species feeds on polychaetes and hard-shelled invertebrates, including mollusks, crustaceans, and echinoderms, that they can crush with their strong jaw and pharyngeal teeth.

Mojarras, Gerreidae: Mojarras are a family of small demersal fishes that are very abundant in Florida coastal and estuarine waters (Motta et al. 1995, Pierce and Mahmoudi 2001, Paperno et al. 2001). Their highly protrusible jaw morphology makes them effective suctorial predators on small benthic organisms like polychaetes, amphipods, and small bivalves (Motta et al. 1995, Nordfors 2001). Although spawning of mojarras has not been directly studied, the appearance of small juveniles in Florida estuaries during summer suggests that adults spawn offshore in spring and early summer. Mojarras are presumed to be important prey for many demersal piscivores and are widely used as bait by anglers.

Sea robins, Triglidae: Although sea robins do not support commercial or recreational fisheries, they were among the most common fishes taken during trawl surveys on sandy substrate in coastal Florida. Eight species of sea robin were frequently collected by a trawl survey of the central western Florida shelf habitats, and they are abundant along the eastern United States from Florida to Maine (McBride 2002, McBride et al. 2002a). Their consumption of benthic organisms, including small crustaceans, polychaetes, and lancelets, and their role as prey for larger piscivorous fishes, make them a potentially significant link in the food web associated with sand borrow sites (Lewis and Yerger 1976, Ross 1983). Different species of sea robins spawn at different times of the year, and spawning seasonality varies with geographic location. However, most species spawn from spring through late summer (Ross 1983, McBride 2002, McBride et al. 2002).

Lizardfish, Synodontidae: Lizardfish are common, small predators found on shallow, sandy substrates throughout tropical habitats. Rarely exceeding 30 cm in size, lizardfish are lurking predators, with pigmentation that makes them difficult to spot against the substrate. Very little is known of the biology and ecology of the three species that are frequently found on sand habitats along the west central Florida coast (Pierce and Mahmoudi 2001) and near Cape Canaveral, Florida (Shenker, personal observation). Given their presumed diet of small demersal fishes, lizardfish are likely to be important predators on new recruits and an important link in the trophodynamic structure of the coastal ecosystem.

Flounders, Bothidae: In addition to the commercially valuable *Paralichthys* spp., numerous small flounders found along the entire Florida coastline include whiffs, *Citharichthys* spp.; dusky flounder, *Syacium papillosum*; ocellated flounder, *Ancyclopsetta ommata*; and fringed flounder, *Etropus crossotus* (Leslie and Stewart 1986, Pierce and Mahmoudi 2001). The biological characteristics and ecological relationships of these small species are poorly known, but they presumably feed on benthic invertebrates in sandy habitats and are prey for larger fishes.

Invertebrate fishery species

White shrimp, *Litopenaeus setiferus*: More white shrimp were landed by the commercial fishery in Northeast Florida in 2005 than any other finfish or invertebrate fishery species. Of the 3.8 million pounds of white shrimp harvested from northeast Florida waters, 70% of the landings were made in Duval County and 14% in Brevard County. White shrimp inhabit estuarine and coastal waters, generally in areas with organic-rich mud substrates in depths less than 90 ft, and are especially abundant near extensive salt marshes and areas of high freshwater runoff. They spawn from April to October in nearshore waters of 20–80-ft. depths. Larvae recruit to seagrass beds and algal mats within estuaries.

Blue crab, *Callinectes sapidus*: Nearly 3.6 million pounds of blue crabs were landed in Northeast Florida in 2005, with peak landings in Brevard County (62%) and Duval County (16%). Adults are generally caught by a trap fishery operating inside estuaries or in nearshore waters. When female crabs are nearly ready to release zoea larvae from egg masses carried on their abdomens, they migrate toward inlets. Larvae drift through the coastal ocean until they reach the megalops stage and begin the use of tidal currents to recruit back to nursery habitats within estuaries (Tankersley et al. 2002).

Brown shrimp, *Farfantepenaeus aztecus*: Over 390,000 pounds of brown shrimp were harvested from northeast Florida waters in 2005, with 64% of the landings made in Duval County and 16% in Nassau County. Brown shrimp inhabit estuarine and coastal waters, generally in areas with organic-rich mud substrates at depths to 180 ft and where the salinity is higher than that preferred by white shrimp. This species spawns at depths of 50–360 ft throughout the year, with peak spawning from February through March. Larvae recruit to nursery habitats within estuaries.

Rock shrimp, *Sicyonia brevirostris*: Only 128,000 pounds were landed in 2005, with 42% of the landings in Brevard County, 34% in Flagler County, and 19% in Duval County. Northeast Florida landings before 2005 had been much higher. In 2004, for example, over 3.7 million pounds were landed in Brevard County alone. Sampling along the northeast coast of Florida in the 1970s found that rock shrimp were concentrated on sandy substrates between depths of approximately 100 and 160 ft northward of Cape Canaveral, Florida (Kennedy et al. 1977). Juveniles were found in the same region but were also found to be abundant at depths as shallow as 60 ft. Spawning occurs from November through January.

Protected fish species

The smalltooth sawfish, *Pristis pectinata*, was once widely distributed throughout U.S. Atlantic waters from Texas to New York. A robust population had inhabited the Indian River Lagoon system (Snelson and Williams 1981), which begins 15 km south of borrow site B11. By the early to mid-1900s, the sawfish was nearly extirpated from much of its historical range, largely due to bycatch mortality in fishing nets, direct harvest of their rostrum (which were coveted as curios), as well as coastal habitat modifications. The largest remaining sawfish population is now found in south and southwest Florida (Poulakis and Seitz 2004) where it is still fairly common, with only occasional records elsewhere. In 2003, the smalltooth sawfish was listed as endangered under the Endangered Species Act.

The recent scarcity of sawfish records off East Central Florida may be partly indicative of prohibitions on commercial gill net and longline fisheries in state waters. Adult sawfish commonly inhabit coastal marine waters. Because the species has a known affinity for sand shoals (NMFS 2000), the species should be expected in the study area on occasion. In May 2004, a 3-m sawfish was taken over open sand on a research longline above the Southeast Shoal at Cape Canaveral, 90 km south of borrow site B11 (Reyier et al. In Press), and a juvenile sawfish was captured within Port Canaveral in March 2005.

The shortnose sturgeon, *Acipenser brevirostrum*, can be found along the U.S. eastern seaboard from the St. John River in New Brunswick, Canada south to the St. Johns River, Florida; although Evermann and Bean (1897) recorded specimens from the Indian River Lagoon system south of the proposed sand mining sites. Sturgeon have long been coveted for both their roe and flesh, and an expanding U.S. fishery in the mid-1800s eventually led to considerable overfishing (Gilbert 1989). Consequently, the shortnose sturgeon was declared federally endangered in 1967. The species primarily occupies rivers and estuaries and is unlikely to be encountered in marine waters of Northeast Florida. In a 10-year trawl survey of the SAB by the South Carolina DNR, no *A. brevirostrum* were collected. The larger Atlantic sturgeon, *A. oxyrinchus oxyrinchus*, currently listed as a candidate species for federal protection, shares a similar anadromous life history strategy and geographic range. Although it has greater affinity for marine waters, its center of abundance lies north of Florida.

While not federally listed, several other fishes identified by the state of Florida and NMFS as overfished or prone to overfishing are currently prohibited from harvest. These include the goliath grouper, *Epinephelus itajara*; Nassau grouper, *E. striatus*; spotted eagle ray, *Aetobatus narinari*; manta ray, *Manta birostris*, and 18 species of shark. With the exception of goliath grouper, all species are expected to be rare or transitory in the area of proposed borrow sites.

2.4.3 Seabirds, Sea Turtles, and Marine Mammals

2.4.3.1 Seabirds

Several species of pelagic, migrant, and coastal birds inhabit the eastern inner shelf of Florida. Bird species observed along the coastal regions of east Florida can be divided into six general guilds (shorebirds, waterfowl, wading birds, seabirds, raptors, and passerines) based on utilization of habitats and the relative amount of time spent in the open oceanic waters of the Atlantic. Species most likely to occur in the study area are pelagic birds, pelicans, gulls, and terns. The terms "seabird or sea bird" are used to describe birds that obtain the majority of their food from coastal waters (neritic species) or from the open ocean (pelagic species). Neritic seabirds use the land for feeding or resting at certain times, whereas pelagic seabirds are largely independent of the land except for nesting (Browne et. al. 2004). The study area falls narrowly between pelagic and neritic habitats.

Regulatory protection of seabirds in Northeast Florida is covered under three provisions the USFWS Endangered Species Act (ESA), the Migratory Bird Treaty Act (MBTA), and the Florida Endangered and Threatened Species Act (FETSA). In some cases, local counties or towns also have ordinances protecting seabirds. With the exception of non-native species, all birds identified as potentially occurring in the northeast Florida study area are protected under the MBTA (Williams 2004).

Pelagic Seabirds

Pelagic seabirds represent a wide range of species that spend much of their time in or over water and are capable of staying far from land for long periods of time. Most of these birds have adaptive salt glands that allow them to regulate the salt content in their blood (Ehrlich et al. 1988). Some species, such as albatross, frigatebirds, shearwaters, boobies, gannets, and petrels, spend the majority of their life cycle offshore, while others, such as gulls, terns, pelicans, and cormorants, divide their time more or less equally between offshore and coastal waters (Ehrlich et al. 1988). Most species in this guild are also colonial nesters that leave the nest to venture far from natal areas. Pelagic seabirds typically feed in upwellings on abundant fish and zooplankton species. They have been associated with eddies and cold core currents in the Gulf that increase productivity of primary organisms (Ribic et al. 1997) and probably follow similar productivity spikes in the Atlantic and in correlation with the distribution of *Sargassum* "islands" (Haney 1986).

Information on the population status and movements of pelagic birds is limited, largely due to the vast geographical areas, the differences among species-specific migration, the difficulty in studying bird movement during adverse weather conditions, and the lack of standard methodology (Tasker et al. 1984, Michel and Burkhard 2007). Several pelagic species have trans-equatorial travel habits, migrating between the two Poles each year. For example, Wilson's storm-petrels breed in the Antarctic during December and January and fly nearly 10,000 miles to the mid- and northern Atlantic Ocean for May to August. Many species nest on crowded islands yet inhabit wide-open ocean spaces during the non-breeding season. Seabird surveying is complicated by the ability to conduct aerial or marine field surveys in variable weather conditions. Occasionally weather events bring birds close enough to shore to document them. Forsell and Koneff (2006) presented deficiencies in the available scientific knowledge of these birds and their use of offshore shoals. They recommended uniform study methods to better understand the birds' ecological relationship with offshore shoals in order to minimize impacts of mining on foraging habitat (Forsell and Koneff 2006).

Neritic Seabirds

Pelicans, gulls, terns, and cormorants are considered neritic, meaning that they are more common in the coastal waters, although some can be seen with regularity well offshore (Erhlich et al. 1988). These species are common in nearly all offshore environments. The east coast of Florida populations of Brown Pelican, *Pelecanus occidentalis*, are listed as a species of special concern by the state of Florida (FWC 2004), but they are excluded from the MBTA list. Some neritic seabirds that may occur in the study area are listed in Table 2.4.

Data collected and discussed on seabirds for the study area relied on information available for the Atlantic Coast of the U.S. and the east coast counties in Florida (Cruickshank 1980, Lee and Cardiff 1993, USFWS 1995, FWC 2003, USFWS no date). Pelagic species data includes many birds uncommon to Florida's east coast, yet may have occurred seasonally or accidentally. Some of the seabirds that spend significant portions of their lifecycle offshore and that may occur in the study area are listed in Table 2.4 below.

Table 2.4. Seabirds of the Northeast Florida Study Area.

Common Name	Scientific Name	Common Name	Scientific Name
Frigatebirds		**Terns**	
Magnificent Frigatebird	*Fregata magnificens*	Black Tern	*Chlidonias niger*
Shearwaters		Least Tern	*Sterna antillarum*
Cory's Shearwater	*Calonectris diomedea*	Sooty Tern	*S. fuscata*
Greater Shearwater	*Puffinus gravis*	Common Tern	*S. hirundo*
Sooty Shearwater	*P. griseus*	Roseate Tern	*S. dougallii*
Audubon's Shearwater	*P. lherminieri*	Sandwich Tern	*S. sandvicensis*
Manx Shearwater	*P. puffinus*	Caspian Tern	*S. caspia*
Boobies		Forster's Tern	*S. forsteri*
Brown Booby	*Sula leucogaster*	Royal Tern	*S. maxima*
Gannets		Gull-billed Tern	*S. nilotica*
Northern Gannet	*Morus bassanus*	**Gulls**	
Petrels		Herring Gull	*Larus argentatus*
Wilson's Storm-Petrel	*Oceanites oceanicus*	Ring-billed Gull	*L. deltawarensis*
Cormorants		Greater Black-backed Gull	*L. marinus*
Double-crested Cormorant	*Phalacrocorax auritus*	Laughing Gull	*L. atricilla*
Anhinga	*Anhinga anhinga*	Bonaparte's Gull	*L. philadelphia*
Jaegers		Black-legged Kittiwake	*Rissa tridactyla*
Parasitic Jaeger	*S. parasiticus*	**Pelicans**	
Pomarine Jaeger	*S. pomarimus*	Brown Pelican*	*Pelecanus occidentali*
		White Pelican	*P. erythrorhynchos*

* Excluded from MBTA, listed as Florida Species of Special Concern

2.4.3.2 Sea Turtles

Of the seven species of marine turtles known to exist worldwide, five species are likely to occur off Florida's east coast: the giant leatherback, *Dermochelys coriacea*; green sea turtle, *Chelonia mydas*; loggerhead, *Caretta caretta*; hawksbill, *Eretmochelys imbricate*; and Kemp's ridley, *Lepidochelys kempii*. Of these five species, three are likely to nest on Florida's northeastern beaches: the loggerhead (most common), green, and, to a lesser extent, the leatherback (USFWS 2007a, 2008 and FWRI 2009). Rare instances of nesting by hawksbill and Kemps ridley turtles have been recorded in Volusia County, with only one hawksbill and four Kemp's ridley nests having been recorded in Volusia County between 1979 and 2006. No nests for either species have been recorded in the other project area counties (FWRI 2009b).

The vast oceanic range of sea turtles make surveying difficult. Thus, population trends are based on nesting data and ancillary data, including old fishery records, anecdotal accounts of abundance, beach surveys for nests and females, trawl and aerial surveys for turtles offshore, and satellite telemetry (Dodd 1995, Byles and Dodd 1989). Most population status and trend data are derived from counts of females and nests, thereby excluding a large percentage of turtle populations (Dodd 1995).

Generally, in the first 20–30 years of life, sea turtles cycle through phases of pelagic and inshore feeding before reaching sexual maturity. Female adults briefly move onshore to nest on beaches, then return to the ocean. The diet of an adult sea turtle may change according to habitat preference and migration patterns. This diet potentially consists of seaweed, infauna associated with seaweed and algae, and more complex animals such as jellyfish, mollusks and crabs, depending on habitat and location. In recent years, satellite telemetry data has been used to track individual turtles, allowing observation of the widely dispersed post-nesting movements of marine turtles. Real-time tracking of migration routes by satellite telemetry for select individual adult and juvenile sea turtles is available through the Caribbean Conservation Corporation & Sea Turtle Survival League (http://www.cccturtle.org) and the Sea Turtle Conservation and Research Program of Mote Marine Laboratory (MML) (http://www.mote.org). Phase(s) of the life cycle spent in U.S. waters, in particular the east coast of Florida, varies seasonally and with each species.

The protection of marine turtles is regulated by multiple federal agency jurisdictions and is largely due to their endangered or threatened status. Turtles in the water are under the jurisdiction of the NMFS, while nesting turtles, eggs, and hatchlings are under USFWS jurisdiction. In recent years, critical habitat has been established for some turtle species in the U.S. Virgin Islands and Puerto Rico; however, no critical habitat has been designated in the study area. Marine turtles are also listed by the state of Florida, under the jurisdiction of the FWC and/or FDEP. State designations are the same as the federal status for each species (§68A-27.003-004 F.A.C.).

During dredging and beach renourishment projects, of all the protected marine species, sea turtles are most likely to suffer harm in some stage of their life cycle. Thus, sea turtle protection is regulated under multi-tiered jurisdictions for distinct stages of their life cycle. Operations could involve NMFS for turtle takes on dredges and/or offshore and USFWS for impacts to turtle nests on beaches. The state of Florida also has additional protection requirements and regional beach regulations for nesting turtles and turtle nesting habitat. The FDEP and the Florida Fish and Wildlife Conservation Commission both review permits for coastal construction affecting marine turtles under Chapter 62B, F.A.C. Local jurisdictions in the project area counties may also have lighting ordinances and/or habitat conservation plan agreements, all of which are designed to protect marine turtles and their habitat.

Table 2.5 lists the five species of marine turtles documented in the western Atlantic, the protection status of each, and their nesting and/or seasonal presence. Between 1979 and 2006, all five species were reported to have nested in one of the project area counties at least once; however, only one hawksbill and four Kemp's Ridley nests have been recorded in Volusia County, and no nests for either species have been recorded in the other project area counties (FWRI 2009b). The last hawksbill nest was recorded in 1982, while two Kemp's ridley nests were recorded in 1996 and one nest each in 2003 and 2006. Due to the relative rarity of these turtles in general, nesting by these species in the project areas may be considered unlikely. Nesting data by loggerhead, green, and leatherback turtles have been recorded in all the project area counties between 1993 and 2006, with loggerhead nests by far the most common recorded and leatherback nests being fairly uncommon (less than 200 nests recorded in project area counties between 1993 and 2006). Nesting data may be obtained from the FWRI's website, http://research.myfwc.com/. Information for each species likely to occur offshore of northeastern Florida is discussed below. The presence or absence of nests varies in location by species.

Table 2.5. Sea Turtles of Northeast Florida.

Common Name	Scientific Name	Seasonal Presence	Status [b]
Giant Leatherback	*Dermochelys coriacea*	+Year round: [a] Nests (March–July)	E
Green Sea Turtle	*Chelonia mydas*	+Year round: [a] Nests (June–September)	E*
Loggerhead	*Caretta caretta*	+Seasonal: [a] Nests (May–August)	T
Hawksbill Turtle	*Eretmochelys imbricate*	Year round: [a] Nests (April–November)	E
Kemp's Ridley Turtle	*Lepidochelys kempii*	Year round: [a] Nests (April–June)	E

\+ nesting present in all project area counties (FWRI 2007b)
[a] nest counts available for 2006 in study area (FWRI 2007b)
[b] 50 CFR §17.11(h) (October 2007)
* breeding colony populations in Florida and on the Pacific Coast of Mexico are listed as endangered; all others are listed as threatened (§50 CFR 17.11)

2.4.3.3 Marine Mammals

Studies of marine mammal populations in waters off the U.S. Atlantic Coast began in the 1970s coincident with the passage of the Marine Mammal Protection Act of 1972. Early studies under the supervision of NMFS were conducted to investigate mammal populations (NMFS 1980). While data exists on coastal populations of common species such as bottlenose dolphins, Atlantic spotted dolphins, and Florida manatee, marine mammal records were obtained primarily from historic hunting or stranding records until the 1980s. In 1995, NMFS issued the first Marine Mammal Stock Assessment Reports (NMFS SAR). The Service formed three independent regional scientific review groups representing Alaska, the Pacific Coast (including Hawaii), and the Atlantic Coast (including the Gulf of Mexico) to advise NMFS and USFWS on the status of stocks, research needs for and impacts to stocks, and methods to reduce incidental mortality of marine mammals as a result of fishing operations. This research substantially increased the information available on marine mammal range, habitat, reproduction, and population status. Several entities work for the NMFS to conduct marine mammal research in the western north Atlantic region, including academic institutions, government-sponsored institutes, and private contractors.

Previous studies conducted along the east coast of the U.S. were used to identify marine mammals likely to be found, preferred feeding and reproduction habitats, and migratory pathways that may coincide with the study area (Schmidly 1981, Barros et al. 1998, Reeves et al. 2002). Many species documented in the North Atlantic Ocean are considered rare or extralimital, occurring only by accident or during unusual circumstances (CETAP 1982, NMFS SAR 1998-2005, Cole et. al. 2005, Read et al. 2008). Species documented solely by stranding records are likely extralimital species. While more than 30 species are listed as observed in the western North Atlantic Ocean, few species regularly frequent the Atlantic coast near the study areas. Marine mammal species recorded near the northeast coast of Florida are discussed in this section.

All marine mammals are protected under the Marine Mammal Protection Act (MMPA) of 1972 and are under the jurisdiction of NMFS. The MMPA prohibits, with certain exceptions, the taking of marine mammals in United States waters by U.S. citizens on the high seas and the importation of marine mammals and marine mammal products into the U.S. (NMFS 2005). There are a number of species also protected under the Endangered Species Act (ESA). Federally protected species commonly found on Florida's northeast coast are the northern right whale, *Eubalaena glacialis*, and the Florida manatee, *Trichechus manatus latirostris*; they are also listed as endangered by the state of Florida (FWC 2009a). In addition, the Florida manatee is protected by the Manatee Sanctuary Act of 1978 and also may be protected by local regulations. The humpback whale, *Megaptera novaeangliae*, is also a state and federally listed endangered species, though occurrence in the project study area is expected to be limited.

Listed Marine Mammal Species

Northern right whale—The northern right whale is recognized as the most endangered large whale in the western Atlantic Ocean. It was described as a single species until genetic studies provided evidence that the North Atlantic Ocean and North Pacific Ocean populations are two separate species (Best et al. 2001, U.S. Federal Register 2003). The northern right whale population is estimated at approximately 300 individuals (NMFS 2007a) and ranges from Iceland to eastern Florida, primarily in coastal waters. During the summer, the waters around Cape Cod and the Great South Channel serve as feeding, nursery, and mating habitat (Kraus et al. 1988, Schaeff et al. 1993). Atlantic waters off the coast of the southeastern U.S. are important wintering and calving grounds. Between December and March, Northern right whales, including pregnant females, migrate from northern feeding areas to waters off the coasts of Georgia and northern Florida where females calve (NMFS 2007a). In 1994, the NMFS designated coastal areas off Florida and Georgia as critical habitat to provide protection during calving. Critical habitat area extends from the Atlantic coast of Southeast Georgia and Northeast Florida, varying in distance from 5 to 15 nm offshore. A map showing critical habitat boundaries is shown in Figure 2-38.

Northern right whales are expected to occur in the study area, especially in winter. Right whale observations have been recorded along Florida's east coast as far south as Dade County, although the Cape Canaveral region is generally their southern limit (NMFS SARS 1998–2005). Approximately 79 whales were observed in coastal waters off the Southeast U.S. during the 2005–2006 winter calving season (MRC 2006). Human-induced mortality via boat strikes and fishing gear entanglement represent about 30% of known right whale deaths (FWC 2009a, NMFS SARS 1998–2005). Disturbance from ships and noise from industrial activities may also affect right whales. As a result, NMFS published regulations in 1997 that prohibit vessels from approaching within 500 yards of right whales (50 CFR §224.103).

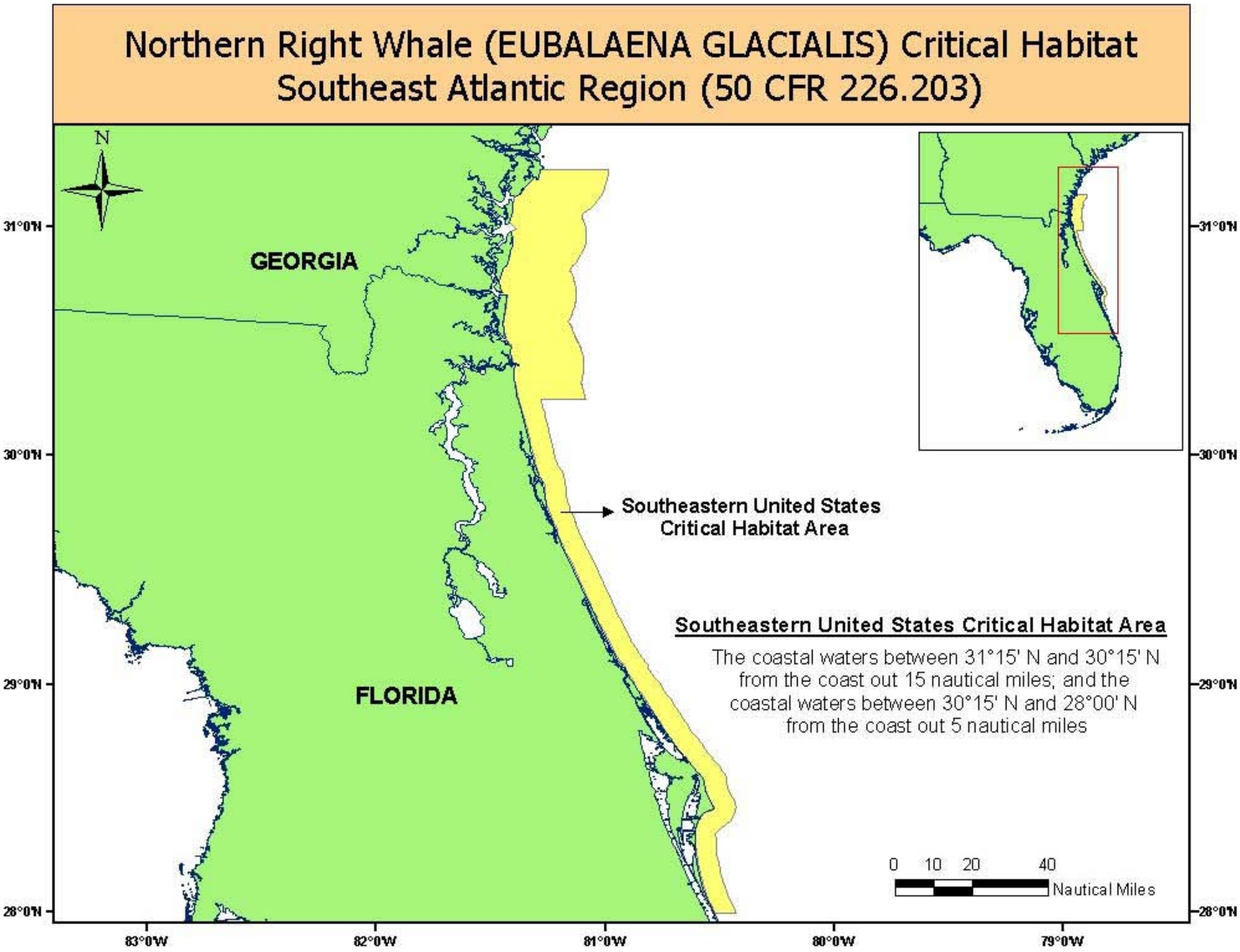


Figure 2-38. Critical habitat of North Atlantic right whale *Eubalaena glacialis* (from NMFS, 2008;http://www.nmfs.noaa.gov/pr/pdfs/conservation/ch_rightwhale_southeast.pdf).

Florida manatee—The West Indian manatee, *Trichechus manatus*, may occur within the project area. The West Indian manatee ranges from Brazil, north to Mexico, and east to the southeastern U.S., including the Caribbean Islands (USFWS 2007). It includes two subspecies: the Antillean manatee, *Trichechus manatus manatus*, and the Florida manatee, *Trichechus manatus latirostris*. Antillean manatees range from Brazil to Mexico including the Caribbean Islands, while Florida manatees occur in the southeastern U.S., primarily Florida (USFWS 2007a). The West Indian manatee (including both subspecies) is currently a federally listed endangered species (USFWS 2007a); and the Florida manatee is also listed as endangered by the state of Florida (FWC 2009a). The basis for its endangered status is the number of documented mortalities (natural and human-related) relative to the estimated population level and the continuing severe threats to critical manatee habitats in the southeastern U.S. (USFWS 2007a). Annual winter synoptic surveys from 1991-2007 resulted in population estimates between 1,267 and 3,300 individuals (FWC 2009e).

In April 2007, USFWS completed their five-year review of both subspecies of the West Indian manatee. The review considered extensive data, including evidence indicating that "the overall population of the Florida manatee has increased and the Antillean manatee levels are stable, and neither subspecies is currently in danger of becoming extinct within all or a significant portion of their range" (USFWS 2007b). As such, USFWS made the recommendation that both subspecies of the West Indian manatee be downlisted to a threatened species. The recommendation has no impact on the current endangered status other than to advise that future federal rulemaking may reclassify the manatee as a threatened species; and there is no specific timeframe for this action. FWC also conducted a biological review in 2006. The review was followed by a Florida Manatee Management Plan in 2007, which considered downlisting the Florida manatee to threatened but was deferred by FWC commissioners in Dec. 2007 (FWC 2009c, d). The Florida manatee remains protected under the MMA and the Manatee Sanctuary Act (370.12 (2), Florida Statutes), which provides specific protection for manatees and is independent of, and not contingent upon, its status as a listed species.

Florida manatees maintain a variety of habitats, including freshwater, brackish, and marine environments. They feed on submerged, emergent, and floating vegetation, and those inhabiting marine environments may regularly seek out freshwater sources such as creeks or industrial outfalls for drinking (FWC 2009c). Manatees cannot tolerate cold temperatures and will typically seek out warmer inland waters such as natural springs and power plant outfalls when the water temperature drops below about 20°C (68°F) (FWC 2009c). Their winter range is generally restricted to Central Florida and inland waters of peninsular Florida. However, during warmer months (approximately April–October), manatees may disperse to coastal waters, major rivers, and estuaries and may migrate north into southeastern Georgia, and rarely, further north as far as Massachusetts. Florida manatees may occur in the study area seasonally when waters exceed 20°C. Critical habitat has been designated for the Florida manatee in intercoastal and inland waterways and does not include offshore.

Humpback whale—The humpback whale, *Megaptera novaeangliae*, is a state and federally listed endangered species (USFWS 2007a). In the spring, summer, and fall, humpback whales inhabit northern feeding grounds in coastal and continental shelf waters off the northeastern U.S., Canada, and Greenland. In the winter, they may travel thousands of miles to calving areas in waters of the West Indies (Reeves et al. 2002, NMFS 2007b). In northern feeding waters, humpback distribution and behavior is largely correlated to abundance of prey species and bottom topography (NMFS SARS 1998–2005). Although most humpback whales travel to the waters of the West Indies for mating and calving, considerable numbers do not and may be found in areas of the mid- and upper-latitudes during winter (NMFS 2007b, Clapham et al. 1993, Swingle et al. 1993).

During migration, humpbacks from all feeding areas may travel through deep waters. Humpback whales have been increasingly observed off the mid-Atlantic coast, including the Chesapeake and Delaware Bays, and strandings have been documented along the mid-Atlantic and southeastern U.S. coasts—in particular the coasts of Virginia and North Carolina (NMFS 2007b). Most stranded whales were juveniles. Researchers suspect that these areas may be important habitat for juvenile whales and that the whales may be susceptible to anthropogenic factors in the areas that may negatively impact them (NMFS 2007b, Wiley et. al. 1995). A number of wintertime humpback whale sightings in coastal waters of the southeastern U.S. have also been reported (NMFS 2007b). It is unknown whether the sightings are correlated to a distributional change, to increases in sighting efforts and reports, or to an increase in whale abundance (NMFS 2007b). They are regularly sighted during annual right whale surveys off the Florida and Georgia coasts (NMFS SARS 1998–2005). Humpback whales may occur in the study area during migrations, although occurrence is expected to be seasonal (December–March) and limited. No critical habitat has been designated for this species.

Other listed marine mammal species—A number of species identified as potentially occurring in the Western Atlantic are considered rare or extralimital, occurring in southeastern U.S. or northeastern Florida waters only by accident or during unusual circumstances. Marine mammal species listed as endangered and considered rare or extralimital include the blue whale, *Balaenoptera musculus*; fin whale, *Balaenoptera physalus*; sei whale, *Balaenoptera borealis*; Bryde's whale, *Balaenoptera edeni*; and sperm whale, *Physeter macrocephalus*. They are not expected to occur in the study area.

Non-listed marine mammal species—Nearly all of the non-listed cetaceans mentioned below rarely occur in waters less than 100 m deep unless stranded. Most inhabit waters greater than 100 m, and some may even be found at depths up to and exceeding 2,000 m. This group includes the minke whale, *Balaenoptera acutorostrata*; pygmy sperm whale, *Kogia breviceps*; dwarf sperm whale, *Kogia simus*; and Cuvier's beaked whale, *Ziphius cavirostris*. Other beaked whales include Blainville, *Mesoplodon densirostris*; Sowerby, *M. bidens*; True's, *M. mirus*; and Gervais, *M. euopaeus*. Non-listed members of the family Delphinidae that are unlikely to occur in the study area include the killer whale, *Orcinus orca*; false killer whale, *Pseudorca crassidens*; pygmy killer whale, *Feresa attenuata*; long-finned pilot whale, *Globicephala melas*; short-finned pilot whale, *G. macroryhnchus*; and melon-headed whale, *Peponocephala electra*.

Various dolphins inhabit coastal and offshore waters of the Atlantic from approximately 10 m to 200 m depths. Only the bottlenose dolphin, *Tursiops truncates*, and the spotted dolphin, *Stenella frontalis*, are expected to regularly to occur in coastal waters less than 100 m deep. Both populations are estimated at more than 20,000 individuals and are likely to occur in the project study areas (Curry 1997 *in* NMFS SAR, 2002). Additional dolphin species observed offshore in deeper waters of the Atlantic (100 m depth or greater) but unlikely to occur in the study area include rough-toothed dolphin, *Steno bredanesis*; Risso's dolphin, *Grampus griseus*; pantropical spotted dolphin, *Stenella attenuate*; spinner dolphin, *Stenella longirostris*; clymene dolphin, *Stenella clymene*; striped dolphin, *Stenella coeruleoalba*; and Frasier's dolphin, *Lagenodelphis hosei*. The populations of deep-water dolphin species range from 200 to thousands of individuals. Although all of dolphins the listed above are protected by the MMPA, none are listed under the ESA.

3.0 FIELD SURVEYS 2005 AND 2006 FOR BIOLOGICAL AND SEDIMENT SAMPLING

3.1 Introduction

The purpose of the two field sampling events was to augment the literature research by characterizing the biological communities present on and off the shoals near the study areas. Sediment grab samples were taken using Smith McIntyre samplers to identify benthic organisms and to assess the sedimentary environment. Water quality indicators (salinity, temperature, chlorophyll-a, and dissolved oxygen) were determined from water column samples collected during the field events. Fishes and plankton were identified from samples collected using fish trawls and plankton tows. Observers were located on the field vessels to sight and document marine mammals, sea turtles, and seabirds during field events. A data management plan and a cruise plan developed prior to the first field event outlined the methods described in the next section.

3.2 Methods

The 2005 field event was conducted from November 4 to 9, 2005, aboard the research vessel M/V *Thunderforce*. Field sampling included collection of 76 Smith McIntyre grabs (0.1 m^2), 17 conductivity-temperature-depth (CTD) casts, epifauna video camera sled transects, and otter trawls and plankton tows described in Sections 3.2.1–3.3.5. Observers were onboard to record sightings of listed species. The locations of 2005 benthic grab, otter trawls, and video sled transects are shown in Figures 3-1 to 3-5.

The 2006 field event was conducted from June 4 to 8, 2006, also aboard the research vessel MV *Thunderforce*. Field sampling included collection of 85 Smith McIntyre grabs (0.1 m^2), 17 CTD casts, and otter trawls and plankton tows described in Sections 3.2.1–3.3.5. Due to extremely high infaunal abundances in the 2006, only 39 of the benthic samples were randomly selected and processed. The locations of 2006 benthic grab and otter trawls appear in Figures 3-1 to 3-5. Geo-position data for all benthic grabs, trawls, and video transects conducted during the project is provided in Appendix B.

3.2.1 Water Column

A continuous profile of salinity, temperature, dissolved oxygen, and chlorophyll-a throughout the water column was collected using a Sea-Bird CTD (model SBE-19 equipped with a Sea-Bird SBE23 dissolved oxygen [DO] sensor and self-contained underwater fluorescence apparatus [SCUFA] fluorometer) at selected benthic grab stations within the five study areas. Three CTD casts were performed within each study area during each survey, except for area A4, where five CTD casts were made. The data were plotted using the program SEASAVE V7, displaying the downcasts only. The locations of benthic stations where water quality profiles were conducted are presented in Appendix B.

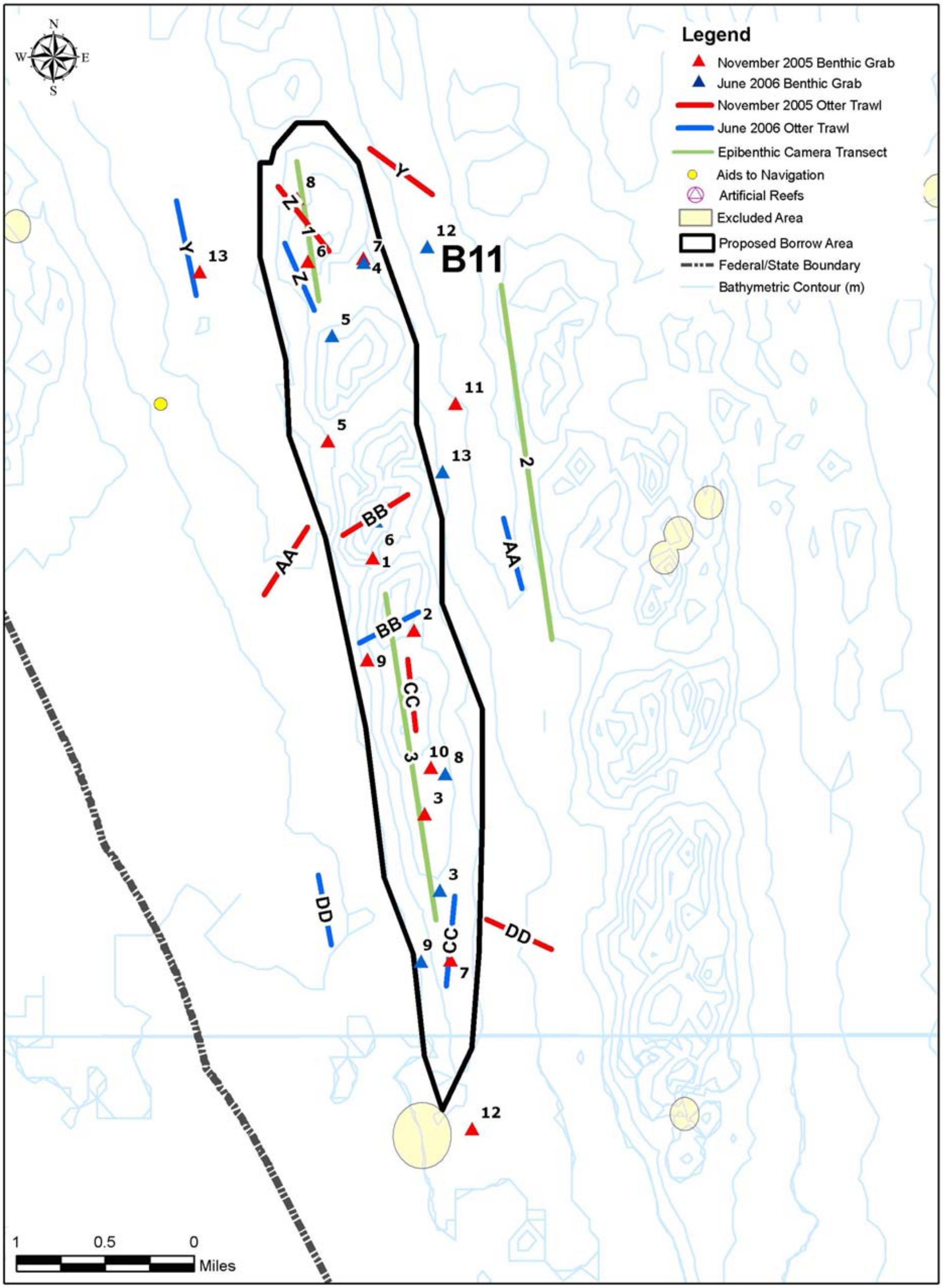


Figure 3-1. Locations of benthic grabs, video transects, and otter trawls at shoal B11.

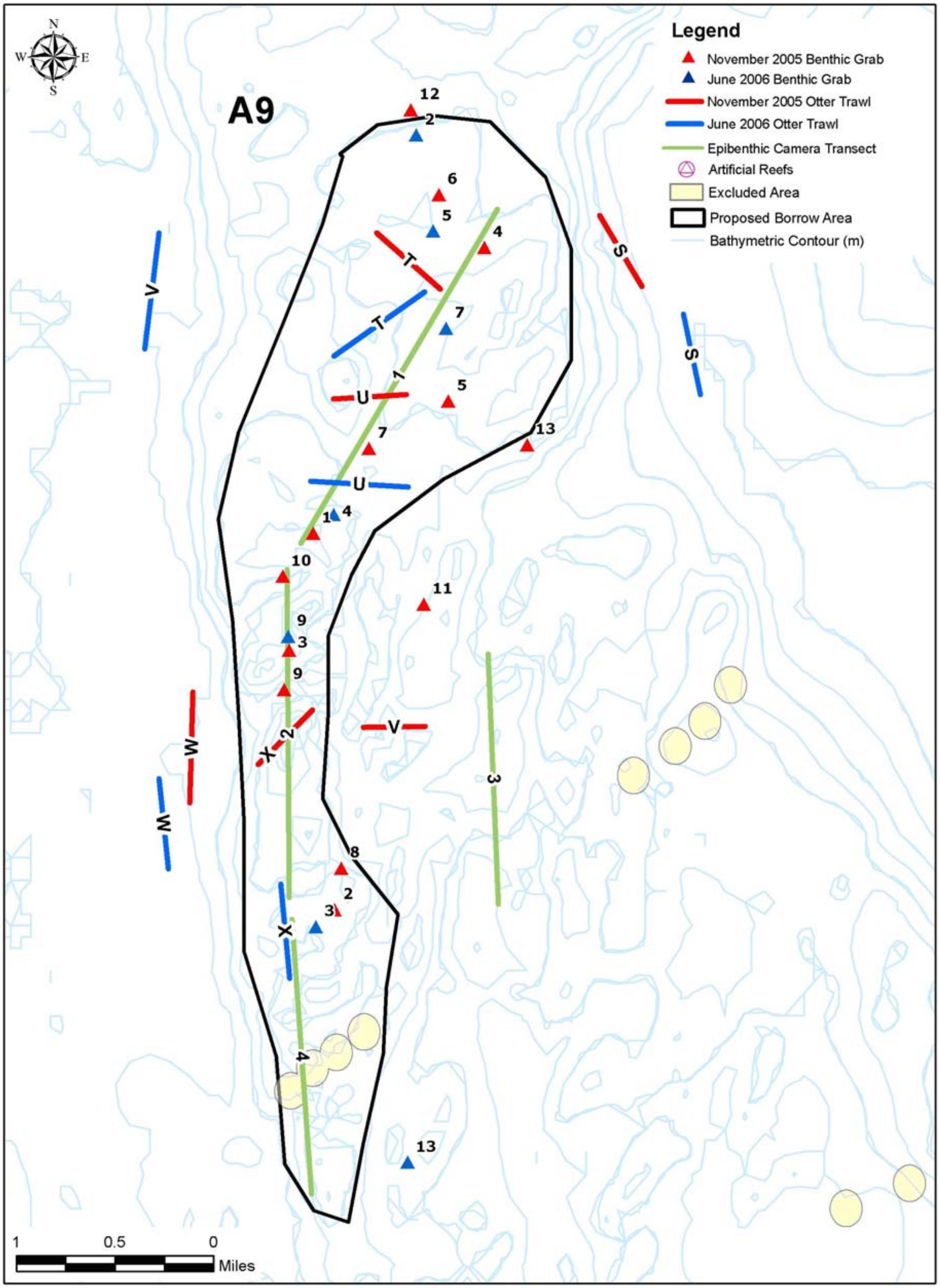


Figure 3-2. Locations of benthic grabs, video transects, and otter trawls at shoal A9.

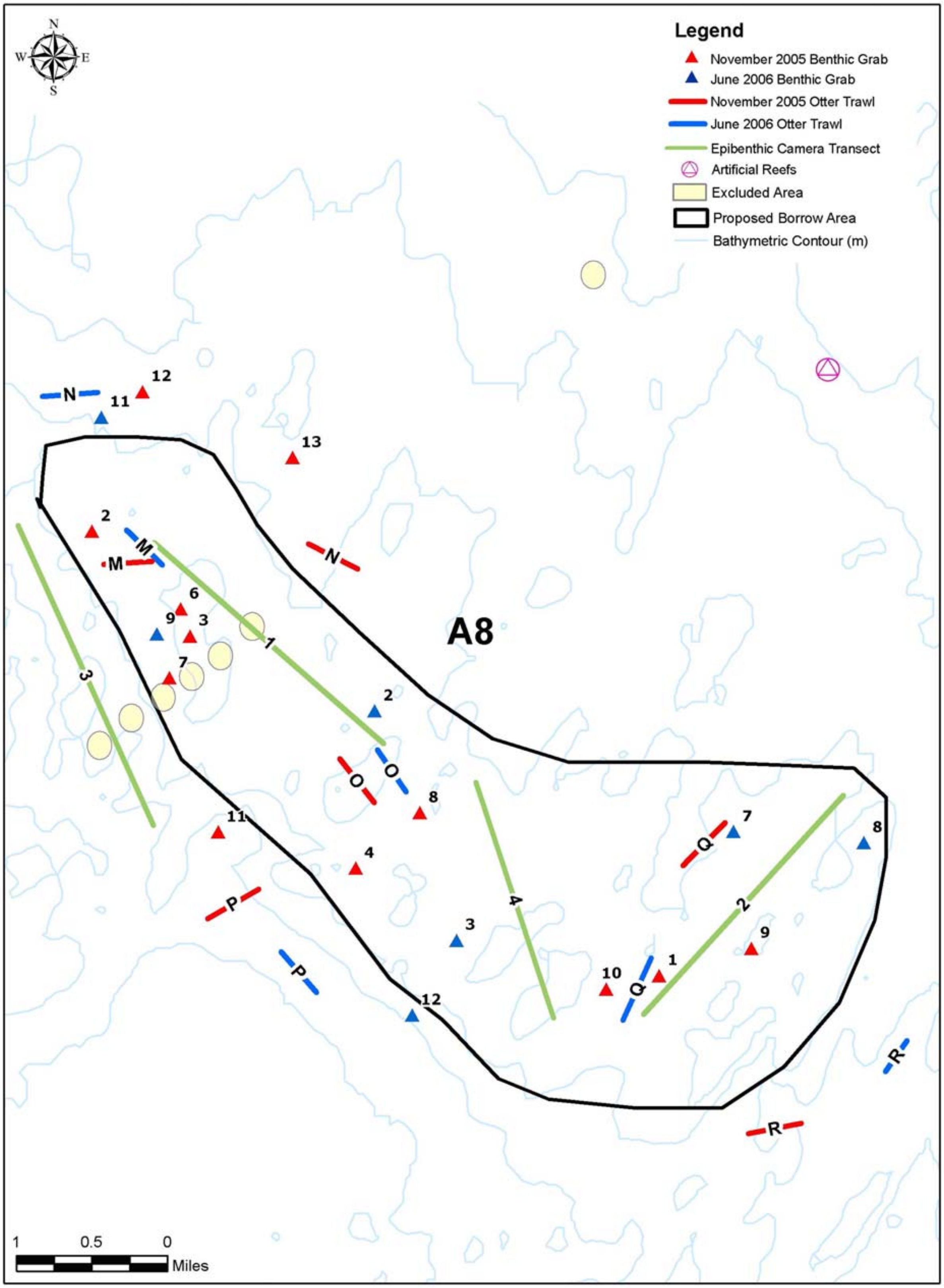


Figure 3-3. Locations of benthic grabs, video transects, and otter trawls at shoal A8.

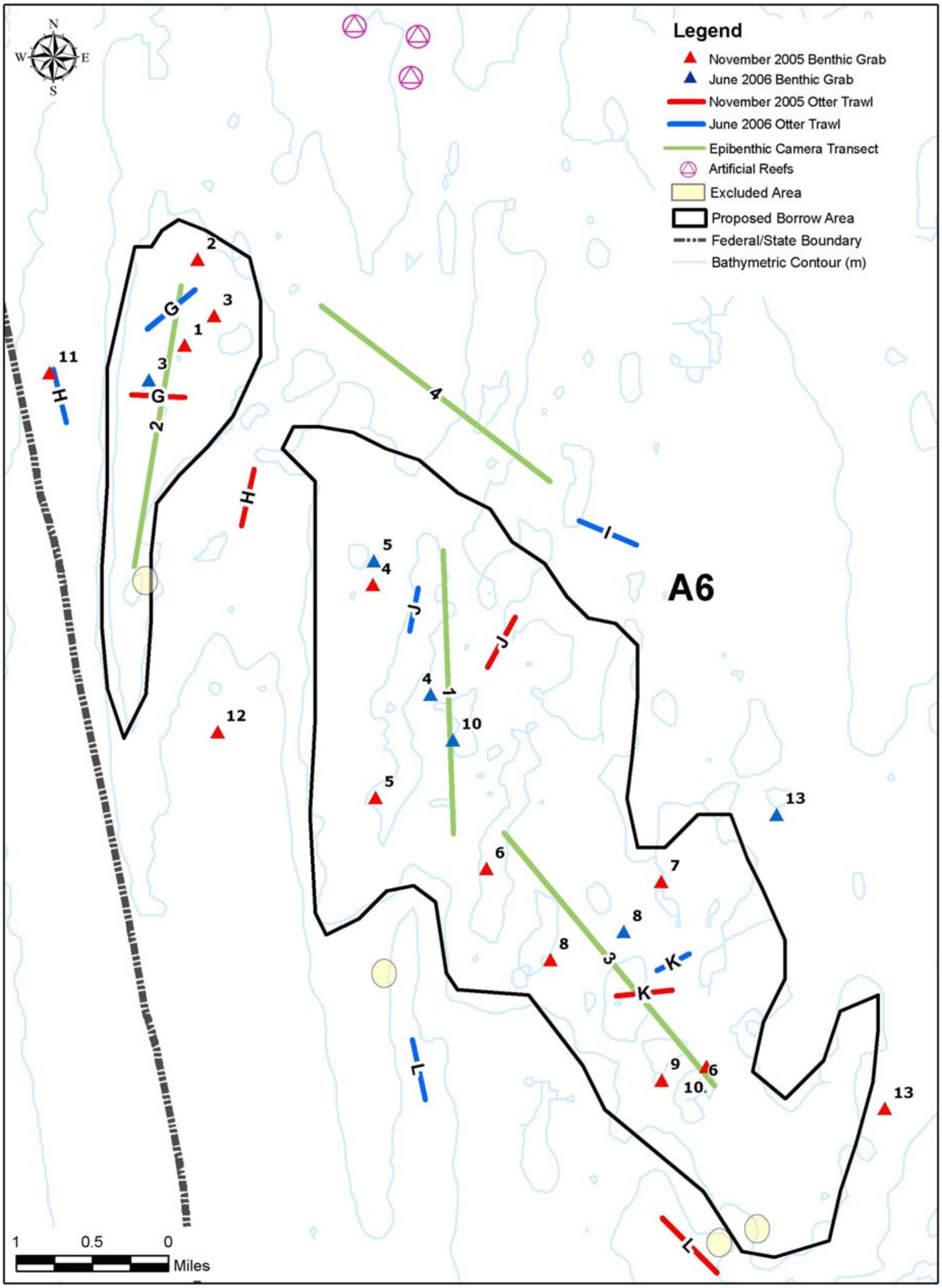


Figure 3-4. Locations of benthic grabs, video transects and otter trawls at shoal A6.

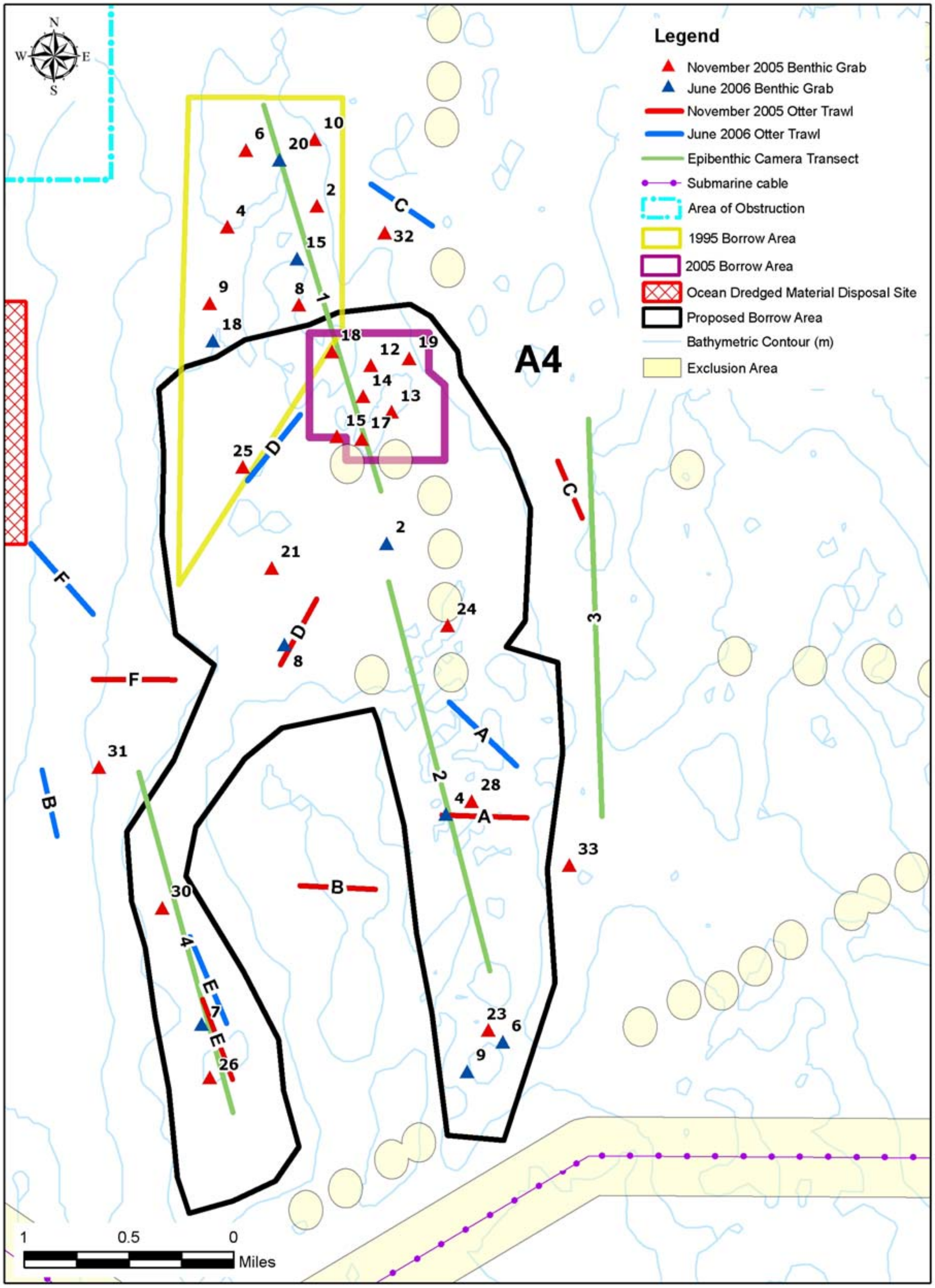


Figure 3-5. Locations of benthic grabs, video transects, and otter trawls at shoal A4.

3.2.2 Sediments

3.2.2.1 Sediment Grab Samples and Laboratory Methods

A subsample was collected from each benthic sediment grab sample taken at a station and prior to processing or sieving for macrofauna. Each subsample was placed into pre-labeled, plastic, self-locking bags with the station number and date. Sediment subsamples were transported to the laboratory for grain-size analysis.

Grain size analysis of sediment samples followed American Standard Testing Materials (ASTM) standard D-422 for mechanical (sieve) particle size analysis of soils. This is the standard accepted by the USACE Jacksonville District and FDEP (ASTMa, 2008).

Each sample was split into two sub-samples if there was an adequate amount of material. One of the two sub-samples was used to perform the various analyses, and the second sub-sample was archived. For bulk fine (silt and clay fraction) and coarse content, the ASTM D1140 (ASTMb, 2008) and the Wentworth procedures of determining percent fine fraction were followed. A sub-sample of approximately 30 g was wet-sieved through a #230 mesh screen (0.074 mm opening) to remove the fine fraction (Wentworth, 1929). The coarse fraction remaining on the #230 screen was dried and mechanically sieved. Any residual fine material passing through the #230 screen was weighed and the weight was added to the fine fraction calculations. The percent fine sediment passing through a #200 sieve was calculated and reported as well.

Grain-size analysis of the sand fraction remaining on the #230 sieve after wet sieving for the fine fraction content was accomplished using mechanical methods described under ASTM D-422. The sieving technique consisted of a set of nested screens that divided sediments into class sizes at 1/2 phi-intervals. Intervals between classes are arithmetic on the phi scale and logarithmic on the millimeter scale. Weight retained on each sieve was used to compute grain-size distribution in terms of weight percent of sample in each size class. Weights were recorded on a Lab Grain Size Data Sheet.

The percent organic content of each sample was determined using ASTM D2974, which is a gravimetric analysis based on loss on ignition (ASTM, 2008c). Sub-samples were air-dried, weighed with a precision electronic balance, and then ignited in a high-temperature oven for approximately eight hours. Data were recorded on a Carbonate-Organic Lab Data Sheet. After cooling, the sample was re-weighed to determine loss of weight. The sample was returned to the oven for carbonate analysis described in the next paragraph. These data were used to compute the approximate amount of organic carbon not contained in the carbonate (shell fraction).

A high-temperature burn method was used to determine the percent calcium carbonate content (shells and shell fragments) of marine sediments. This is a method described in standard texts on sedimentologic analysis and involves igniting a pre-weighed 10-g sample at approximately 1100^0 C for eight hours. During ignition, the carbonate (calcite) crystal lattice is broken, carbon dioxide is released, and only the calcium atoms remain. Thus, the weight percent of carbonate can be easily calculated knowing the atomic weights of the atoms forming the calcite lattice.

3.2.2.2 ICONS Vibracore Processing Method

Section 2 of this report provides a review of the USAC Inner Continental Shelf and Structure Program, or ICONS. Many of the original cores collected in the late 1960s off the northeast Florida coast were never completely analyzed. Scientific Environmental Applications, Inc. (S.E.A.) possesses some of the original ICONS core samples and analyzed 17 cores that were taken near study areas B11, A8, A6, and A4 during the ICONS Program (Figure 3-6). Composite samples from the upper sandy intervals of these cores were processed for textural and compositional properties to help characterize the near-surface lithology of the shoals. The regional lithology and the potential for beach-compatible sand within the shoals were described under Section 2.2.1 of this report. The regional analysis was based on recent efforts to develop beach-quality sand resources within some of the shoals included in this study (Phelps and Holem 2005, USACE 2007, Zarillo 2009).

3.2.2.3 Analytical Methods

The grain-size distribution of samples processed by mechanical sieving was analyzed using the method of moments and according to graphic methods described by Folk (1974). The moments method is similar to the computation of the center of the mass, or moments, of inertia described in any elementary calculus text. The first and second moments provide the arithmetic mean grain-size and variance (standard deviation) in phi units, which are equivalent to the geometric mean and standard deviation in millimeters. Higher moments provide the basis for computing skewness and kurtosis of the grain-size distribution, which are measures of deviation from a normal (Gaussian) grain-size distribution. The median grain-size is determined as the size corresponding to the 50th percentile. The modal grain-size is the size that occurs with highest frequency and can be determined visually from a frequency distribution plot.

Presentation of grain-size analysis for each sample includes a plot of frequency vs. grain size and a plot of cumulative frequency vs. grain size on USACE Engineering Form 2087. The plot includes data on percentages of fines (#200 and #230), carbonate, organics, and classification. All samples were plotted on Form 2087 and are provided in Appendix C.

A table was generated in Excel $^{\text{TM}}$, using gINT$^{\text{TM}}$ 6.0 geotechnical software for each sample mechanically sieved. Reported in the table were sieve size, phi size, mesh size in millimeters, weight of sediment retained (g), cumulative percent retained, and cumulative percent passing.

Textural classification of ICONS cores were logged in accordance with the Unified Soils Classification System, as described in ASTM Standard D-2487 (ASTM, 2008d). The lithology for each core was entered in gINT$^{\text{TM}}$ 6.0 geotechnical software, which posts processes data into USACE Form 1836 (Core log). Core logs are provided in Appendix D1. Thirty-five composite samples or a continuous subsample of 25% along the length of a core was taken from each core. Composite samples taken from the cores were processed for grain-size analysis using the same method as described above for the grab samples and are provided in Appendix D2.

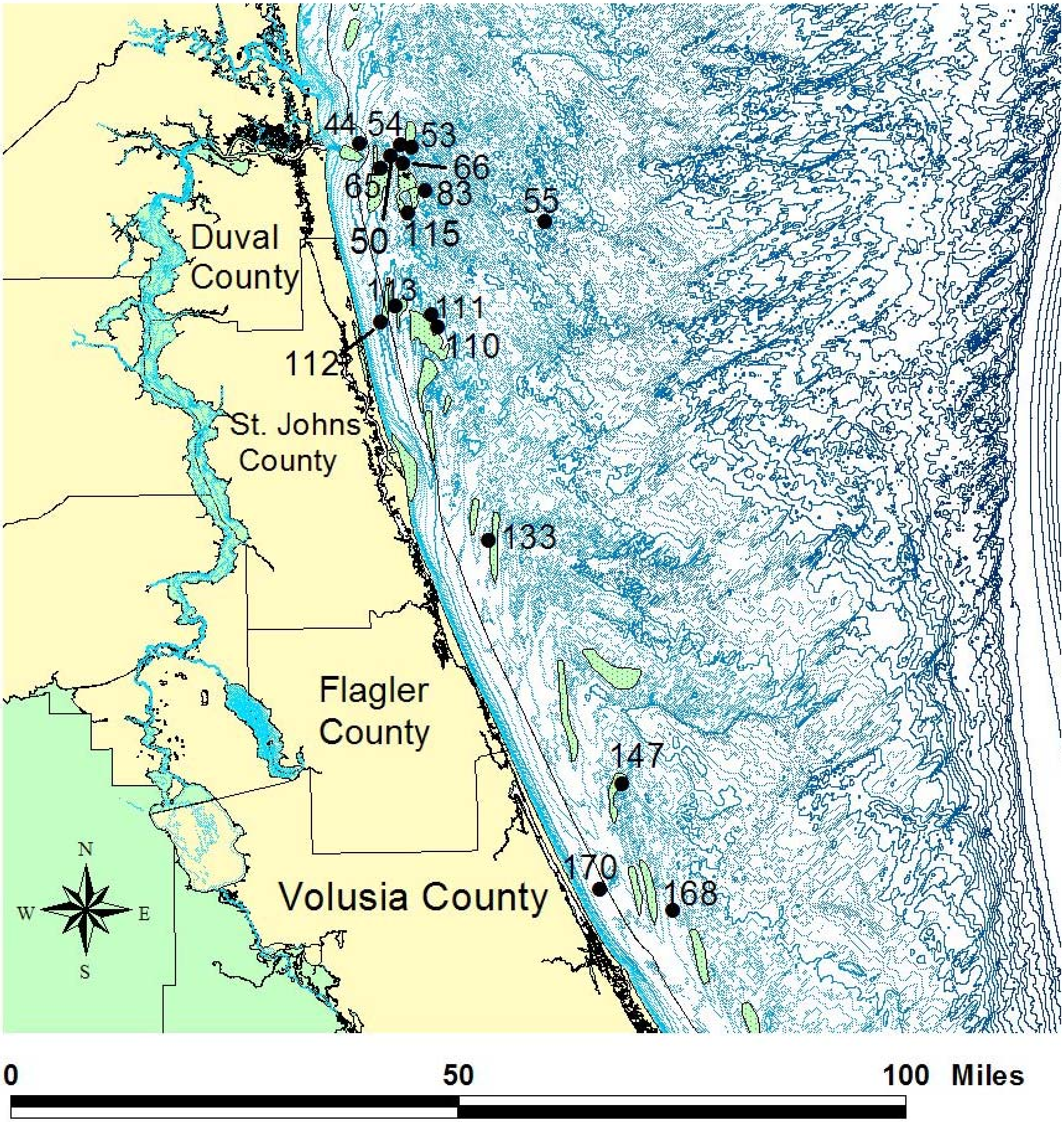


Figure 3-6. Location of the ICONS cores near or on shoals within the NE Florida project area.

3.2.3 Benthos

3.2.3.1 Field Sample Collection

Samples were collected at pre-selected positions. Exact sample station coordinates were recorded. Each Smith McIntyre grab sample was visually inspected to ensure that the sample collected was undisturbed and an adequate volume of sediment was collected. If the grab volume was less than 50%, it was rejected, and another grab was collected. Additionally, disturbed samples (e.g., sediment surface disrupted) were discarded. Photographs were taken on deck of sample retrieval and processing. Selected photographs are provided in Appendix B.

One-hundred-and-sixty-one benthic grabs were taken in the five study areas during the 2005 and 2006 surveys. Seventy-six grabs were taken during the 2005 survey; 13 samples each from areas B11, A9, A8, A6, and 24 samples from area A4, in an attempt to collect samples within an area that had been dredged in 2005. Eighty-five grabs were taken during the 2006 survey; 13 samples each from areas B11, A9, A8, A6, and 33 from area A4.

3.2.3.2 Laboratory Processing

Individual grab samples were handled and processed separately. After subsamples were collected, the remaining sediment collected in the grab was emptied into 5-gallon tubs. The contents were then transferred to a 0.5-mm sieve bucket/tray. The bottom of the sieve bucket/tray was immersed in an approximately 30-gallon trash can filled with ambient seawater, shaken, and swirled to suspend the larger material, allowing fine sands, silts, and clays to pass through the sieve screen. The residual material on the sieve screen was washed into 0.5- or 1-gallon sample jars pre-labeled with permanent ink on the outside and Mylar label on the inside. After sieving, the screen was inspected for any organisms not washed into the sample container. Such organisms were removed with dissecting forceps and placed into the appropriate sample jar. Samples were fixed in a 10% buffered ambient seawater formalin solution. Sodium borate was used as a buffer. A 1% solution of rose Bengal stain was premixed and added to the formalin solution.

Samples were transferred from formalin to 70% ethanol within approximately 2 weeks of collection. Samples were initially sorted from the sediment matrix and identified into four major groups—polychaetes, crustaceans, molluscs, and other/miscellaneous. Organisms were placed into separate vials, which contained 70% ethanol, representing the four groups. Subsequently, all specimens were identified to the lowest practical taxonomic level. All species counts were recorded on Lab Taxonomy Data Sheets.

A reference collection of all macrobenthic species was established. Up to five representative specimens of each taxon were placed in the voucher collection; macrofauna were placed in labeled vials and archived in 70% ethyl alcohol with glycerol. When specimens were removed from the samples for the reference collection, it was noted on the appropriate Lab Data Sheet. Attempts were made to include a variety of size classes for each species.

3.2.3.3 Epifauna Camera Sled

During the first survey in November 2005, an epifauna camera sled was towed on predetermined transects throughout the five study areas. The camera was a Simrad OE Model 9030 Underwater Color TV System with integrated light and DVD recording. The sled was towed at approximately 2–3 knots and approximately 3 ft off the bottom.

A separate DVD recording with a date and time stamp was made of each transect. Although the image does not contain position information, the vessel's position was logged and time-stamped by the GPS receiver and was synchronized with the video time stamp, allowing a relative measure of where the particular image originated.

Four transects were conducted in areas A9, A8, A6, and A4, while three transects were conducted in area B11. The length of camera transects at each study area were as follows: 7,518 m at B11; 10,126 m at A9; 12,626 m at A8; 12,558 m at A6; and 11,883 m at A4. A total of 54,711 m (34 miles) of camera transects were collected. The locations of the epifauna camera transects are shown in Figures 3-1 to 3-5.

Qualitative observations of the transect recordings were made and lists of observed epifauna and fish were compiled. The epifauna camera sled survey was conducted in early November 2005, about two weeks after the passage of Hurricane Wilma across Florida. Visibility in some areas was limited, and a number of video transects were repeated several days after the first attempt, with slightly better results.

3.2.3.4 Statistical Analyses

Summary statistics, including number of taxa, number of individuals, density, diversity (*H'*), evenness (*J'*), and species richness (*D*), were calculated for each sample station. Diversity (*H'*), also known as Shannon's index (Pielou, 1966), was calculated as follows:

$$H' = -\sum_{i=1}^{S} p_i \ln(p_i)$$,

where *S* is the number of taxa in the sample, *i* is the *i*th taxa in the sample, and *Pi* is the number of individuals of the *i*th taxa divided by the total number of individuals in the sample.

Evenness (*J'*) was calculated with Pielou's (1966) index of evenness:

$$J' = \frac{H'}{\ln(S)}$$,

where *H'* is Shannon's index as calculated above and *S* is the total number of taxa in a sample.

Species richness (D) was calculated by Margalef's (1958) index:

$$D = \frac{(S - 1)}{\ln(N)}$$,

where *S* is the total number of sample taxa and N is the number of individuals in the sample.

Spatial and temporal patterns in infaunal assemblages were examined with cluster analysis. Cluster analyses were performed on similarity matrices constructed from raw data matrices consisting of taxa and samples (for each station and survey). Cluster analysis excluded those taxa that were not identified to at least family-level. Of these taxa, only those contributing at least 0.1% of the total abundance were included. Raw counts of each individual infaunal taxon in a sample (n) were transformed with the $\log_{10}$ (n+1) transformation prior to similarity analysis. Both normal (stations) and inverse (taxa) similarity matrices were generated using the Bray-Curtis (1957) index that was calculated using the following formula:

$$B_{jk} = \frac{2\sum_i \min(x_{ij}, x_{ik})}{\sum_i (x_{ij} + x_{ik})}$$

where *Bjk* (for normal analysis) is the similarity between samples *j* and *k*; *xij* and *xik* are the abundances of species, *i* in samples *j* and *k*. *B* ranges from 0.0 when two samples have no species in common to 1.0 when the distribution of individuals among species is identical between samples. For inverse analysis, the *Bjk* is the similarity between species *j* and *k*; *xij* and *xik* are the abundances of species *j* and *k* in sample *i*. Normal and inverse similarity matrices were clustered using the group averaging method of clustering (Boesch, 1973). Multi-dimensional scaling was used to determine the relationship between station sediment parameters (mean grain size, percent fines, and percent carbonate) and station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance.

3.2.4 Fisheries Methods Fishes, Ichthyoplankton, and Fisherman Survey

3.2.4.1 Trawl Collections

Sand shoals off the northeast Florida coast may possess differences in bathymetry, current patterns, and sediment composition from the surrounding uniform bottom habitats, conditions which may support a distinct fish fauna. Therefore, demersal fish and macroinvertebrate communities in the vicinity of the five proposed sand borrow sites (B11, A9, A8, A6, and A4) were characterized on the November 2005 and June 2006 cruises using otter trawls. At each site, three nocturnal trawls were made within the borrow site footprint and three immediately adjacent to each site. The otter trawl had a 7.6-m headrope with 2.5-cm stretched mesh and heavy cod-end chafing gear. A ¼-in, fine mesh liner was sewn inside to enable the capture of small fishes and invertebrates. Tows were made at 2.5 knots for 10 minutes, with precise trawl distances calculated from GPS locations. Dates and coordinates for the starting and stopping points of each trawl are provided in Appendix B. Following net retrieval, the catch of fishes and macroinvertebrates was sorted to the lowest practical identifiable taxon and up to 25 fishes per species were measured to the nearest mm standard length (SL). Individuals that could not be identified on deck were frozen for later species confirmation in the laboratory. Specimens of various demersal fish species were also retained for gut content analyses. Trawl catches were standardized to densities (individuals per hectare [ha]) by dividing captures into area swept during each tow. Area swept (ha) was calculated by multiplying the distance trawled (m) by headrope width (m) and dividing this product by 10,000 m^2/ha.

Spatiotemporal differences in the otter trawl fish and macroinvertebrate species assemblage were explored using non-metric multidimensional scaling (MDS). Densities (individuals per ha) of replicate samples from each site and time combination were averaged and fourth-root transformed, a practice that "downweights" numerically dominant species, thus allowing less abundant taxa to contribute to sample discrimination (Thorne et al., 1999). A sample similarity matrix was then constructed using the Bray-Curtis similarity coefficient (Bray and Curtis, 1957). MDS was then employed to generate a low-dimensional ordination (map) of sample similarities across sites and cruises, where interpoint distances are proportional to overall faunal similarity (Clarke, 1993). Although a small number of juvenile fishes and invertebrates were not identified to species level, they were included in this analysis at genus or family level since ordination with them removed from the dataset yielded comparable results.

3.2.4.2 Feeding Habits

To identify the trophic relationships between the local invertebrate fauna and abundant demersal fish taxa, fish specimens from 11 fish species retained from trawl collections were returned to the laboratory where viscera were removed from up to 10 individuals per taxa from each collection. Species of greatest interest included those with potential recreational or commercial fishery importance, along with the demersal species that dominated catches. All stomachs were then preserved in 70% isopropyl alcohol pending further examination. The first step in processing was to record semi-quantitative assessments of (1) stomach fullness, and (2) state of digestion of prey items:

(1) Fullness Index, where
  0 = empty;
  1 < 1/3 full;
  2 = 1/3–2/3 full;
  3 > 2/3 full; and
  4 = distended, rugae (inner folds of stomach lining) fully flattened; and

(2) Digestion Index, where
  0 = fully digested, unrecognizable;
  1 = only hard parts and major structures recognizable, may be identifiable to group;
  2 = easily identifiable to major group; and
  3 = fully identifiable to species.

Prey items in stomachs were identified to the lowest practical taxon, enumerated, and wet weights were recorded. Because the relative dietary value of different prey is a function of prey size, mass, and abundance, these data were then used to calculate an index of relative importance (IRI) for each prey item (i) for each species examined:

$$IRI_i = O_i * (\%W_i + \%N_i), \text{ where}$$

O_i = frequency of occurrence of prey (i) among all stomachs in the sample;
$\%W_i$ = proportion of weight of prey (i) to the total weight of all prey; and
$\%N_i$ = proportion of numerical abundance of prey (i) to the total numbers of all prey.

3.2.4.3 Plankton Tows

Nocturnal ichthyoplankton tows were conducted to characterize larval fish abundance and community composition in the vicinity of the five proposed sand borrow sites. On each cruise, proposed sampling effort was equally divided among three linear transects positioned between borrow sites, with each transect consisting of three replicate neuston (surface) tows and three sub-surface plankton tows (18 total tows per cruise). However, loss of the net occurred during Cruise 2 and resulted in only one transect (6 tows) at this time. Dates and coordinates for the ichthyoplankton collections are provided in Appendix B.

During Cruise 1, surface samples were taken with a 1 m wide × 0.3 m deep rectangular neuston net towed at 1 m/sec for 10 minutes just below the air–water interface. Sub-surface tows were conducted with a 1-m conical plankton net towed in a stepped oblique fashion, 5 minutes each at 3.0-m and 6.1-m depths. Mesh width for both nets was 500 µm. The protocol for Cruise 2 was identical, except the conical plankton net was used for both surface and sub-surface collections. Water volume filtered during each tow was calculated with a General Oceanics 2030 flow meter. All samples were fixed in 10% buffered formalin in the field and subsequently transferred to 70% ethanol prior to sorting. In the laboratory, fish larvae were removed from samples, identified to the lowest practical taxon under a dissecting microscope, and measured to the nearest mm notocord length for preflexion larvae or standard length for flexion/postflexion larvae. Larval density (individuals per 1000 m^3) was generated from flow-meter data.

3.2.4.4 Fishermen Surveys

In January and February 2007, interviews were conducted at known ports of entry for fishermen off the northeast coast of Florida in Flagler and Volusia counties. Over three days, boat captains, charter fishing guides, and owners of boat supply, bait and tackle stores and dive shops were interviewed to obtain information about fishing practices on and/or near the MMS study sites and their perceptions of dredging impacts to the fishing industry. During interviews, information was gathered to identify the categories of fishermen (commercial or recreational), primary target fish species, target habitat (hardbottom, sand bottom, artificial reef, and/or open water), fishing location on study sites and/or within 5 miles, and fisherman concerns about dredging. A summary of the survey is included in Appendix B (see NE Coast Florida Fisherman Survey Memorandum Report, 2007).

3.2.5 Seabirds, Sea Turtles, and Marine Mammals

Two methods were employed for protected marine species data collection:

1) Visual detection with photographic documentation
2) Acoustic detection with spectral analysis documentation

Two trained visual observers were deployed during daylight hours to document seabirds, sea turtles, and marine mammals. Equipment for visual observations included a Canon S1 digital camera, 8X50 binoculars, notebook, and polarized sunglasses. Visual observations for protected species occurred from sunrise until sunset while sediment sampling was being conducted. During bad weather, observations occurred on the deck. In good weather, observations were conducted above the wheel house to achieve a 360˚ view. Short breaks in observations occurred during passive acoustic monitoring deployment, when only one observer was working.

Observation data was recorded at least every 15 minutes; start and stop times were noted on observer logs–Location and Effort Data (Appendix B). Protected species observations were recorded on a Record of Sighting form (Appendix B). Digital still imagery was collected when possible to document sightings and potentially identify individuals.

Acoustic monitoring occurred on the same days as visual surveys. Hydrophones were deployed during daylight hours. The passive acoustic monitoring system included hydrophones from Cetacean Research, a dynamic signal acquisition system from Sound Technology Corporation, and a mobile computer with several acoustic analysis programs. The hydrophones from Cetacean Research were omnidirectional on a plane with a frequency response of 15 Hz to 250 kHz. The software programs used to analyze the data in real-time were Whistle, from the International Fund for Animal Welfare, and Ishmael, from NOAA.

A digital sound file was compiled for each survey within the spectral analysis program, Ishmael (David Mellinger, NOAA). The program was set to record in a continuous monitoring mode onto the PC hard drive; however, the program was automatically set to trigger recording at specific energy contents or frequencies and to annotate those specific recordings. Recordings were reviewed and saved on a USB mass storage device. Recordings of species or possible species of interest were filed separately. All recordings were time and date stamped. An associated acoustic monitoring form was filled out for each monitoring session. Sessions were assigned unique numbers and formatted Year_Month_Day_00:00 start–00:00 end. GPS locations were taken at the start and finish of any recording session and recorded on the data sheets. Following collection and post processing, all data was recorded in Microsoft Access databases. Acoustic observation sessions recorded on acoustic data sheets are presented in Appendix B.

3.3 Results of Data Analysis from Fall 2005 and Spring 2006 Field Surveys

3.3.1 Water Column

In the fall, bottom water temperatures at B11 were approximately 23°C, with temperatures about a degree cooler at the surface. Dissolved oxygen concentrations were approximately 7 mg/L and were uniform throughout the water column. Salinities were approximately 32 PSU at the surface and 33.5 PSU at the bottom. Chlorophyll fluorescence varied between 2 ug/L and 3.5 ug/L, with no particular pattern associated with depth. In the spring, surface water temperatures were approximately 26.5°C, while bottom temperatures were about 2° cooler. Dissolved oxygen concentrations were approximately 6.5 mg/L and were uniform throughout the water column. Salinities were approximately 36.5 PSU throughout the water column. Chlorophyll fluorescence increased from approximately 1 ug/L at the surface to 1.6 ug/L at the bottom. Table 3.1 shows water quality parameters at the five study sites by each cruise. Figure 3-7 presents a water quality profile for A4 Station 1, taken during November of 2005. All of the water quality profiles taken during the project appear in Appendix B.

Table 3.1. Summary of Water Quality Parameters.

Area	Cruise	Temperature (°C)	DO (mg/L)	Salinity (PSU)	Chlorophyll (ug/L)
B11	Fall	22.0–23.0*	7.0	32.0–33.5*	2.0–3.5
	Spring	24.5*–26.5	6.5	36.5	1.0–1.6*
A9	Fall	22.0–23.0*	7.0	32.5–34.0*	1.6–3.2*
	Spring	23.0*–26.0	6.5-7.0*	36.5	0.8
A8	Fall	23.4	7.0	34–34.5*	1.5–2.5*
	Spring	24.0*–26.0	6.5-6.8*	36.5	0.8
A6	Fall	22.0–22.5*	7.2	30.5–33.5*	1.6–3.5
	Spring	26.5	6.5	36.5	1.4–2.0*
A4	Fall	22.0–23.0*	7.0*-7.5	28.0–34.0*	1.6*–4.0
	Spring	26.0*–26.5	6.5	36.6	1.0–3.0*

*denotes bottom values

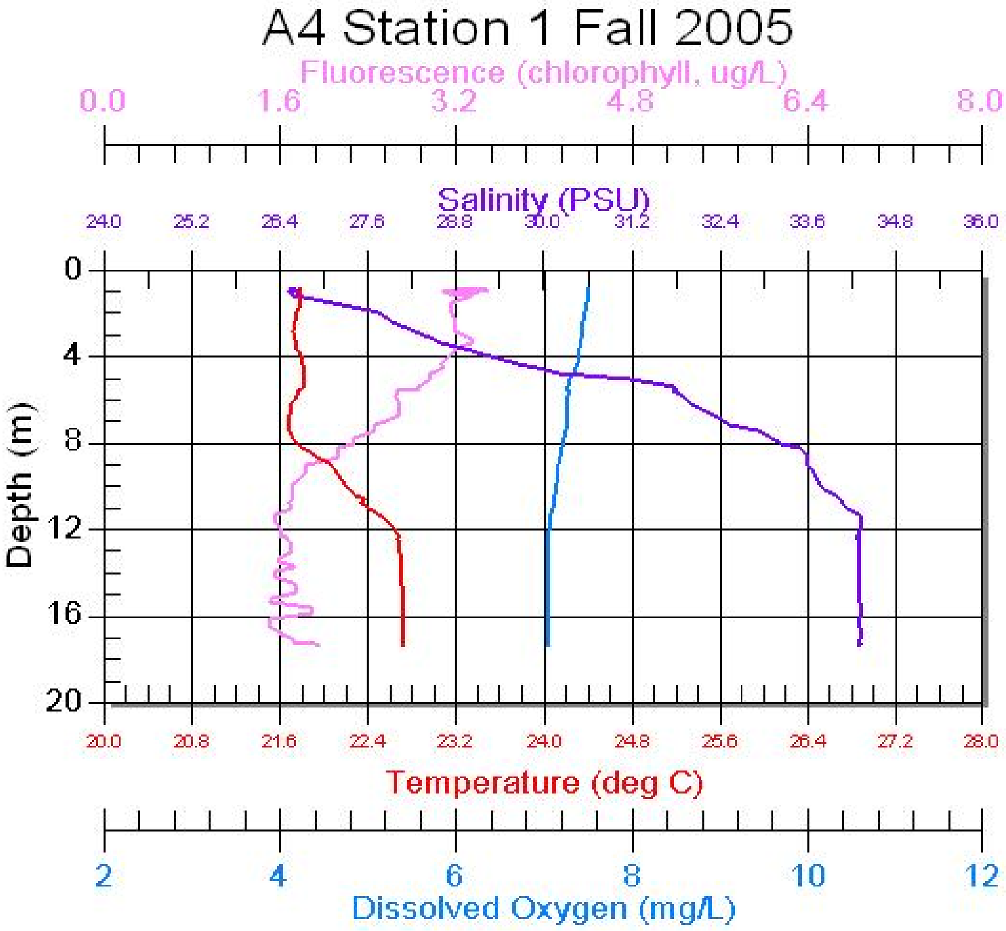


Figure 3-7. Water quality profile for A4 Station 1 taken during November 2005.

Bottom water temperatures at A9 in the fall were approximately 23°C, with temperatures about a degree cooler at the surface. Dissolved oxygen concentrations were approximately 7 mg/L and were uniform throughout the water column. Salinities were approximately 32.5 PSU at the surface and 34 PSU at the bottom. Chlorophyll fluorescence was approximately 1.6 ug/L at the surface, increasing to 3.2 ug/L at the bottom. In the spring, surface water temperatures were approximately 26°C, while bottom temperatures were about 3° cooler. Dissolved oxygen concentrations at the surface were approximately 6.5 mg/L, increasing to about 7 mg/L toward the bottom. Salinities were approximately 36.5 PSU throughout the water column. Chlorophyll fluorescence was about 0.8 ug/L and was uniform throughout the water column.

In the fall, water temperatures at A8 were approximately 23.4°C and were similar throughout the water column. Dissolved oxygen concentrations were approximately 7 mg/L and were uniform throughout the water column. Salinities were approximately 34 PSU at the surface and 34.5 PSU at the bottom. Chlorophyll fluorescence was approximately 1.5 ug/L at the surface, increasing to 2.5 ug/L at the bottom. In the spring, surface water temperatures were approximately 26°C, while bottom temperatures were about 2° cooler. Dissolved oxygen concentrations at the surface were approximately 6.5 mg/L, increasing to about 6.8 mg/L toward the bottom. Salinities were approximately 36.5 PSU throughout the water column. Chlorophyll fluorescence was about 0.8 ug/L and was uniform throughout the water column.

Surface water temperatures at A6 in the fall were approximately 22°C, with temperatures about half a degree warmer at the bottom. Dissolved oxygen concentrations were approximately 7.2 mg/L and were relatively uniform throughout the water column. Salinities were approximately 30.5 PSU at the surface and 33.5 PSU at the bottom. Chlorophyll fluorescence varied between 1.6 ug/L and 3.5 ug/L, with no particular pattern associated with depth. In the spring, water temperatures were approximately 26.5°C throughout the water column. Dissolved oxygen concentrations were approximately 6.5 mg/L and were uniform throughout the water column. Salinities were approximately 36.5 PSU throughout the water column. Chlorophyll fluorescence increased from approximately 1.4 ug/L at the surface to 2 ug/L at the bottom.

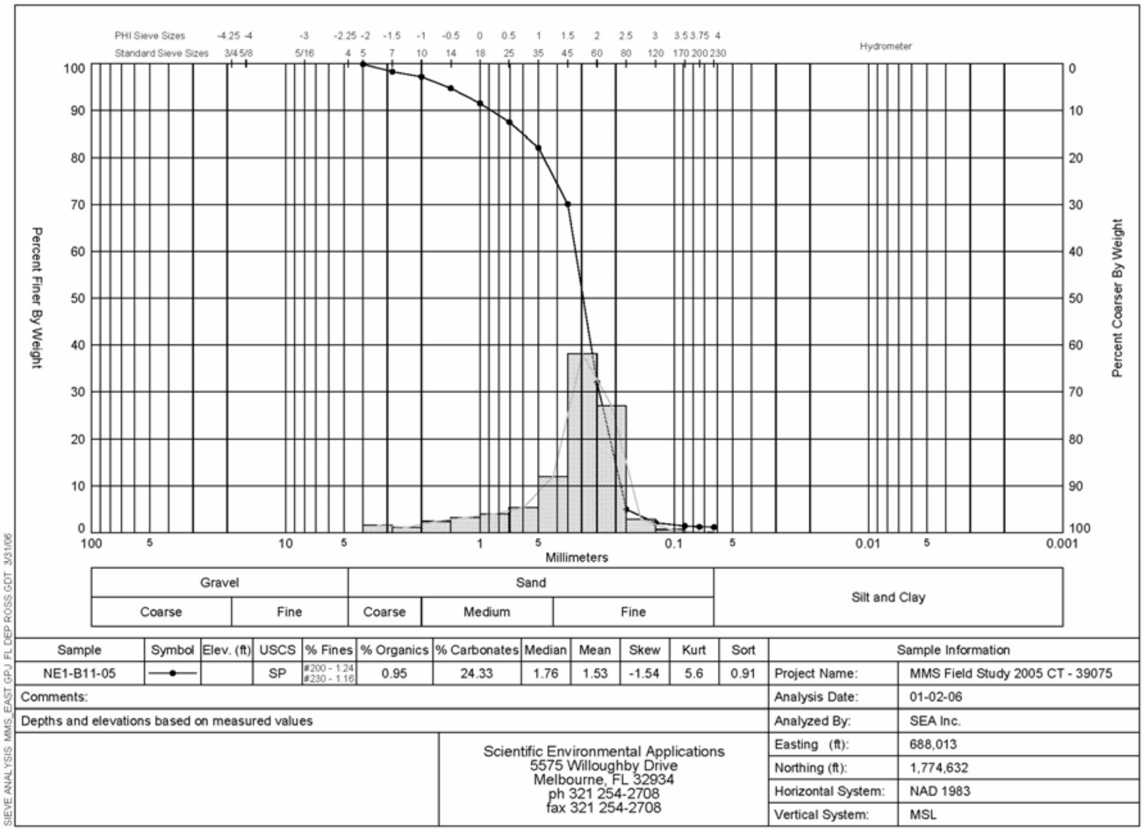
In the fall, surface water temperatures at A4 were approximately 22°C, with temperatures nearly a degree warmer at the bottom. Dissolved oxygen concentrations were approximately 7.5 mg/L at the surface and 7 mg/L at the bottom. Salinities were approximately 28 PSU at the surface and 34 PSU at the bottom. Chlorophyll fluorescence was approximately 4 ug/L at the surface, decreasing to about 1.6 ug/L near the bottom. In the spring, surface water temperatures were approximately 27°C, while bottom temperatures were about half a degree cooler. Dissolved oxygen concentrations were approximately 6.5 mg/L and were uniform throughout the water column. Salinities were approximately 36.6 PSU throughout the water column. Chlorophyll fluorescence increased from approximately 1 ug/L at the surface to about 3 ug/L at the bottom.

3.3.2 Sediments

One hundred and sixty-one (161) sediment grab samples collected during two field events (76 samples in November 2005) and (85 samples in June 2006) were processed for grain-size distribution, percent carbonate, and organic content. Thirty-five (35) samples collected from twenty-two (22) ICONS cores were mechanically sieved for grain-size analysis. Presentation of grain-size analysis for each sediment grab sample is shown in a plot of frequency vs. grain size and a plot of cumulative frequency vs. grain size on USACE engineering Form 2087. The plot includes data on percentages of fines (#200 and #230), carbonate, organics, and classification according to the Unified Soils Classification System (USCS) for each sediment grab sample; and percentages of fines for ICONS composite samples. Tables of grain size data provide the weight percentage by size class and cumulative weight percentage retained on each sieve as the sediment passed through the stack of sieves. Appendix C contains results for sediment grab samples from both events in data sheet and plot formats. ICONS core logs and composite sample results are in Appendix D.

3.3.2.1 Sediment Sample Results from November 2005 and June 2006 Field Events

Seventy-six (76) grab samples were collected in November 2005. Figure 3-8 is an example of a sediment grain-size distribution plot on Form 2087 from the crest of shoal B11. Sample NE1-B11-05 is one of the coarser samples containing a relatively large percentage of carbonate shell fragments in the medium to coarse sand range. Quartz was the primary mineralogy of the fine sand fraction of most samples.



Sample	Symbol	Elev. (ft)	USCS	% Fines	% Organics	% Carbonates	Median	Mean	Skew	Kurt	Sort
NE1-B11-05	—●—		SP	#200 - 1.24 #230 - 1.16	0.95	24.33	1.76	1.53	-1.54	5.6	0.91

Comments:

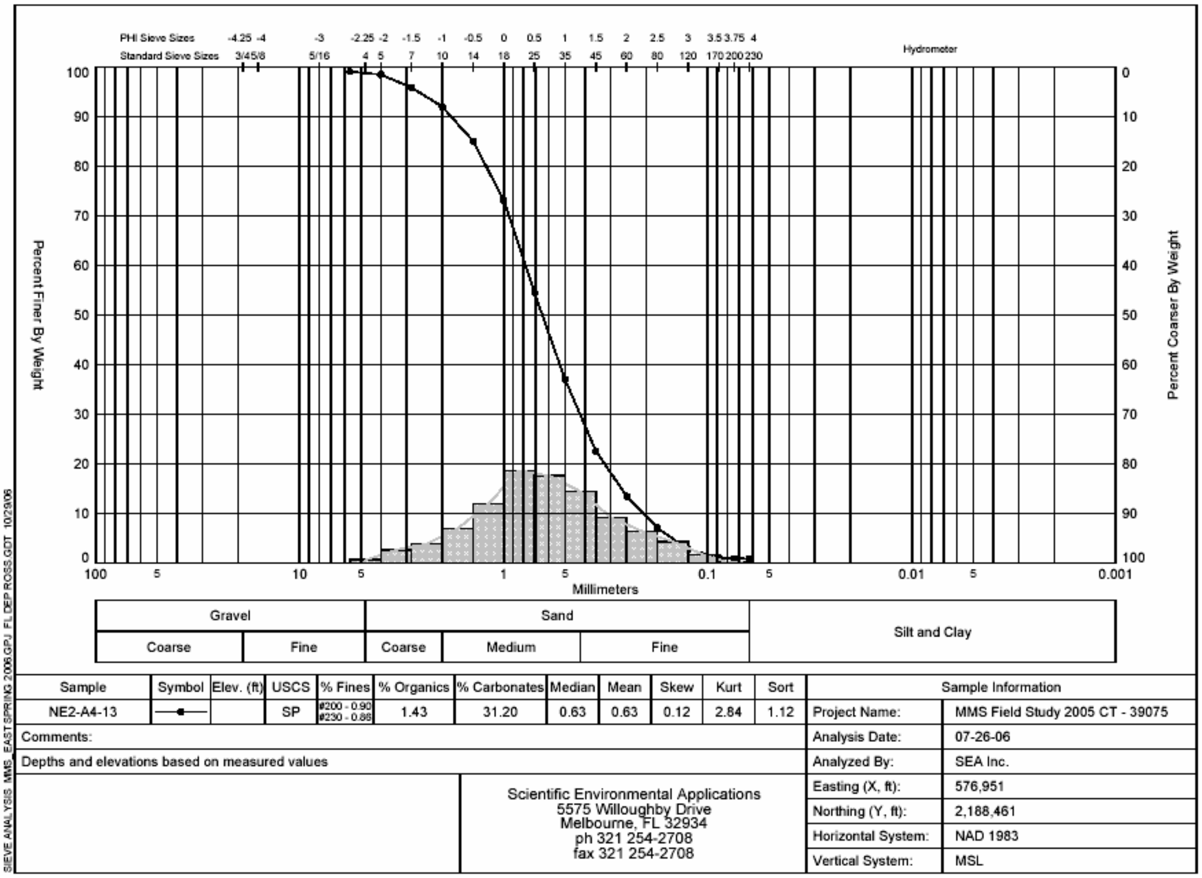
Depths and elevations based on measured values

Scientific Environmental Applications
5575 Willoughby Drive
Melbourne, FL 32934
ph 321 254-2708
fax 321 254-2708

Sample Information	
Project Name:	MMS Field Study 2005 CT - 39075
Analysis Date:	01-02-06
Analyzed By:	SEA Inc.
Easting (ft):	688,013
Northing (ft):	1,774,632
Horizontal System:	NAD 1983
Vertical System:	MSL

Figure 3-8. Grain size frequency distribution of sample NE1-B11-05 from the crest of the B11 shoal offshore of Volusia County (see Appendix C for sample details).

In June 2006, 85 samples were collected and processed for grain-size analysis, percent carbonate, and organic content. Figure 3-9 is an example of a sediment grain-size distribution plot on Form 2087 for sample NE2-A4-13 from the crest of the A4 shoal. Sample NE2-A4-13 is one of the coarser samples containing more than 30% carbonate in the form of coarse shell fragments. Quartz was the dominant mineralogy of the fine sand fraction. In addition to being coarse, surficial samples from the crest of most shoal features have more broadly distributed textures due to the higher percentages of carbonate. It is likely that topographically higher areas of the shoals are more frequently reworked by storm-generated waves and current leaving a coarse carbonate lag material.



Sample	Symbol	Elev. (ft)	USCS	% Fines	% Organics	% Carbonates	Median	Mean	Skew	Kurt	Sort
NE2-A4-13	—●—		SP	#200 - 0.90 #230 - 0.86	1.43	31.20	0.63	0.63	0.12	2.84	1.12

Comments:

Depths and elevations based on measured values

Scientific Environmental Applications
5575 Willoughby Drive
Melbourne, FL 32934
ph 321 254-2708
fax 321 254-2708

Sample Information	
Project Name:	MMS Field Study 2005 CT - 39075
Analysis Date:	07-26-06
Analyzed By:	SEA Inc.
Easting (X, ft):	576,951
Northing (Y, ft):	2,188,461
Horizontal System:	NAD 1983
Vertical System:	MSL

Figure 3-9. Grain size frequency distribution of sample NE2-A4-13 from the crest of the A4 shoal offshore of Duval County, FL (see Appendix C for sample details).

Table 3.2 summarizes the major textural and compositional features of samples collected from the five study shoals during the two field events. Percent fines ranged from 0% to slightly greater than 19%. Organic content ranged from 0.2% to 4.2%. Calcium carbonate content of samples in the form of shell fragments and scattered whole shells ranged from 3.8% to 43.6%. Based on sample textural properties and the percent fine material (silts and clays), most samples were classified using the USCS designation SP, indicating that the samples consisted primarily of sandy textures. Few samples had 11% or more of fine material passing the #200 sieve (finer that 74 microns). For example, a sample from the lower flank of shoal A6 was classified under USCS with the SM designation, indicating a sandy textural composition, but a fine fraction exceeding 11% by weight. The coarsest textures were found in samples having either high calcium carbonate content or samples collected from the higher elevations of the shoals. Samples having the highest carbonate content were retrieved from the top of the B11 and A8 shoals offshore of Volusia County. In addition to high percentages of carbonate, these samples and samples from similar topographic settings were the coarsest in terms of mean and median grain size. Samples with high carbonate content had median and mean grain sizes generally exceeding 0.25 mm and up to a maximum of 0.50 mm. Samples obtained from topographically lower positions on the flanks of the shoal, completely off the shoal structure, or containing lower percentages of carbonate (shells and shell fragments) had average grain sizes less than 0.25 mm. Overall, the textures and compositions found in the surficial grab samples were consistent with geologic models of continental shelf sedimentary environments that have been strongly influenced by the Holocene sea level transgression and characterized by linear sand bodies in (Swift et al. 1972, Stubblefield et al. 1984, Snedden et al. 1999).

Table 3.2. November 2005 and June 2006 Summary Grab Sample Sediment Textures

Shoal	Mean grain size range (mm)	Percent fines	Percent Carbonate	Percent Organic
A4–A6	0.13–0.65	0–19.4	3.8–31.2	0.3–2.2
A8–A9	0.21–0.53	0–2.8	4.4–42.8	0.2–1.8
B11	0.16–0.55	0–8.0	5.0–43.6	0.4–4.2

Similar textures of surface sediments were found on each shoal during both field sessions. For instance, Figure 3-10 compares the mean grain size of samples obtained from shoal A9 between the fall of 2005 and spring of 2006. The spatial density of the samples was not great enough to generate a meaningful contour plot for comparison. However, over the crest of the shoal sample, results indicated a similar pattern of average sediment size that was within the fine sand range of 0.08–0.43 mm according to the USCS. According to the Wentworth Classification System, which differs in the boundaries assigned to fine and medium sand, the range of mean grain size included both fine and medium sand, which had an upper boundary of 0.50 mm. Seasonal variations in the texture of surficial sands of the shoals is likely to be dependent on the occurrence of storms that include long-period waves and wind-driven currents that have the ability to mobilize sediment at depths of 35–50 ft.

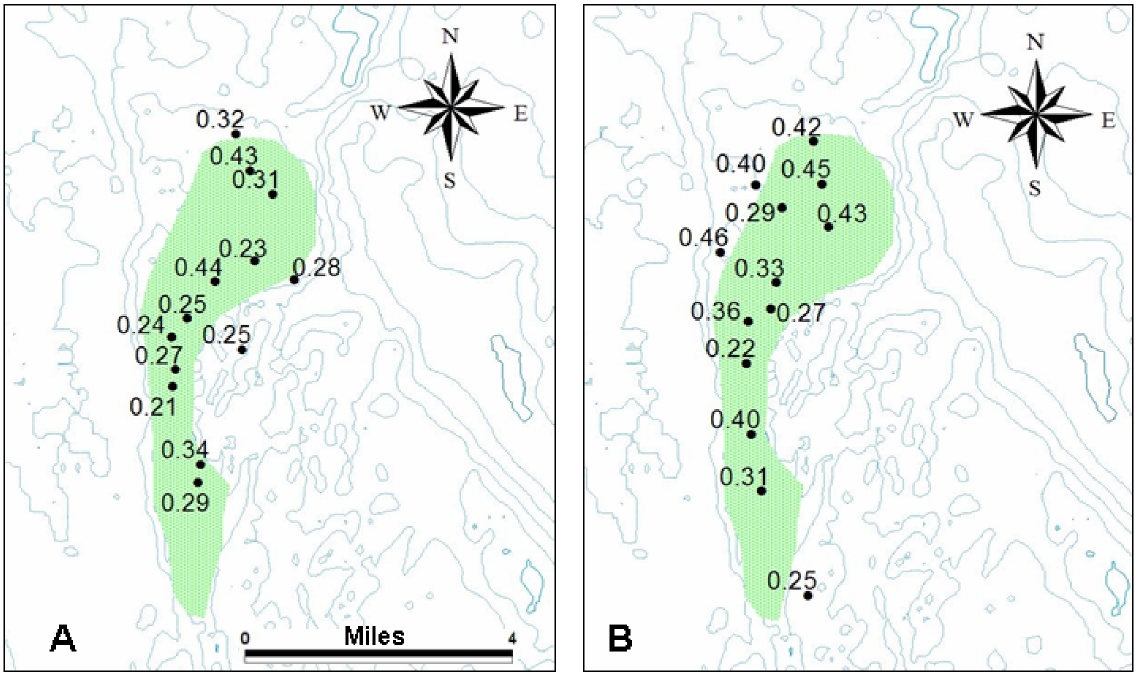
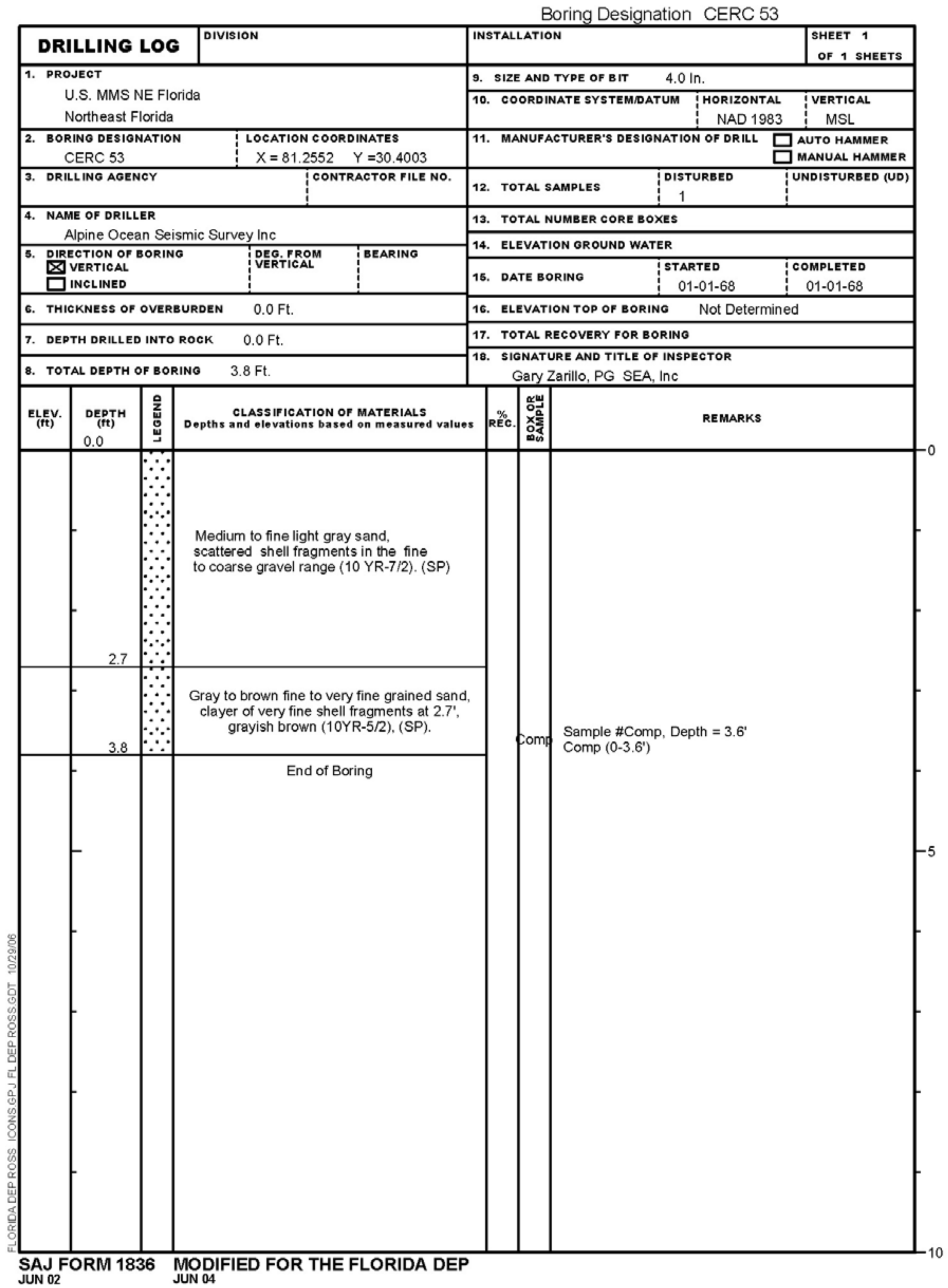


Figure 3-10. Comparison of mean grain size in mm of surficial sand samples collected during the Fall 2005 field event (A), and during the Spring 2006 field event (B).

3.3.2.2 ICONS Cores and Sample Analysis

Section 2 of this report provides a review of the USACE ICONS Program. From S.E.A.'s in-house collection of ICONS cores (100+) collected offshore of northeastern Florida (Figure 3-6), 22 were processed in more detail for comparison with the surficial grab samples described.

Most of the ICONS cores were clustered in the vicinity of shoal features, but some were located in the topographically lower swale areas adjacent to the shoals. Core CERC-53, located on the crest of a shoal to the north of A4, has a minimum of 4 ft of clean sand (Figure 3-11). Conversely, Core CERC-111, located on the lower flank of A6, includes only about 1.4 ft of clean sand overlying lower units of silts and clays. Similar patterns of lithology can be found in cores located to the south in the vicinity of shoals B11, A9, and A8. Core CERC 147, from the crest of shoal A9, contains at least 11 ft of clean sand above lower units of silty sand and clay (see Figure 2-17). Core CERC-168, to the east of shoal B11 (Figure 3-12), contains less than 3 ft of sand over a layer of fine silty sand containing a fine fraction of more than 11%.



Boring Designation CERC 53

DRILLING LOG | DIVISION | INSTALLATION | SHEET 1 OF 1 SHEETS

1. PROJECT
U.S. MMS NE Florida
Northeast Florida

2. BORING DESIGNATION: CERC 53
LOCATION COORDINATES: X = 81.2552 Y =30.4003

3. DRILLING AGENCY
CONTRACTOR FILE NO.

4. NAME OF DRILLER
Alpine Ocean Seismic Survey Inc

5. DIRECTION OF BORING
☒ VERTICAL
☐ INCLINED
DEG. FROM VERTICAL
BEARING

6. THICKNESS OF OVERBURDEN 0.0 Ft.

7. DEPTH DRILLED INTO ROCK 0.0 Ft.

8. TOTAL DEPTH OF BORING 3.8 Ft.

9. SIZE AND TYPE OF BIT 4.0 In.

10. COORDINATE SYSTEM/DATUM
HORIZONTAL: NAD 1983
VERTICAL: MSL

11. MANUFACTURER'S DESIGNATION OF DRILL
☐ AUTO HAMMER
☐ MANUAL HAMMER

12. TOTAL SAMPLES
DISTURBED: 1
UNDISTURBED (UD)

13. TOTAL NUMBER CORE BOXES

14. ELEVATION GROUND WATER

15. DATE BORING
STARTED: 01-01-68
COMPLETED: 01-01-68

16. ELEVATION TOP OF BORING Not Determined

17. TOTAL RECOVERY FOR BORING

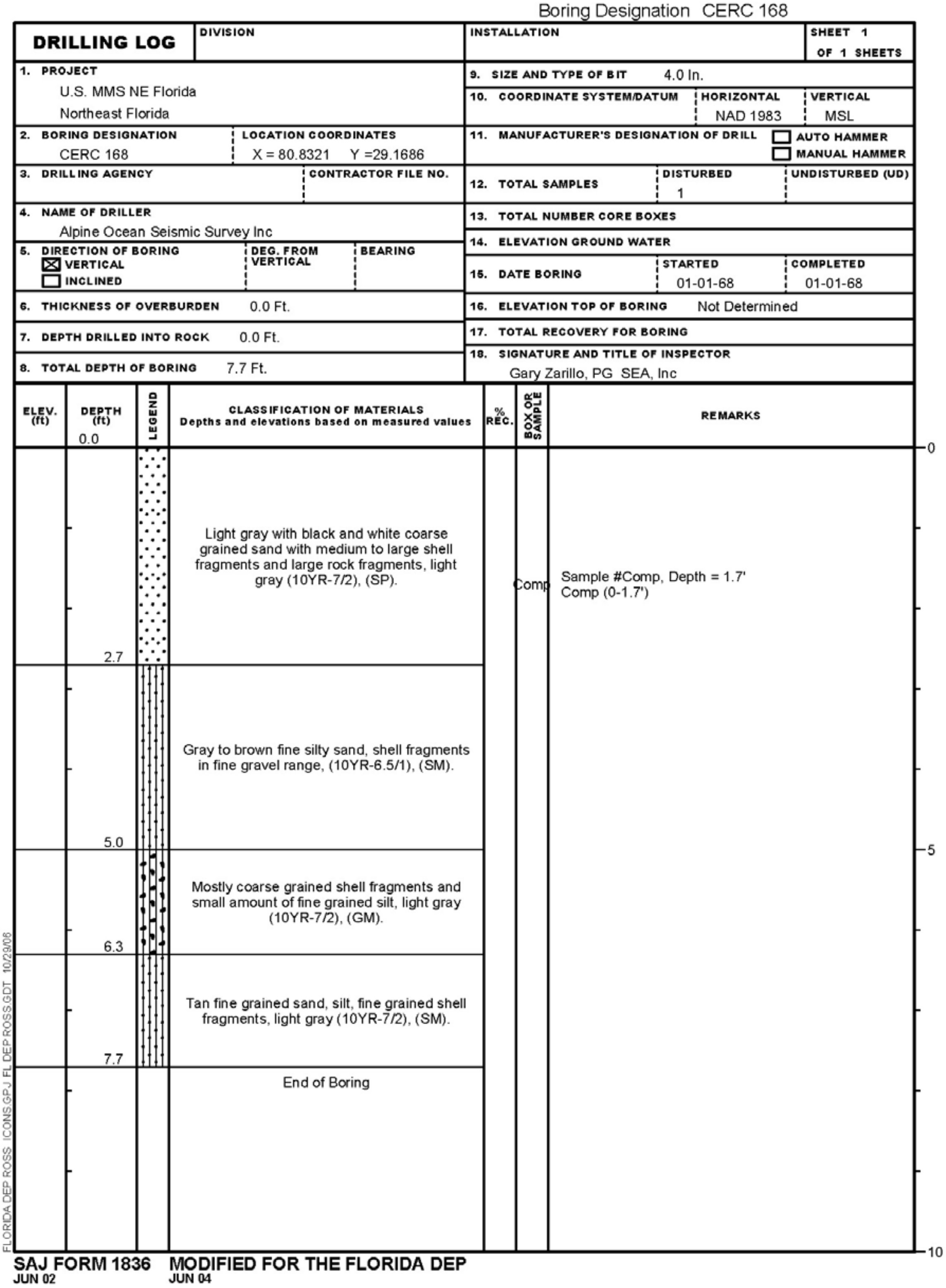
18. SIGNATURE AND TITLE OF INSPECTOR
Gary Zarillo, PG SEA, Inc

ELEV. (ft)	DEPTH (ft)	LEGEND	CLASSIFICATION OF MATERIALS Depths and elevations based on measured values	% REC.	BOX OR SAMPLE	REMARKS
	0.0					
	2.7		Medium to fine light gray sand, scattered shell fragments in the fine to coarse gravel range (10 YR-7/2). (SP)			
	3.8		Gray to brown fine to very fine grained sand, clayer of very fine shell fragments at 2.7', grayish brown (10YR-5/2). (SP).		Comp	Sample #Comp, Depth = 3.6' Comp (0-3.6')
			End of Boring			

FLORIDA DEP ROSS ICONS.GPJ FL DEP ROSS.GDT 10/29/06

SAJ FORM 1836 JUN 02 MODIFIED FOR THE FLORIDA DEP JUN 04

Figure 3-11. Lithology of ICONS Core CERC-53 from the crest of a shoal to the north of A4 (see Figure 3-6 for location).



Boring Designation CERC 168

DRILLING LOG | DIVISION | INSTALLATION | SHEET 1 OF 1 SHEETS

1. PROJECT
U.S. MMS NE Florida
Northeast Florida

2. BORING DESIGNATION: CERC 168
LOCATION COORDINATES: X = 80.8321 Y =29.1686

3. DRILLING AGENCY
CONTRACTOR FILE NO.

4. NAME OF DRILLER: Alpine Ocean Seismic Survey Inc

5. DIRECTION OF BORING: ☒ VERTICAL ☐ INCLINED
DEG. FROM VERTICAL
BEARING

6. THICKNESS OF OVERBURDEN: 0.0 Ft.

7. DEPTH DRILLED INTO ROCK: 0.0 Ft.

8. TOTAL DEPTH OF BORING: 7.7 Ft.

9. SIZE AND TYPE OF BIT: 4.0 In.

10. COORDINATE SYSTEM/DATUM: HORIZONTAL: NAD 1983; VERTICAL: MSL

11. MANUFACTURER'S DESIGNATION OF DRILL: ☐ AUTO HAMMER ☐ MANUAL HAMMER

12. TOTAL SAMPLES: DISTURBED: 1; UNDISTURBED (UD):

13. TOTAL NUMBER CORE BOXES

14. ELEVATION GROUND WATER

15. DATE BORING: STARTED: 01-01-68; COMPLETED: 01-01-68

16. ELEVATION TOP OF BORING: Not Determined

17. TOTAL RECOVERY FOR BORING

18. SIGNATURE AND TITLE OF INSPECTOR: Gary Zarillo, PG SEA, Inc

ELEV. (ft)	DEPTH (ft)	LEGEND	CLASSIFICATION OF MATERIALS Depths and elevations based on measured values	% REC.	BOX OR SAMPLE	REMARKS
	0.0					
	2.7		Light gray with black and white coarse grained sand with medium to large shell fragments and large rock fragments, light gray (10YR-7/2), (SP).		Comp	Sample #Comp, Depth = 1.7' Comp (0-1.7')
	5.0		Gray to brown fine silty sand, shell fragments in fine gravel range, (10YR-6.5/1), (SM).			
	6.3		Mostly coarse grained shell fragments and small amount of fine grained silt, light gray (10YR-7/2), (GM).			
	7.7		Tan fine grained sand, silt, fine grained shell fragments, light gray (10YR-7/2), (SM).			
			End of Boring			

SAJ FORM 1836 JUN 02 MODIFIED FOR THE FLORIDA DEP JUN 04

Figure 3-12. Lithology of ICONS core CERC-168, east of shoal B11 (see Figure 3-6 for location).

Table 3.3 lists the mean and median grain size of samples processed from the ICONS cores along with the percent fines. A complete listing of core lithology and sample texture is provided in Appendix D. The review of the ICONS cores is in agreement with the conclusions of most published findings that the crest areas of discrete and composite shoal features of the inner northeast Florida shelf are constructed of clean, relatively coarse sand, where as the lithology of the lower flanks of the shoals consists of finer grain sand containing higher percentages of the silts and clays.

Table 3.3. Summary of ICONS Core Composite Sample Textures

Sample ID	Fine %	Mean mm	Med mm	St. Dev.	Skew.	Kurt.
CERC 44	33.15	0.29	0.11	1.52	-0.52	2.16
CERC 50	2.52	0.27	0.22	1.03	-1.05	4.10
CERC 53	1.93	0.20	0.17	0.74	-1.85	8.63
CERC 54	1.89	0.32	0.30	0.93	-0.36	3.13
CERC 55	6.75	0.22	0.19	0.74	-1.39	6.32
CERC 65	1.46	0.39	0.32	1.26	-0.44	2.53
CERC 66	6.81	0.27	0.19	1.03	-0.62	3.39
CERC 83	1.18	0.21	0.19	0.76	-1.32	6.12
CERC 110	0.88	0.60	0.50	1.14	0.28	2.29
CERC 112	7.12	0.21	0.19	0.64	-2.36	14.36
CERC 113	10.10	0.17	0.15	0.71	-2.18	9.91
CERC 115	4.22	0.73	0.58	1.09	0.70	3.46
CERC 133	0.41	0.24	0.22	0.79	-1.84	8.09
CERC 147	1.94	0.42	0.33	0.95	-0.88	3.58
CERC 168	7.57	0.44	0.33	0.78	-0.19	4.36
CERC 170	8.02	0.20	0.17	0.83	-2.16	9.36
CERC 111	2.96	0.26	0.19	1.09	-1.22	4.25

Figure 3-13 shows the position of the 17 cores from the ICONS study along with the mean grain size of a composite sample of the uppermost sand unit in each core. Most of the cores were located on the crest of a shoal or on the higher elevations of a flank of a shoal. The top elevation of most cores is -50 MSL or less. Two cores, CERC 170 and CERC 112 (Figure 3-6) were not associated with a distinct shoal and were located in Florida state water to the west of the three-nautical-mile federal boundary. The composite mean of samples at or near the crest of a shoal was 0.25 mm or larger. Mean grain size of composite samples not directly associated with a shoal were generally less than 0.25 mm with the exception of the composite from Core CERC 168. The composite sample mean of this core (0.44 mm) was due to a high content of large shell fragments and rock fragments, as shown in Figure 3-12.

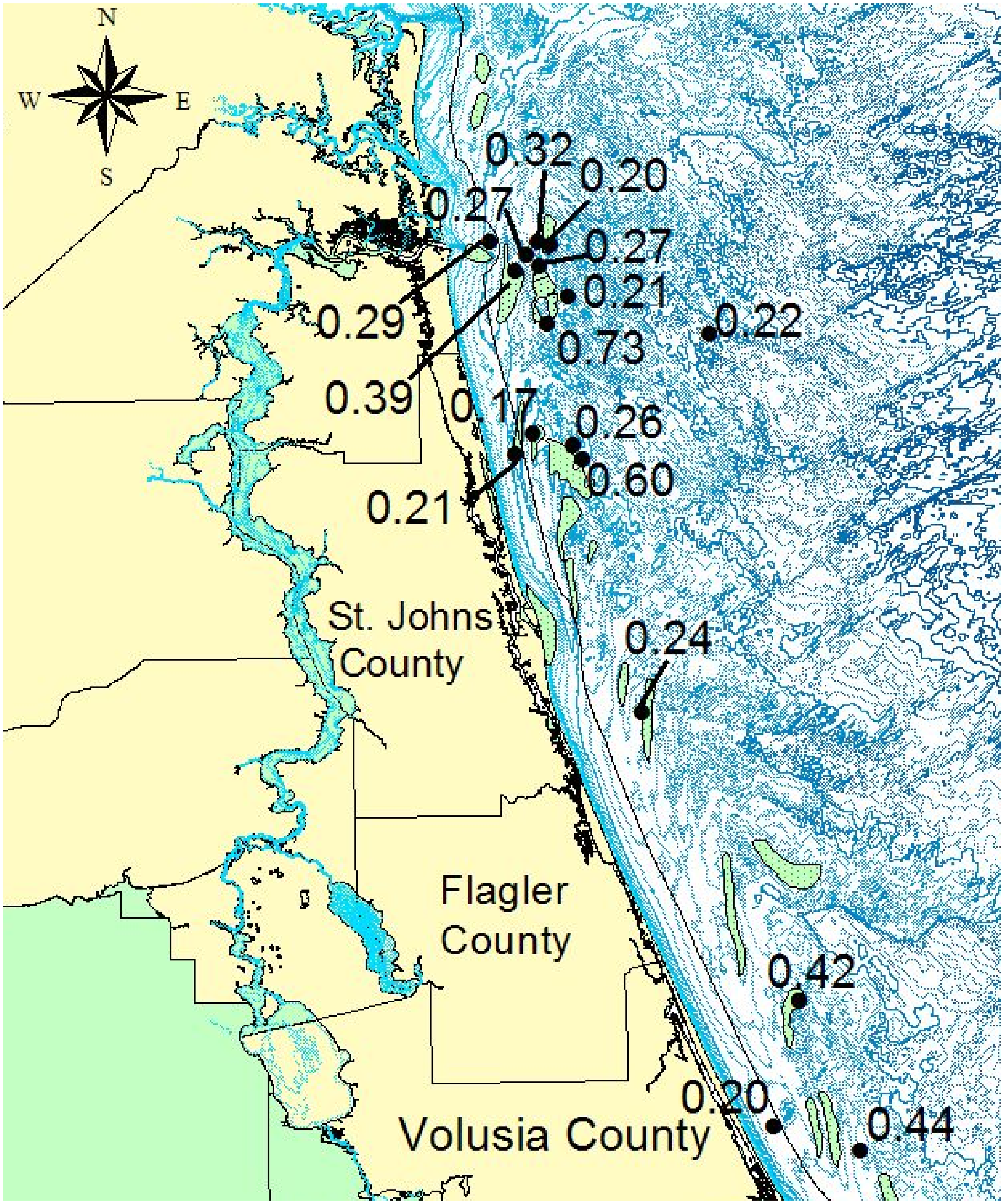


Figure 3-13. Mean grain size in mm of the upper sand units in selected ICONS cores from the project area. Core numbers are shown in Figure 3-6.

3.3.3 Benthos

A taxonomic listing of infauna collected in bottom grabs during the November 2005 and June 2006 surveys is presented in Appendix B. Over both surveys, 25,751 individuals were collected, representing 379 taxa in 12 separate phyla. Most taxa collected were polychaetes (155 taxa) followed by crustaceans

(118 taxa) and bivalve (40 taxa) and gastropod (39 taxa) molluscs. Overall abundance was markedly dissimilar across surveys. Grab samples yielded an average of 139.8 individuals per grab in November 2005 and 387.9 in June 2006. A total of 198 taxa (52.2% of total) were common to both surveys. There were 90 taxa restricted to the June survey, while the November survey included 90 taxa not found in June samples. The passage of Hurricane Wilma across Florida in late October 2005 may be partly responsible for the lower abundance and number of taxa in the November 2005 survey.

Polychaetes of the genus *Prionospio* were numerically dominant in the grabs, representing 7.2% of all infauna censused over both surveys. Due to the difficulty in confidently identifying all individuals of *Prionospio* to species (i.e., *Pr. fallax, P. cristata, P. steenstrupi*) because a large number of individuals were in early settlement stages and damaged, we aggregated all *Prionospio* individuals into *Prionospio* spp. Other taxa that were among the top 10 numerical dominants during both the November and June surveys included the amphipods *Protohaustorius wigleyi* and *Metharpinia floridana*, the hemichordate *Branchiostoma floridae*, the polychaetes *Apoprionospio pygmaea* and *Goniadides carolinae*, and bivalves of the family Tellinidae.

Table 3.4 lists the numerically dominant infaunal taxa sampled from each of the shoals and overall for the both surveys. The numerically dominant taxa collected during the November 2005 survey were *Metharpinia floridana* (6.3% of all individuals collected), the hemichordate *Branchiostoma floridae* (5.4%), bivalves of the family Tellinidae (4.9%), the amphipod *Protohaustorius wigleyi* (3.5%), the bivalve *Strigilla mirabilis* (3.3%), and the polychaetes *Paraonis pygoenigmatica* (2.6%), *Goniadides carolinae* (2.5%), *Glycera* sp. (2.3%), *Magelona pettiboneae* (2.3%), and *Apoprionospio pygmaea* (2.2%). These taxa comprised 35.5% of infaunal individuals collected in November.

The numerically dominant taxa sampled during the June 2006 survey included polychaetes of the genus *Prionospio* (11.5% of all individuals collected), the amphipod *Metharpinia floridana* (6.6%), polychaete *Apoprionospio pygmaea* (5.3%), amphipod *Protohaustorius wigleyi* (5.2%), bivalves of the family Tellinidae (LPIL) (4.3%), the polychaetes *Spiophanes bombyx* (3.3%) and *Mediomastus californiensis* (2.4%), the tanaid *Tanaissus psammophilus* (2.3%), the hemichordate *Branchiostoma floridae* (1.6%), and the polychaete *Goniadides carolinae* (1.6%). Together, these taxa comprised 44.1% of infaunal individuals collected in June.

Table 3.5 presents summary statistics for each of the five shoals in the study area for the November 2005 and June 2006 surveys. Values are provided for number of taxa, number of individuals, species diversity, evenness, and richness.

The highest mean numbers of infaunal taxa per station during the study occurred at shoals A8 (82.4 taxa), A6 (63.6 taxa), and A9 (62.3 taxa) during the June 2006 survey. Shoal B11 yielded the lowest mean number of taxa per station in both the November and June surveys (29.8 and 42.0, respectively). Highest infaunal abundances during the study were at shoal A8 (station average = 523.1 individuals), A4 (station average = 408.3 individuals), and A9 (station average = 386.9 individuals) during the June survey. Lowest mean abundances during the study occurred in the November survey at shoals B11 (station average = 115.8 individuals) and A4 (station average = 92.5 individuals).

Mean values of species diversity and evenness were similar for November and June ($p>0.05$). Mean values of richness ($F=0.46$, $p<0.01$) were greater in June than November. During November, the highest mean values of species diversity and richness were found at shoal A8 (3.21 and 8.49, respectively). Shoal

B11 had the lowest values of species diversity and richness in November (2.74, and 6.07, respectively). Evenness was very similar across all five shoals in November (ranging from 0.83 to 0.86). During June, the highest mean values of species diversity and richness were at shoal A8 (3.58 and 13.14, respectively). The highest mean values of evenness in June were at shoals A6 and A8 (0.84 and 0.81, respectively). The lowest mean values of diversity, evenness, and richness in June were at shoal B11 (2.65, 0.72, and 7.41 respectively).

Table 3.4. Ten most abundant taxa in grab samples from the study shoals B11, A9, A8, A6, and A4 for the November 2005 and June 2006 surveys off the coast of Northeast Florida.

Area	November 2005 Survey		June 2006 Survey	
	Taxonomic Name	Abundance*	Taxonomic Name	Abundance*
B11	*Protohaustorius wiglei*	12.6	*Protohaustorius wigleyi*	41.1
	Strigilla mirabilis	11.7	*Mediomastus californiensis*	25.7
	Metharpinia floridana	8.5	*Metharpinia floridana*	17.8
	Tellinidae (LPIL)	6.9	*Prionospio* spp.	17.0
	Acanthohaustorius intermedius	5.8	*Goniadides carolinae*	15.6
	Nemertea (LPIL)	3.2	*Euclymene* sp. A	12.7
	Eudevanopus honduranus	3.1	Tellinidae (LPIL)	10.1
	Nephtys picta	2.6	*Lucina multilineata*	9.4
	Oligochaeta (LPIL)	2.6	*Aricidea* sp. C	6.1
	Lumbrinereis verrilli	2.4	*Strigilla mirabilis*	5.0
A9	*Metharpinia floridana*	14.2	*Prionospio* spp.	41.9
	Tellinidae (LPIL)	12.0	Tellinidae (LPIL)	29.6
	Branchiostoma floridae	8.5	*Spiophanes bombyx*	28.4
	Protohaustorius wiglei	5.5	*Metharpinia floridana*	27.3
	Nephtys picta	5.5	*Protohaustorius wigleyi*	23.6
	Goniadides carolinae	5.0	Syllidae (LPIL)	22.6
	Glycera sp.	4.9	Ophiuroidea (LPIL)	12.3
	Semele nuculoides	4.6	*Brania swedmarki*	9.7
	Strigilla mirabilis	4.2	*Acanthohaustorius intermedius*	9.4
	Magelona pettiboneae	4.0	*Glycera* sp.	9.3
A8	*Branchiostoma floridae*	24.8	*Prionospio* spp.	91.7
	Paraonis pygoenigmatica	12.2	*Metharpinia floridana*	38.3
	Metharpinia floridana	12.2	Tellinidae (LPIL)	22.4
	Magelona pettiboneae	11.2	*Spiophanes bombyx*	17.1
	Goniadides carolinae	10.0	*Armandia maculata*	16.6
	Parapionosyllis longicirrata	9.2	*Branchiostoma floridae*	16.3
	Tellinidae (LPIL)	8.4	*Protohaustorius wigleyi*	13.6
	Acteocina caniculata	7.7	*Lembos* sp.	12.7
	Synelmis sp. B	7.5	*Tanaissus psammophilus*	12.4
	Glycera sp.	6.3	*Mediomastus californiensis*	10.9
A6	*Magelona* sp. G	7.8	*Prionospio* spp.	35.7
	Brania wellfleetensis	7.5	*Tanaissus psammophilus*	19.4
	Metharpinia floridana	6.5	*Aricidea cerrutii*	17.0
	Paraonis pygoenigmatica	5.8	*Owenia* sp. A	16.1
	Branchiostoma floridae	5.8	Tellinidae (LPIL)	15.9
	Schistomeringos sp.	5.5	*Metharpinia floridana*	15.6
	Tanaissus psammophilus	5.5	*Syllis cornuta*	12.9
	Crassinella martinicensis	5.5	*Branchiostoma floridae*	12.7
	Parapionosyllis longicirrata	5.0	*Apoprionospio pygmaea*	12.6
	Reticulocythereis sp.	5.0	*Protohaustorius wigleyi*	11.4

Table 3.4. Ten most abundant taxa in grab samples from the study shoals B11, A9, A8, A6, and A4 for the November 2005 and June 2006 surveys off the coast of Northeast Florida *(continued)*.

Area	November 2005 Survey		June 2006 Survey	
	Taxonomic Name	Abundance*	Taxonomic Name	Abundance*
A4	*Apoprionospio pygmaea*	8.9	*Apoprionospio pygmaea*	76.3
	Apoprionospio dayi	7.5	*Prionospio* spp.	44.4
	Metharpinia floridana	5.8	*Metharpinia floridana*	29.2
	Tellinidae (LPIL)	4.7	*Caecum bipartitum*	15.2
	Eudevanopus honduranus	3.7	*Spio pettiboneae*	12.9
	Echiura (LPIL)	3.0	*Tanaissus psammophilus*	10.6
	Branchiostoma floridae	2.9	*Apoprionospio dayi*	10.1
	Aonides paucibranchiata	2.5	Tellinidae (LPIL)	8.9
	Strigilla mirabilis	2.5	*Protohaustorius wigleyi*	8.8
	Glycera sp.	2.4	*Spiophanes bombyx*	7.8
All Areas	*Metharpinia floridana*	8.9	*Prionospio* spp.	44.6
	Branchiostoma floridae	7.7	*Metharpinia floridana*	25.4
	Tellinidae (LPIL)	6.9	*Apoprionospio pygmaea*	20.7
	Protohaustorius wiglei	4.9	*Protohaustorius wigleyi*	20.2
	Strigilla mirabilis	4.6	Tellinidae (LPIL)	16.6
	Paraonis pygoenigmatica	3.6	*Spiophanes bombyx*	12.7
	Goniadides carolinae	3.5	*Mediomastus californiensis*	9.3
	Glycera sp.	3.3	*Tanaissus psammophilus*	8.9
	Magelona pettiboneae	3.2	*Branchiostoma floridae*	6.3
	Apoprionospio pygmaea	3.1	*Goniadides carolinae*	6.3

Table 3.5. Summary of infaunal statistics for the November 2005 and June 2006 surveys in shoals B11, A9, A8, A6, and A4.

Survey		November 2005					June 2006				
Area		B11	A9	A8	A6	A4	B11	A9	A8	A6	A4
Number of Stations		13	13	13	13	24	9	7	7	7	9
Number of Taxa	Mean per Station	29.8	36.8	46.8	40.0	30.0	42.0	62.3	82.4	63.6	59.4
	Standard Deviation	12.36	7.31	7.70	9.75	7.92	14.63	14.44	8.79	9.20	13.89
Number of Individuals	Mean per Station	115.8	136.7	229.3	164.8	92.5	268.0	386.9	523.1	381.4	408.3
	Standard Deviation	40.12	41.40	84.54	92.37	44.04	164.27	147.82	243.78	100.43	106.34
H' Diversity	Mean per Station	2.74	3.08	3.21	3.13	2.88	2.65	3.23	3.58	3.50	3.01
	Standard Deviation	0.51	0.20	0.25	0.20	0.40	0.35	0.33	0.27	0.12	0.41
J' Evenness	Mean per Station	0.83	0.86	0.84	0.86	0.86	0.72	0.79	0.81	0.84	0.74
	Standard Deviation	0.07	0.03	0.06	0.05	0.10	0.09	0.05	0.07	0.12	0.07
D Richness	Mean per Station	6.07	7.30	8.49	7.76	6.52	7.41	10.36	13.14	10.55	9.73
	Standard Deviation	2.43	1.10	1.08	1.35	1.32	1.96	1.96	0.70	1.23	2.12

3.3.3.1 Cluster Analysis

Patterns of infaunal similarity among stations were examined with cluster analysis. Cluster analysis excluded those taxa that were not identified to at least the family level, as well as taxa that comprised less than 0.1% of total abundance. When examined over both surveys, normal cluster analysis produced five groups (Groups A–E) of stations (samples) that were similar with respect to species composition and relative abundance. Normal cluster analysis of samples is shown in Figure 3-14. Figures 3-15 to 3-19 show the geographic distribution of infaunal stations grouped by normal analysis.

Station Group A was represented by 22 stations, 21 of which were from the June survey and included most of the A9, A8, and A6 stations sampled during June. These stations comprising Group A were distinguished from other stations primarily by high numbers of the polychaetes *Prionospio* spp., *Spiophanes bombyx*, and *Armandia maculate*; the amphipod *Metharpinia floridana*; bivalves of the family Tellinidae; the tanaid *Tanaissus psammophilus*; and polychaetes of the family Syllidae. Group A stations had the highest average number of individuals per grab and the highest number of taxa of all station groups (429.3 individuals per grab, 118 taxa). Sediment at Group A stations was relatively coarse with mean grain sizes between 0.26 and 0.55 mm. The composition of Group A sediment was 0.14%– 3.89% fines and 8.9%–43.7% calcium carbonate.

Group B was represented by 20 stations, all from the June survey. Most of the B11 and A4 stations from the June survey were in this station group. Stations in Group B were characterized most prominently by the amphipod *Protohaustorius wigleyi*; the polychaetes *Apoprionospio pygmaea*, *Mediomastus californiensis*, and *Scolelepis squamata*; and the bivalve *Lucina multilineata*. Group B stations had the second highest average number of individuals per grab and the second highest number of taxa of all station groups (241.9 individuals per grab, 107 taxa). Sediment at Group B stations was moderately coarse, with mean grain sizes between 0.17 and 0.33 mm. The composition of Group B sediment was 0.03%–2.95% fines and 5.9%–16.3% calcium carbonate.

Group C (32 stations) consisted exclusively of stations from the November survey. These included most of the A8 and A6 stations, half of the A9 stations, several A4 stations, and one B11 station. Stations in Group C were characterized by the hemichordate *Branchiostoma floridae*, the polychaetes *Goniadides carolinae*, *Paraonis pygoenigmatica*, *Parapionosyllis longicirrata*, and *Brania wellfleetensis*, the gastropod *Acteocina caniculata*, and the sand dollar *Encope michelini*. Group C stations contained an average of 151.2 individuals per grab and 99 taxa. Sediments at Group C stations were relatively coarse with mean grain sizes between 0.26 and 0.50 mm. The composition of Group C sediments was 0.66% to 2.61% fines, and 3.8% to 34.8% calcium carbonate.

Group D (25 stations) consisted exclusively of stations from the November survey. These included the majority of the B11 stations, half of the A9 stations, and several stations from A8, A6, and A4. Stations in Group D were characterized most prominently by the bivalve *Strigilla mirabilis*, the amphipods *Acanthohaustorius intermedius* and *Protohaustorius wigleyi*. A number of polychaete taxa were present, but in low abundance. Group D stations contained an average of 105.4 individuals per grab and 93 taxa. Sediments at Group D stations were moderately coarse, with mean grain sizes between 0.18 and 0.31 mm. The composition of Group D sediments was 0.42% to 3.33% fines, and 4.4% to 23.9% calcium carbonate.

Group E (16 stations) also consisted exclusively of stations from the November survey. These stations include half of the A4 stations, as well as two off-shoal stations from both the B11 and A6 shoals. Group E stations included all six stations within the A4 shoal that was dredged in 2005. Stations in Group E were characterized most prominently by the polychaetes *Apoprionospio dayi*, *Magelona* sp. G, *Lumbrinereis verrilli*, *Ceratocephale oculata* and the bivalve *Corbula contracta*. A number of crustacean and molluscan taxa were present but in low abundance. Overall, stations in Group D were relatively depauperate, having few taxa and low abundances. Group E stations had the lowest average number of individuals per grab and the lowest number of taxa of all of the station groups (83.8 individuals per grab, 74 taxa). Sediments at Group E stations were relatively fine, with mean grain sizes between 0.13 and 0.23 mm. The composition of Group E sediments was 0.86%–19.36% fines and 5.2%–24.0% calcium carbonate.

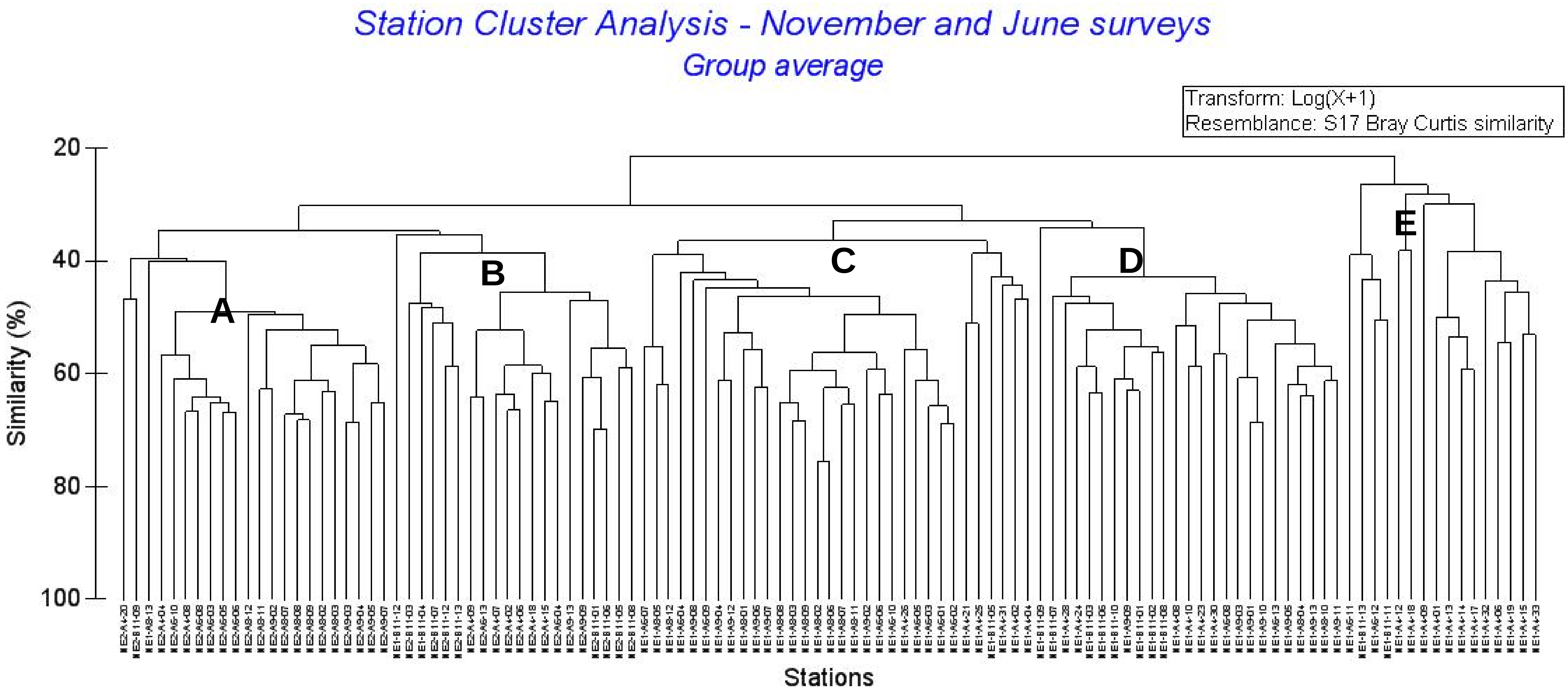
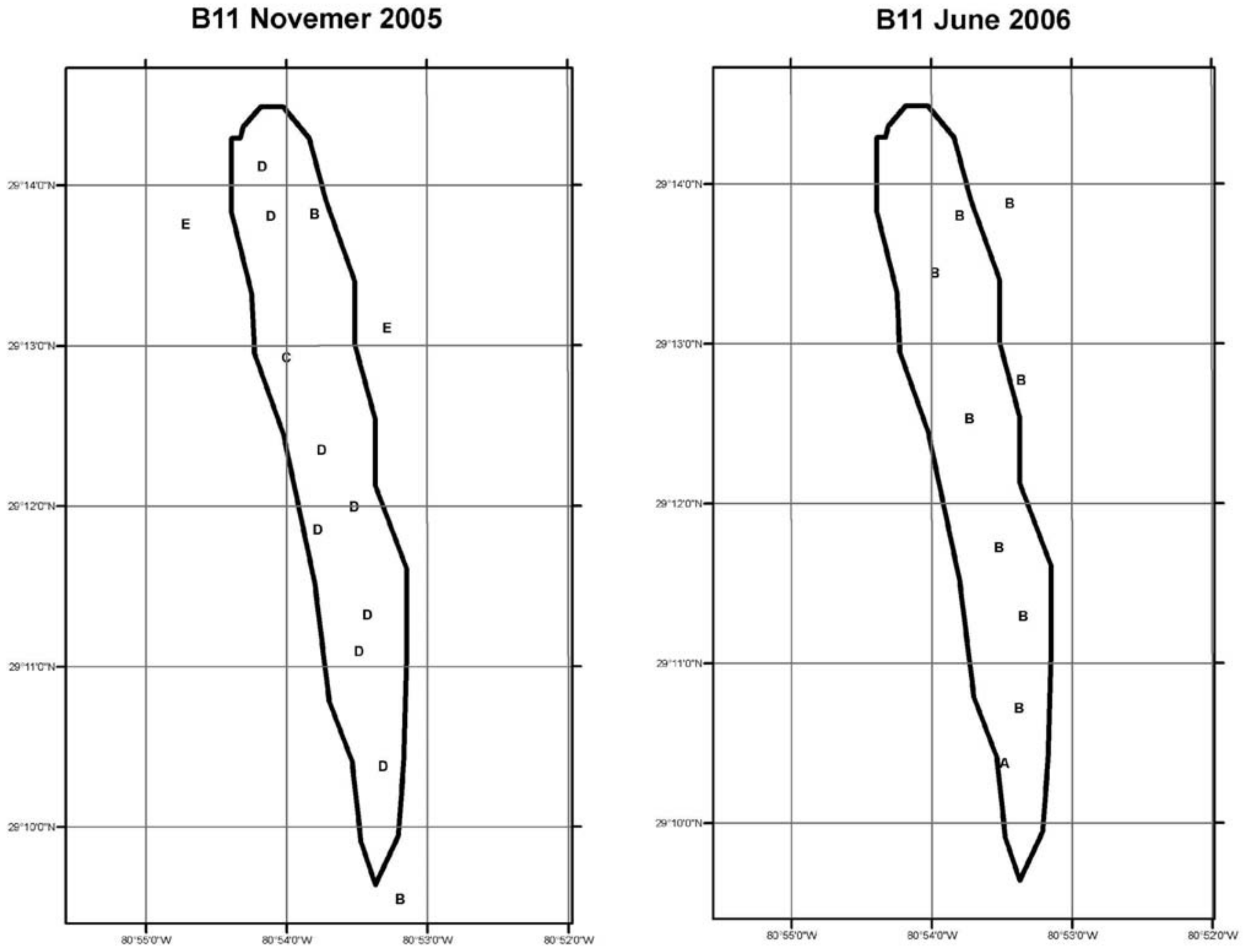


Figure 3-14. Normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys in the study shoals B11, A9, A8, A6, and A4.



B11 Novemer 2005

B11 June 2006

Figure 3-15. Station groups formed by normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys of shoal B11.

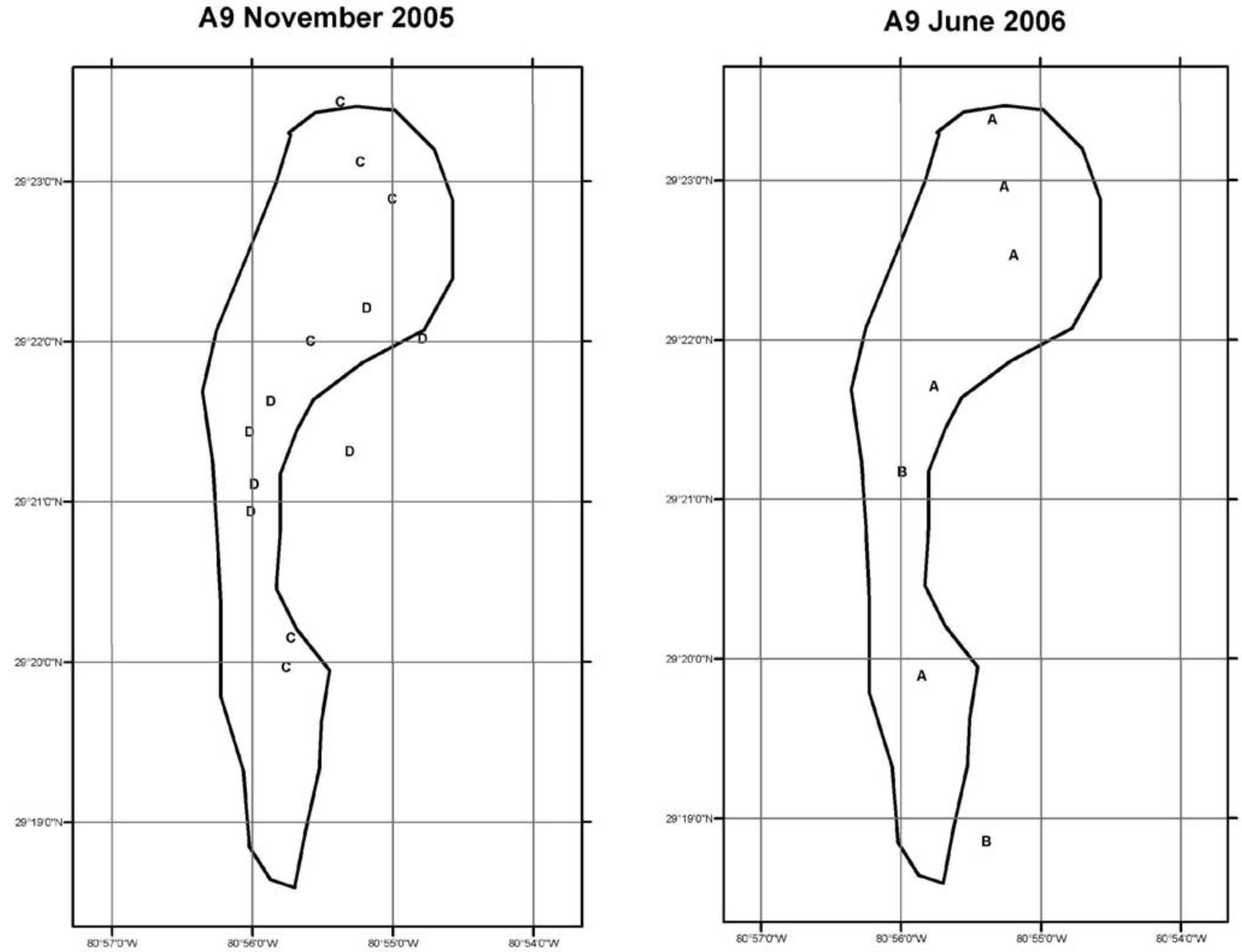


Figure 3-16. Station groups formed by normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys of shoal A9.

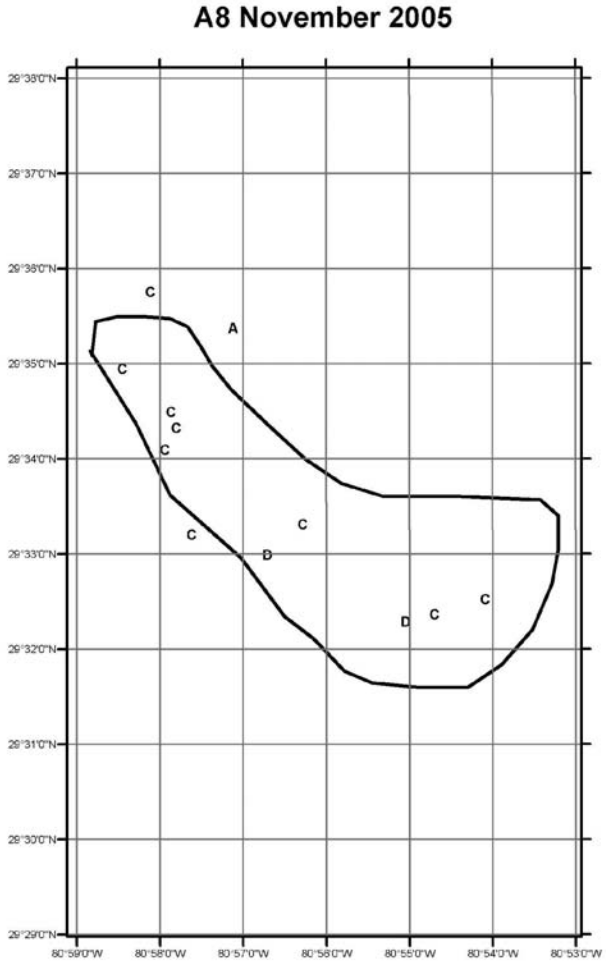


Figure 3-17. Station groups formed by normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys of shoal A8.

Figure 3-18. Station groups formed by normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys of shoal A6.

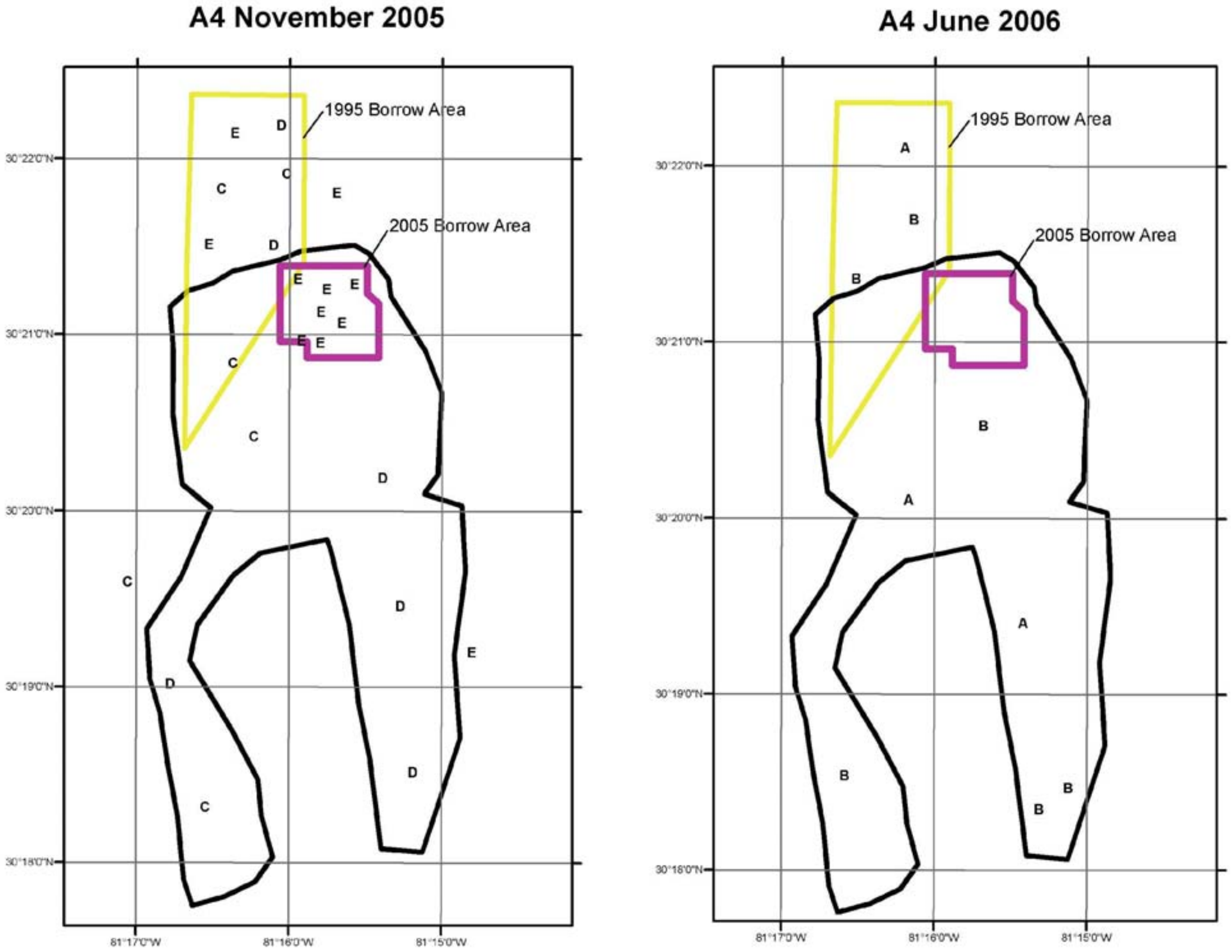


Figure 3-19. Station groups formed by normal cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys of shoal A4.

The inverse cluster analysis examining both the November and June surveys resulted in four groups of taxa (Groups 1–4) that reflected their co-occurrence in the samples (Figure 3-20; Table 3.6). Many infauna included in the cluster analysis were relatively rare and heterogeneously distributed; therefore, these taxa were not included in the four groups defined by the inverse analysis.

Taxa in Group 1 were not particularly abundant, and their presence was primarily restricted to the June survey. Group 1 taxa included polychaetes of the family Ampharetidae; the bivalve *Chione intapurpurea*; the amphipods *Rudilemboides naglei*, *Photis pugnator*, and *Lembos* sp.; and the shrimp *Processa hemphillli*. The highest average number caught per grab of these taxa occurred in station Group A, which is closely associated with shoals A9, A8, and A6. These taxa were present but uncommon in station Group B and rare or absent in station Groups C, D, and E. Sediments at station Group A were relatively coarse, with a small percentage of fines.

Group 2 taxa consisted of moderately abundant taxa including the tanaid *Tanaissus psammophilus*, the polychaetes *Aonides paucibranchiata* and *Streptosyllis pettiboneae*, the bivalve *Crassinella martinicensis*, the amphipod *Metatiron triocellatus*, and the ostracod *Reticulocythereis* sp. Group 2 taxa were most common in station Groups A and C, which includes most of the stations in shoals A9, A8, and A6 in both the November and June surveys. Sediments at station Groups A and C were relatively coarse, with a small percentage of fines.

Group 3 taxa included the hemichordate *Branchiostoma floridae*; the polychaetes *Paraonis pygoenigmatica*, *Brania wellfleetensis* and *Parapionosyllis longicirrata*; the gastropod *Acteocina caniculata*; and the bivalves *Macoma brevifrons* and *Semele nuculoides*. The highest average number caught per grab of these taxa occurred in station Group C, which is closely associated with the shoals A9, A8, and A6 in the November survey. Taxa in Group 3 were also common in station Group A, but were uncommon or absent in the other station groups. Sediments at station Groups A and C were relatively coarse, with a small percentage of fines.

Group 4 taxa included the amphipods *Metharpinia floridana*, *Protohaustorius wigleyi*, and *Eudevanopus honduranus*; the bivalves *Strigilla mirabilis* and Tellinidae; and the polychaetes *Glycera* sp. and *Nephtys picta*. These were some of the more abundant taxa identified during the study and were common in all station groups except Group E. Numerically, these seven taxa accounted for 12.6% of individuals collected during the study. The relative scarcity of these major taxa at station Group E was probably related to the higher percentages of fines in station Group E sediment.

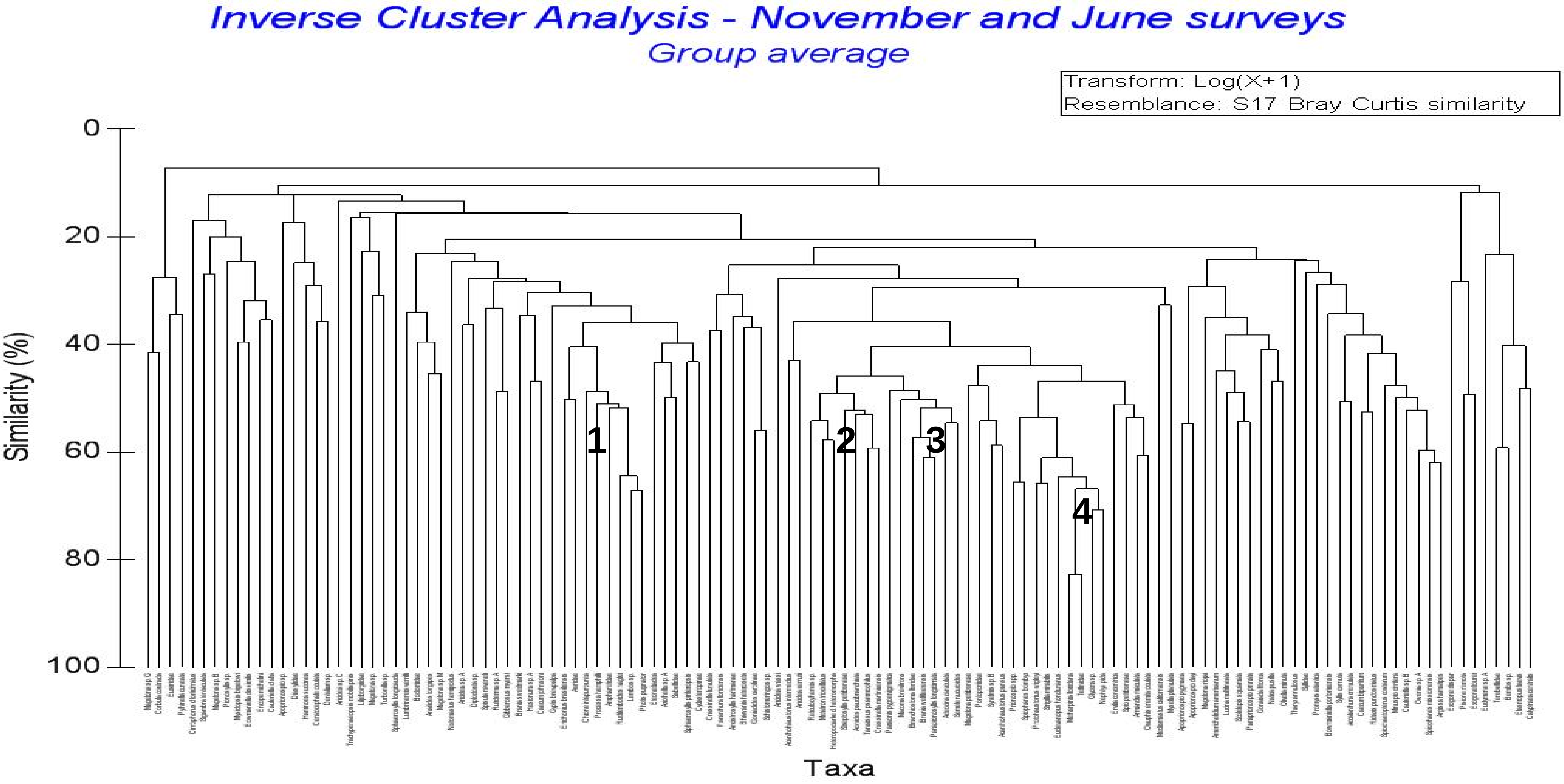


Figure 3-20. Inverse cluster analysis of infaunal samples collected during the November 2005 and June 2006 surveys in areas B11, A9, A8, A6, and A4.

Table 3.6. Infaunal taxa groups resolved from inverse cluster analysis of all samples collected in the November 2005 and June 2006 surveys in the study shoals B11, A9, A8, A6, and A4.

Taxa Group	Taxa	Category
1	Ampharetidae (LPIL)	polychaete
	Chione intapurpurea	bivalve
	Rudilemboides naglei	amphipod
	Photis pugnator	amphipod
	Lembos sp.	amphipod
	Processa hemphillli	shrimp
2	*Tanaissus psammophilus*	tanaid
	Aonides paucibranchiata	polychaete
	Streptosyllis pettiboneae	polychaete
	Crassinella martinicensis	bivalve
	Metatiron triocellatus	amphipod
	Reticulocythereis sp.	ostracod
3	*Branchiostoma floridae*	chordate
	Paraonis pygoenigmatica	polychaete
	Brania wellfleetensis	polychaete
	Parapionosyllis longicirrata	polychaete
	Acteocina caniculata	gastropod
	Macoma brevifrons	bivalve
	Semele nuculoides	bivalve
4	*Metharpinia floridana*	amphipod
	Protohaustorius wigleyi	amphipod
	Eudevanopus honduranus	amphipod
	Strigilla mirabilis	bivalve
	Tellinidae (LPIL)	bivalve
	Glycera sp.	polychaete
	Nephtys picta	polychaete

Data collected during the two surveys were analyzed using cluster analysis to determine which environmental factors most affected the distribution of station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance. The non-metric, multi-dimensional scaling plot of station sediment parameters appears in Figure 3-21. This plot shows a strong relation between sediment parameters (mean grain size, percent fines, and percent carbonate) and station groups formed by normal cluster analysis. Stations in Groups A and C occupy the left half of the plot and are somewhat overlapping. Groups A and C contain most of the stations in shoals A9, A8, and A6 but are separated temporally, with Group A present in the June survey and Group C in the November survey. Station Groups B and D occupy the right upper quadrant and are overlapping. Groups B and D contain most of the stations in shoal B11 and a considerable number of stations from shoal A4. They also are separated temporally, with Group B present in the June survey and Group D in the November survey. Station Group E occupies the right lower quadrant and consists of stations in the northern portion of area A4, which were dredged in 2005, as well as several off-shoal stations in shoals B11 and A6.

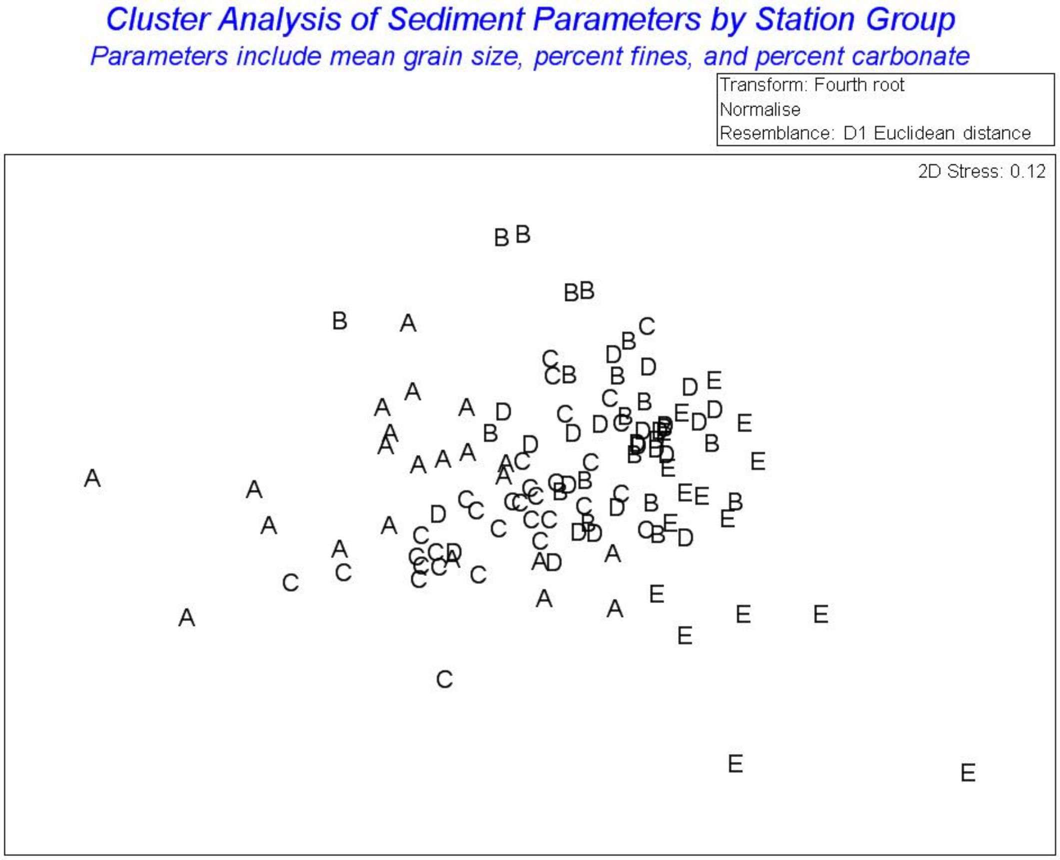


Figure 3-21. Multi-dimensional scaling plot of station sediment parameters and station groups identified by normal cluster analysis as being similar with respect to species composition and relative abundance.

3.3.3.2 Epifauna Camera Sled Results

The epifauna camera sled survey was conducted in early November 2005, about two weeks after the passage of Hurricane Wilma across Florida. Visibility in some areas was limited, and a number of video transects were repeated several days after the first attempt, with slightly better results. Four transects were conducted in shoals A9, A9, A6, and A4, while three transects were conducted in shoal B11. Transects were performed during the day and at night; however, natural lighting was generally not bright enough to illuminate fish and epifauna, and lighting on the camera sled was used. Representative images of demersal fish and epibenthos taken from the epibenthic camera sled appear in Figures 3-22 through 3-31.

The terms abundant, common, and numerous are used interchangeably to describe the video survey results and to qualify the relative presence of organisms. Abundant, common, and numerous simply mean that a taxon was frequently observed in transects of a particular study site, as opposed to a taxon seen only once or infrequently, which was described as present. Exact numbers could not be determined, as images might have been blurry, the animals were moving too fast, or they were at the edge of the screen frame.

Shoal B11

The seabed of the B11 shoal consisted of well-formed sand waves with sharply defined ridges that were approximately 3–4 inches high and spaced about 10–12 inches apart. These sand-wave formations were common in the five study shoals. In B11, these waves were generally aligned NNW/SSE.

The sea star *Luidia clathrata* was abundant in this area. The sand dollar *Encope michelini* was relatively common. Other species present included an unidentified brittle star, the brittle star *Ophioderma brevispinum*, portunid crabs, hermit crabs, and bamboo worms. Fish species observed included numerous sea robins, *Prionotus* spp.; banded drum *Larimus fasciatus*; a seatrout, *Cynoscion* spp.; and unidentified flounder.

Shoal A9

Visibility during the video transects at the A9 area was fair to poor. Three of the video transects were repeated four days after the first set of transects were performed at shoal A9, and visibility was only slightly improved. The seabed in this area generally consisted of sharply defined sand. Waves were aligned NW/SE.

Fish and epibenthos were sparsely distributed. The sea star *Luidia clathrata* was the most frequently observed species, but it was not abundant. Other species present included the sea star *Luidia alternate*, banded drum, lizardfish *Synodus* spp., sea robins, and bamboo worms. No sand dollars were observed at the A9 shoal.

Shoal A8

The seabed of the A8 shoal consisted of well-formed sand waves, aligned NNW/SSE. Numerous fish (primarily lizardfish and banded drum) were observed along the transects, although spot (*Leiostomus xanthurus*) and sea robins were also common. Fish were noticeably more abundant, and greater species diversity was noted in transects conducted after sunset. A transect performed from 8 to 9 p.m. (transect 2) had the greatest number of fish, including more than 20 banded drum. Few fish were seen on a transect performed from 4 to 5 p.m. (transect 3), and those were primarily lizardfish. The sand dollar *Encope michelini* was abundant in the A8 shoal, but only in some spots. The sea star *Luidia clathrata* was also relatively common.

Other species present included the sea star *Astropecten articularis*, unidentified brittlestars, box crabs, portunid crabs, unidentified shrimp, bamboo worms, unidentified flounder, offshore tonguefish *Symphurus pusillus*, and pipefish.

Shoal A6

The seabed of shoal A6 primarily consisted of well-formed sand waves with sharply defined ridges, aligned N/S. Fish species frequently observed included lizardfish, banded drum, and spot. Other fish present included sea robins, sea trout, and numerous small silver fish (possibly *Branchiostoma*) frequently swimming around the camera lights and burrowing into the sand.

As in the A8 shoal study, one transect was performed during daylight hours (transect 2, from 2 to 3 p.m.), and only four lizardfish were observed. In the following transect (3), performed from 5:30 to 6:30 p.m., 28 fish of at least four different demersal species were observed. The seabed along both of these transects had the same type of sand-wave formations.

Astropecten articularis was the most frequently observed epibenthic macroinvertebrate. Other invertebrates observed included the sea stars *Luidia clathrata* and *Luidia alternate*, the snail *Oliva sayana*, portunid crabs, unidentified sand dollars, and bamboo worms. Several small schools of brief squid were observed near the seabed. Paired openings of U-shaped burrows of the snapping shrimp were also observed.

On transect 4, outside of the A6 shoal, a different habitat was encountered for approximately five minutes (a distance of approximately 400 yards). This habitat consisted of a flat, shelly bottom, with sea urchins present and what appeared to be live shells emerging from the seabed (possibly mussels, goose barnacles etc.).

Shoal A4

The seabed of the A4 shoal consisted of variably defined, sand-wave formations and large areas of flat, silty bottom. The flat bottom areas contained numerous craters, polychaete mounds, and track marks from snails, crabs, and sand dollars. Where sand waves were present, they were generally aligned NNW/SSE.

Spot was the most common fish observed, while other fish species observed included lizardfish; sea robins; banded drum; pipefish; kingfish, *Menticirrhus* spp.; Flounder; and small silver fish (possibly *Branchiostoma*) swimming around the camera lights. *Astropecten articularis* was abundant in this area of the study. Other invertebrates observed included sea stars *Luidia clathrata*, sand dollars *Encope michelini*, horseshoe crabs, portunid crabs, hermit crabs, several types of unidentified large snails, brief squid, and bamboo worms. Several detached balls of algae were seen rolling over the seabed.

Figure 3-22. Sand waves viewed under daylight conditions in the area of shoal A8.

Figure 3-23. The sea star *Luidia clathrata*, common in the Northeast Florida study area.

Figure 3-24. The sea star *Astropecten articularis*, common in the study area.

Figure 3-25. The brittle star *Ophioderma brevispinum* in the B11 shoal.

Figure 3-26. The sand dollar *Encope michelini*, very common at the study area.

Figure 3-27. A portunid crab in the B11 shoal.

Figure 3-28. Inshore lizardfish, *Synodus foetens*, commonly seen in video transects.

Figure 3-29. Spot, *Leiostomus xanthurus*, another common fish at the shoal A8.

Figure 3-30. A sea robin, *Prionotus* spp., in the A6 shoal.

Figure 3-31. Tonguefish *Symphurus pusillus* near shoal A8.

3.3.4 Fisheries Results: Fisherman Survey, Fishes, and Ichthyoplankton

3.3.4.1 Trawl Collections

In total, 29 successful otter trawl tows were completed during the first survey (November 2005) and 29 during the second survey (June 2006). Mean area trawled (±1 SD) was 0.49 ± 0.09 ha. A total of 4,551 fishes from 77 identifiable taxa were collected, as listed in Table 3.7. Catches were numerically dominated by the pelagic striped anchovy, *Anchoa hepsetus*, which alone comprised 34% of the catch. Other common species taken included the sea robins *Prionotus scitulus* and *P. carolinus*; inshore lizardfish, *Synodus foetens*; and juvenile whiffs, *Citharichthys* spp. With the exception of striped anchovy, all common fishes collected were benthic or epibenthic species. The most speciose families were Paralichthyidae (large-tooth flounders, 11 taxa), Sciaenidae (drums and croakers, 8 taxa) and Triglidae (sea robins, 7 taxa). Species important to northeast Florida recreational or commercial fisheries included seabass, *Centropristis* spp.; southern kingfish, *Menticirrhus americanus*; grunts, *Haemulon* spp.; flounder, *Paralichthys* spp.; and weakfish, *Cynoscion regalis*, although these taxa represented a small percentage of overall trawl catches.

Averaged across surveys, the highest fish density (combined inside and outside sites) was observed at shoal A9 (235 fish per ha), and the lowest was at the adjacent shoal A8 (79 fish per ha). More species were collected in trawls taken outside (67) than inside (50), with shoal A9 also producing the most unique taxa (45). The highest mean fish density (223 fish per ha) and most unique taxa (56) were collected outside the shoal footprints in June 2006.

Trawls also yielded 4,451 white shrimp *Litopenaeus setiferus* with a mean density of 115 individuals per ha when averaged across all tows, as shown in Table 3.8. Catch rates were considerably higher in June 2006 (210 inside and 359 outside) than in November 2005 (23 inside and 25 outside). Smaller numbers of pink shrimp *Farfantepenaeus duorarum* and rock shrimp, *Sicyonia* spp., were also taken. In total, these economically valuable crustaceans accounted for 67% of all macroinvertebrates collected. Echinoderms were also abundant, most notably the lined sea star *Luidia clathrata* and five-notched sand dollar *Encope michelini*. At least 16 decapod crustaceans and 10 echinoderm taxa were represented. Averaged by site, macroinvertebrate density appeared to increase from south to north, ranging from 76 individuals per ha at shoal B11 to 449 individuals at shoal A4. Highest densities were observed in June 2006 compared to November 2005.

Results of non-metric, multidimensional scaling suggest that the composition of fish and macroinvertebrate trawl catches grouped strongly by season (see Figure 3-32). In contrast, the fauna was similar between the five proposed borrow sites on each survey and between collections taken inside versus outside individual sites. These patterns strongly suggest that temporal (i.e., seasonal) changes in fish abundance and community composition (due to variable spawning, recruitment, and mortality patterns among species) are of greater importance in structuring the faunal assemblage than spatial differences in habitat conditions between shoals and adjacent open bottom.

Table 3.7. Fishes collected with otter trawls within and adjacent to the five study shoals. Asterisk denotes reef fishes included in the federally managed snapper–grouper complex.

Scientific Name	Common Name	Total Captured	Mean Otter Trawl Catch Per Unit Effort (Individuals Per Hectare)												Mean SL
			All Sites	Inside 2005	Outside 2005	Inside 2006	Outside 2006	Inside Total	Outside Total	Shoal A4 Total	Shoal A6 Total	Shoal A8 Total	Shoal A9 Total	Shoal B11 Total	
Anchoa hepsetus	Striped anchovy	1558	53.3	106.4	95.3	4.9	5.6	54.9	51.8	12.5	36.9		135.6	61.3	49.9
Prionotus scitulus	Leopard searobin	493	16.9	3.7	3.1	29.2	32.0	16.7	17.1	17.5	11.0	19.0	30.1	4.7	77.8
Prionotus carolinus	Northern searobin	484	16.6	0.1		22.4	45.0	11.4	21.8	54.6	23.9	5.3	1.6	0.7	104.8
Synodus foetens	Inshore lizardfish	458	15.7	6.2	3.9	29.5	23.3	18.0	13.3	13.6	9.8	20.0	16.8	18.0	221.2
Citharichthys spp.	Whiff (juvenile)	294	10.1			13.1	28.0	6.6	13.6	20.1	8.1	6.2	14.3	0.8	55.5
Diplectrum formosum	Sand seabass	194	6.6		0.3	2.8	24.4	1.4	12.0	27.7	1.6		3.5	0.7	62.8
Sciaenidae	Drum (juvenile)	154	5.3	9.2	11.7			4.5	6.0	1.4			3.0	21.2	26.9
*Centropristis philadelphica**	Rock sea bass	121	4.1		0.8	0.3	16.1	0.1	8.2	1.8	16.3	0.8	1.9	0.7	72.6
Citharichthys macrops	Spotted whiff	71	2.4	0.7	1.3	5.7	1.9	3.3	1.6	1.4	2.4	6.2	2.1	0.5	89.2
Larimus fasciatus	Banded drum	56	1.9	4.1	3.2	0.1	0.1	2.1	1.7	0.5	7.1		0.6	1.7	139.1
Cynoscion nothus	Silver seatrout	50	1.7	1.8	2.6	0.1	2.4	0.9	2.5	0.7	3.8		0.1	4.0	139.5
Lepophidium brevibarbe	Shortbeard cusk-eel	42	1.4	0.8	0.3	2.8	1.9	1.8	1.0	0.4	2.2	1.7	2.5	0.3	100.2
Prionotus rubio	Blackwing searobin	40	1.4	0.4	0.5	1.1	3.6	0.7	2.0	0.5	1.8	1.1	2.8	0.3	218.2
Citharichthys arenaceus	Sand whiff	38	1.3	1.0	0.9	1.3	2.0	1.2	1.5	0.7	0.5	3.4	1.0	1.0	104.2
Prionotus ophryas	Bandtail searobin	38	1.3			0.8	4.6	0.4	2.2	1.1	0.4	0.4	4.1		37.8
Etropus spp.	Flounder (juvenile)	31	1.1			0.1	4.3	0.1	2.1	3.0	2.4		0.1		91.7
Calamus spp.*	Porgy (juvenile)	29	1.0				4.1		2.0		5.2				64.2
Micropogonias undulatus	Atlantic croaker	26	0.9	0.8	2.7			0.4	1.4	1.4	0.9	0.2	0.6	1.3	184.8
Ancylopsetta ommata	Ocellated flounder	25	0.9	0.4		1.5	1.6	0.9	0.8	1.9	0.5	0.6	0.3	1.0	146.6
Symphurus plagiusa	Blackcheek tonguefish	25	0.9			0.1	3.4	0.1	1.7	2.1	2.0		0.3		129.7
Leiostomus xanthurus	Spot	23	0.8	0.7	1.5	0.1	0.9	0.4	1.2	1.8	1.8		0.3	0.2	153.0
Stephanolepis hispidus	Planehead filefish	15	0.5		0.1	0.8	1.1	0.4	0.6	0.4	0.4	0.8	1.0		32.5
Paralichthys lethostigma	Southern flounder	14	0.5			1.1	0.9	0.5	0.4	0.2		0.2	1.5	0.3	194.0
Prionotus spp.	Searobin (juvenile)	14	0.5		0.1	1.1	0.7	0.5	0.4	1.1	0.7	0.4	0.3		29.9
Trichiurus lepturus	Atlantic cutlassfish	14	0.5	0.4	1.5			0.2	0.8				0.9	1.3	120.1
Menticirrhus americanus	Southern kingfish	13	0.4	0.3	1.1		0.4	0.1	0.8	0.5	0.2			1.5	144.9
Ophidion grayi	Blotched cusk-eel	13	0.4		1.1		0.7		0.9		0.2	0.2	1.3	0.3	111.0
Ophidion selenops	Mooneye cusk-eel	11	0.4			0.4	1.1	0.2	0.6			1.1	0.7		86.3
Selene setapinnis	Atlantic moonfish	10	0.3	1.0	0.4			0.5	0.2		0.2		0.6	0.8	28.1
Etropus microstomus	Smallmouth flounder	9	0.3	0.1	1.1			0.1	0.6	0.2		0.9		0.5	101.1
Haemulon spp.*	Grunt (juvenile)	9	0.3	0.1			1.1	0.1	0.6	0.5		0.2	0.7		31.7
Ophidion marginatum	Striped cusk-eel	9	0.3				1.3		0.6	0.5			0.9		95.3
Raja eglanteria	Clearnose skate	9	0.3	0.4	0.3	0.1	0.4	0.3	0.3	0.2	0.4	0.6	0.4		278.8
*Chaetodipterus faber**	Atlantic spadefish	8	0.3		0.1		1.0		0.6	0.7	0.4	0.2	0.1		91.1
Lagodon rhomboides	Pinfish	8	0.3		0.4		0.7		0.6	0.4	0.4	0.4		0.3	102.9
Symphurus urospilus	Spottail tonguefish	8	0.3		0.4	0.7		0.3	0.2	0.4		0.9		0.2	134.5
Bothidae	Flounder (juvenile)	7	0.2	0.7	0.3			0.3	0.1			1.1	0.1		26.7
Chloroscombrus chrysurus	Atlantic bumper	7	0.2	0.4		0.5		0.5		0.7	0.2	0.2	0.1		80.4
Equetus lanceolatus	Jack-knifefish	7	0.2			0.3	0.7	0.1	0.3			0.2	0.9		29.5
Opisthonema oglinum	Atlantic thread herring	7	0.2	0.7	0.3			0.3	0.1					1.2	131.4
Cantherhines macrocerus	Whitespotted filefish	6	0.2			0.5	0.3	0.3	0.1			1.1			18.5
Ophidion holbrookii	Band cusk-eel	6	0.2			0.1	0.7	0.1	0.3			1.1			97.2

Table 3.7. Fishes collected with otter trawls within and adjacent to the five study shoals. Asterisk denotes reef fishes included in the federally managed snapper-grouper complex (*continued*).

Scientific Name	Common Name	Total Captured	Mean Otter Trawl Catch Per Unit Effort (Individuals Per Hectare)												Mean SL
			All Sites	Inside 2005	Outside 2005	Inside 2006	Outside 2006	Inside Total	Outside Total	Shoal A4 Total	Shoal A6 Total	Shoal A8 Total	Shoal A9 Total	Shoal B11 Total	
Brevoortia tyrannus	Atlantic menhaden	5	0.2	0.7				0.3						0.8	133.2
Paralichthys dentatus	Summer flounder	5	0.2	0.4	0.3			0.2	0.1	0.4	0.4		0.1		258.6
Paralichthys albigutta	Gulf flounder	5	0.2	0.1		0.3	0.3	0.2	0.1	0.7		0.2			227.8
Serraniculus pumilio	Pygmy sea bass	5	0.2				0.7		0.3		0.4	0.2	0.3		54.6
Hippocampus reidi	Longsnout seahorse	4	0.1		0.3	0.1	0.1	0.1	0.2	0.2		0.2	0.3		69.8
Prionotus evolans	Striped searobin	4	0.1	0.1	0.4			0.1	0.2			0.8			148.8
Syacium micrurum	Channel flounder	4	0.1			0.3	0.3	0.1	0.1				0.3	0.3	171.3
Symphurus civitatium	Offshore tonguefish	4	0.1		0.1		0.4		0.3		0.7				127.5
Ariosoma balearicum	Bandtooth conger	3	0.1				0.4		0.2			0.2	0.3		204.3
Cynoscion regalis	Weakfish	3	0.1	0.1	0.3			0.1	0.1	0.2	0.2			0.2	206.0
Diplectrum bivittatum	Dwarf sand perch	3	0.1		0.1		0.3		0.2	0.2	0.2	0.2			73.3
*Haemulon plumierii**	White grunt	3	0.1			0.1	0.3	0.1	0.1	0.4		0.2			159.0
Orthopristis chrysoptera	Pigfish	3	0.1				0.4		0.2	0.4	0.2				145.3
Peprilus alepidotus	Harvestfish	3	0.1	0.4				0.2				0.4	0.1		37.0
Scorpaena calcarata	Smoothhead scorpionfish	3	0.1		0.1		0.3		0.2				0.4		77.7
Upeneus parvus	Dwarf goatfish	3	0.1				0.4		0.2	0.2	0.2	0.2			82.0
Aluterus schoepfii	Orange filefish	2	0.1	0.1	0.1			0.1	0.1			0.4			39.0
*Centropristis striata**	Black sea bass	2	0.1				0.3		0.1	0.4					112.0
Chilomycterus schoepfii	Striped burrfish	2	0.1			0.3		0.1			0.2		0.1		159.0
Citharichthys spilopterus	Bay whiff	2	0.1				0.3		0.1		0.2			0.2	70.0
Acanthostracion quadricornis	Scrawled cowfish	2	0.1			0.1	0.1	0.1	0.1	0.2			0.1		183.7
Astroscopus y-graecum	Southern stargazer	1	<0.1			0.1		0.1					0.1		48.0
Bothus ocellatus	Eyed flounder	1	<0.1				0.1		0.1			0.2			75.0
Bothus robinsi	Twospot flounder	1	<0.1	0.1				0.1				0.2			89.0
*Calamus leucosteus**	Whitebone porgy	1	<0.1				0.1		0.1	0.2					133.0
Cyclopsetta fimbriata	Spotfin flounder	1	<0.1				0.1		0.1			0.2			44.0
Cynoscion spp.	Seatrout (juvenile)	1	<0.1	0.1				0.1				0.2			89.0
Dactylopterus volitans	Flying gurnard	1	<0.1				0.1		0.1		0.2				36.0
Dasyatis americana	Southern stingray	1	<0.1			0.1		0.1						0.2	310.0
Pareques umbrosus	Cubbyu	1	<0.1		0.1				0.1	0.2					160.0
*Haemulon aurolineatum**	Tomtate	1	<0.1				0.1		0.1	0.2					136.0
*Haemulon carbonarium**	Caesar grunt	1	<0.1				0.1		0.1	0.2					134.0
*Lutjanus vivanus**	Silk snapper	1	<0.1				0.1		0.1	0.2					105.0
Mullus auratus	Red goatfish	1	<0.1				0.1		0.1					0.2	145.0
Ogcocephalidae	Batfish (juvenile)	1	<0.1	0.1				0.1				0.2			53.0
Prionotus martis	Barred searobin	1	<0.1			0.1		0.1				0.2			102.0
Prionotus tribulus	Bighead searobin	1	<0.1				0.1		0.1		0.2				128.0
Psenes maculatus	Silver driftfish	1	<0.1				0.1		0.1				0.1		30.0
Scorpaena grandicornis	Plumed scorpionfish	1	<0.1				0.1		0.1			0.2			101.0
Scorpaenidae	Scorpionfish (juvenile)	1	<0.1		0.1				0.1	0.2					57.0
Selene vomer	Lookdown	1	<0.1				0.1		0.1	0.2					23.0
Syacium papillosum	Dusky flounder	1	<0.1	0.1				0.1					0.1		198.0
Uranoscopidae	Star gazer (juvenile)	1	<0.1		0.1				0.1				0.1		
	Total Fishes		4551	1040	1022	926	1563	1966	2585	989	798	419	1590	755	
	No. Trawls		59	15	15	15	14	30	29	12	12	12	12	11	
	Mean Fish Per Hectare		155.8	143.2	137.3	123.4	223.1	133.1	178.9	174.6	144.4	79.0	234.9	126.9	
	Unique Taxa		77	31	35	36	56	50	67	44	38	42	45	30	

Table 3.8. Macroinvertebrates collected with otter trawls within and adjacent to five study shoals.

Scientific Name	Common Name	Total Captured	Mean Otter Trawl Catch Per Unit Effort (Individuals Per Hectare)											
			All Sites	Inside 2005	Outside 2005	Inside 2006	Outside 2006	Inside Total	Outside Total	Shoal A4 Total	Shoal A6 Total	Shoal A8 Total	Shoal A9 Total	Shoal B11 Total
Litopenaeus setiferus	White shrimp	4451	152.4	23.4	25.4	209.8	359.4	118.1	187.4	312.5	184.6	114.4	152.2	4.0
Luidia clathrata	Lined sea star	1023	35.0	8.9	17.7	28.4	87.5	18.8	51.6	71.5	21.7	10.7	30.6	39.3
Encope michelini	Five-notched sand dollar	312	10.7	0.4		2.1	41.8	1.3	20.3	0.5		53.7	1.5	2.4
Portunus gibbesii	Iridescent swimming crab	279	9.6	0.1		16.0	22.6	8.2	10.9	5.1	3.3	27.3	10.9	2.2
Lolliguncula brevis	Atlantic brief squid	240	8.2	3.9	8.9	13.5	6.4	8.7	7.7	27.5	1.6	0.2	3.7	8.2
Sicyonia spp.	Rock shrimp	149	5.1			3.7	17.3	1.9	8.4	1.8	0.9	14.7	8.3	
Farfantepenaeus duorarum	Pink shrimp	94	3.2	4.1	8.5		0.1	2.0	4.4	9.2	2.2	1.1	1.5	2.4
Strombus alatus	Florida fighting conch	41	1.4			4.3	1.3	2.2	0.6	0.9	1.6	0.4	3.7	
Stomatopoda	Mantis shrimp	37	1.3		0.1	0.1	5.0	0.1	2.5	3.2	0.4	0.4	2.1	0.2
Asteroidea	Unknown sea star	32	1.1		3.0	0.4	1.0	0.2	2.0		4.2	0.2		1.3
Arbacia punctata	Purple sea urchin	27	0.9			1.1	2.7	0.5	1.3	1.1	1.1	0.9	0.3	1.3
Ophioderma brevispinum	Serpent star	23	0.8		0.1	1.5	1.6	0.7	0.8			0.2	0.3	3.4
Portunus sayi	Sargassum swimming crab	22	0.8	0.1	0.3	0.7	2.0	0.4	1.1	2.5	0.7	0.8		
Callinectes sapidus	Blue crab	22	0.8			0.9	2.1	0.5	1.0	3.0	0.7	0.2		
Astropecten duplicatus	Two-spined starfish	20	0.7	0.8	1.1	0.5	0.3	0.7	0.7	1.2	1.4	0.4		0.5
Ophiuroidea	Unknown brittle star	20	0.7	0.3	0.1	1.3	1.0	0.8	0.6	0.9	0.4	0.6	0.1	1.5
Calappa flammea	Flame box crab	20	0.7		0.1	0.3	2.4	0.1	1.2	0.7	1.3	0.2	1.2	
Luidia alternata	Banded sea star	19	0.7	0.1	0.8		1.7	0.1	1.2	0.5	1.3	1.5	0.1	
Astropecten articulatus	Two-spined starfish	18	0.6			1.2	1.3	0.6	0.6	0.9		0.8	0.9	0.5
Argopecten gibbus	Calico scallop	15	0.5	1.4	0.5	0.1		0.7	0.3				0.7	1.7
Hepatus epheliticus	Calico box crab	15	0.5		0.3	0.1	1.7	0.1	1.0	0.4	0.4	1.5	0.4	
Callinectes similis	Lesser blue crab	11	0.4		0.9		0.6		0.8	0.5	0.2		0.6	0.5
Lytechinus variegatus	Green sea urchin	11	0.4			0.3	1.3	0.1	0.6	0.7	0.2	0.4	0.1	0.5
Polinices duplicatus	Moon snail	8	0.3		1.1				0.6	1.4				
Persephona mediterranea	Mottled purse crab	8	0.3		0.3	0.4	0.4	0.2	0.3	0.2	0.7		0.3	0.2
Metoporhaphis calcarata	False arrow crab	7	0.2	0.6	0.1		0.3	0.3	0.2	0.2	0.2	0.9		
Tripneustes vetricosus	West Indies sea egg	6	0.2		0.8				0.4	0.5	0.4			0.2
Holothuroidea	Sea cucumber	6	0.2			0.4	0.4	0.2	0.2	0.7	0.4			
Paguridae	Hermit crab	4	0.1	0.1		0.3	0.1	0.2	0.1	0.2		0.2	0.1	0.2
Cassis flammea	Flame Helmet	3	0.1			0.1	0.3	0.1	0.1			0.4	0.1	
Portunus spp.	Swimming crab (juvenile)	3	0.1			0.1	0.3	0.1	0.1	0.2		0.2	0.1	
Ophioderma spp.	Brittle star	2	0.1		0.1	0.1		0.1	0.1	0.2	0.2			
Persephona crinita	Pink purse crab	2	0.1		0.1	0.1		0.1	0.1	0.2		0.2		
Busycon contrarium	Lightning whelk	2	0.1			0.1	0.1	0.1	0.1		0.4			
Decapoda	Unknown Crab	2	0.1				0.3		0.1	0.4				
Ovalipes stephensoni	Coarsehand lady crab	2	0.1			0.1	0.1	0.1	0.1		0.2		0.1	
Phalium granulatum	Scotch bonnet	2	0.1			0.3		0.1			0.2		0.1	
Eurythoë spp.	Fireworm	1	<0.1		0.1				0.1		0.2			
Farfantepenaeus aztecus	Brown shrimp	1	<0.1		0.1				0.1					0.2
Lysmata spp.	Cleaner shrimp	1	<0.1				0.1		0.1		0.2			
	Total Captured		6961	322	526	2164	3949	2486	4475	2541	1276	1233	1491	420
	No. Trawls		59	15	15	15	14	30	29	12	12	12	12	11
	Mean No. Per Hectare		238.2	44.3	70.7	288.5	563.7	168.4	309.7	448.7	230.9	232.4	220.3	70.6
	Unique Taxa		35	13	20	26	28	29	34	26	27	23	23	18

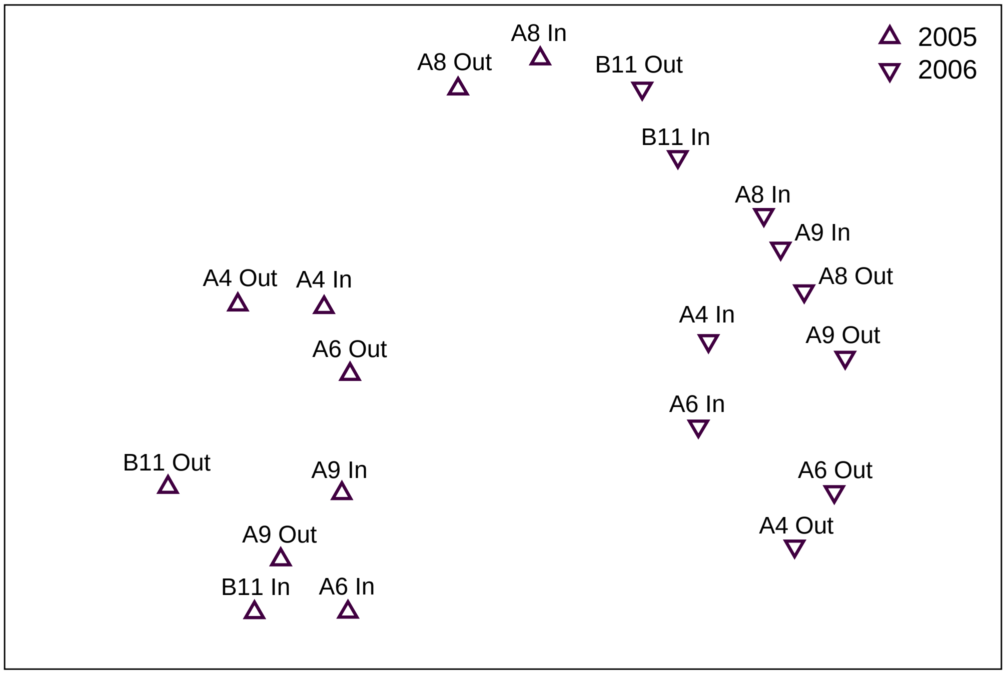


Figure 3-32. Spatiotemporal differences in fish and macroinvertebrate community structure from otter trawls inside and outside study shoals of Northeast Florida as demonstrated by non-metric multi-dimensional scaling. Interpoint distances are proportional to overall faunal similarity. Sites where hardbottom substrates precluded sample collection are excluded. 2D stress = 0.11.

3.3.4.2 Feeding Habits

Guts of 209 fishes from 11 demersal taxa contained prey. Most fishes examined typically had small amounts of well-digested prey in their stomachs, with a mean fullness index and mean digestion index of only 1.7 and 1.4, respectively (Table 3.9). Nonetheless, 15 general prey categories were recognized with mysid shrimp, decapod shrimp, and fish found in guts of most taxa and often with high IRIs. Crustaceans were the most diverse prey group identified, although many (e.g., cumaceans, isopods, and amphipods) were of relatively minor importance. In general, stomach contents were from groups typical of outer shelf benthic invertebrate communities and the communities characterized in this study, illustrating the close coupling between the local invertebrate prey base and demersal fisheries at proposed borrow sites.

3.3.4.3 Plankton Collections

A total of 927 fish larvae representing 36 distinct taxa were collected in 24 total plankton tows (Table 3.10). Unidentified larval gobies (family Gobiidae) dominated collections, comprising nearly 60% of catch. Anchovies (family Engraulidae) and herring (Clupeidae) were also common. Larval densities were very low during November 2005 when only 22 individuals were taken in 18 tows. Densities during June 2006, although based on limited replication, were much higher, especially in sub-surface tows. Most larvae were those of small-bodied benthic or pelagic forage species. The only species of economic value to the region were unidentified sea bass and whiting (*Menticirrhus* spp.) larvae, both of which were uncommon.

Table 3.9. Summary of prey items for 11 species of demersal fish species common to study shoals.

						Prey Category Index of Relative Importance (IRI)															
Scientific Name	Common Name	No. Fish Analyzed	Mean Length (mm)	Mean Fullness Index	Mean Digestion Index	Polychaete	Cumacean	Mysid	Amphipod	Isopod	Tanaid	Stomatopod	Shrimp	Crab	*Branchiostoma* spp.	Gastropod	Bivalve	Cephalopod	Echinoderm	Fish	Unidentified
Synodus foetens	Inshore lizardfish	43	225	1.1	0.6								0.6					0.1		22.6	
Prionotus scitulus	Leopard sea robin	42	133	0.9	0.9		0.1	30.8	0.1	0.1			2.2	0.2		0.1	0.1			0.7	
Larimus fasciatus	Banded drum	33	131	1.4	1.2			60.8	0.1				1.8	0.1						22.6	
Diplectrum formosum	Sand sea bass	19	63.9	2.4	1.4	0.2		66.7			0.4	12.8	0.2	0.7						0.2	0.2
Centropristis philadelphica	Rock sea bass	15	87.8	3.5	2.1	1.1		8.5	3.5	1.0		19.4	20.9	11.0					0.6	1.0	
Cynoscion nothus	Silver seatrout	14	200	2.1	1.4	14.1		6.8				4.4	39.6							21.6	0.2
Ancylopsetta ommata	Ocellated flounder	14	172	1.9	1.9			0.6				17.1	48.7	4.1						2.6	
Citharichthys macrops	Spotted whiff	13	109	2.2	1.6			89.0	0.1				10.1	0.5						3.7	
Menticirrhus americanus	Southern kingfish	8	124	0.6	0.5			1.1					38.4		1.9						
Paralichthys dentatus	Summer flounder	5	260	1.6	1.4									2.3				7.9		23.1	
Raja eglanteria	Clearnose skate	3	286	0.7	2.0			4.7					90.6								

Table 3.10. Larval fish densities collected in neuston (surface) and plankton (sub-surface) samples within the vicinity of study areas. Densities were averaged across sites for each year and were standardized to number of fish per 1000 m^3 water filtered.

Scientific Name	Common Name	Larval Fish CPUE (No. per 1000 m^3 water filtered)					Mean SL or NL
		Total Captured	Neuston 2005	Plankton 2005	Neuston 2006	Plankton 2006	
Gobiidae	Goby	552			29.4	243.1	4.5
Engraulidae	Anchovy	96	0.5	0.5	12.9	32.9	9.0
Sardinella aurita	Round sardinella	67			6.2	27.0	12.8
Clupeidae	Herring	34			10.8	6.4	9.0
Citharichthys spp.	Flounder	23			1.0	10.3	6.6
Chloroscombrus chrysurus	Atlantic bumper	20			5.7	4.4	2.8
Dactyloscopidae	Sand stargazer	19			4.1	5.4	5.4
Blenniidae	Blenny	15	0.5		2.1	4.9	5.9
Stephanolepis hispidus	Planehead filefish	11	3.1	0.8			19.7
sub-family Serraninae	Seabass	10			1.0	3.9	4.7
Gerreidae	Mojarra	9		0.2		3.9	5.5
Microdesmidae	Wormfish	9			2.1	2.5	9.3
Letharchus velifer	American sailfin eel	7			2.1	1.5	23.3
Symphurus spp.	Tonguefish	6			0.5	2.5	11.1
Synodontidae	Lizardfish	5			1.0	1.5	6.1
Triglidae	Searobin	5				2.5	3.8
Decapterus spp.	Scad	4				2.0	4.4
Haemulidae	Grunt	3				1.5	5.2
Menticirrhus spp.	Whiting	3				1.5	2.8
Synodus foetens	Inshore lizardfish	2				1.0	9.1
Sphreaena picudilla	Southern sennet	2			1.0		5.5
Diodontidae	Porcupinefish	2			0.5	0.5	2.8
Elops sp.	Ladyfish	2		0.4			32.0
Ahlia egmontis	Key worm eel	1				0.5	72.0
Opisthonema oglinum	Atlantic thread herring	1				0.5	12.0
Bregmaceros houdei	Stellate codlet	1				0.5	6.1
Ophidiiformes	Cusk eel	1				0.5	6.5
Carrangidae	Jack	1				0.5	3.9
Oligoplites saurus	Leatherjack	1				0.5	5.0
Sparidae	Porgy	1			0.5		4.0
Chaetodipterus faber	Atlantic spadefish	1				0.5	5.0
Parablennius marmoreus	Seaweed blenny	1				0.5	16.0
Scombridae	Mackerel	1				0.5	4.4
Euthynnus alletteratus	Little tunny	1				0.5	8.4
Monacanthus ciliatus	Fringed filefish	1			0.5		12.0
Ostraciidae	Boxfish	1			0.5		3.3
Hippocampus erectus	Lined seahorse	1		0.1			72.0
Syngnathus springeri	Bull pipefish	1	0.5				95.0
Peprilus paru	American harvestfish	1	0.5				37.0
Unidentified		5				2.5	
	Total Captured	927	10	12	159	746	
	Mean No. Per 1000 m^3		5.2	2.0	82.0	363.9	
	No. Tows		9	9	3	3	
	Mean Volume Sampled		207 m^3	623 m^3	646 m^3	679 m^3	
	Unique Taxa		5	5	17	27	

3.3.4.4 Responses from Fishermen Surveys

Seventeen fishermen were interviewed in Volusia and Flagler counties over three days in 2006. Respondents included boat captains, charter fishing guides, and owners of boat supply stores, bait and tackle stores, and dive shops. Responses were provided for fishing practices on and/or near the MMS study shoals and perceptions of impacts that dredging may have on the fishing industry. A summary of the survey responses and all comments are provided in Appendix B.

Fishermen were classified as either commercial (24%) or recreational (79%) with the exception of three fishing guides. Respondents often included more than one response per question. Fishermen targeted grouper, red snapper, kingfish, whiting, pompano, tarpon, seatrout, mullet, unidentified reef fish, dolphin, tuna, wahoo, flounder, black drum, and sheepshead. Preferred habitats chosen for fishing were hardbottom, sand bottom, artificial reef, and open water. Twelve respondents (71%) fished on or within five miles of shoal B11. Five respondents (29%) either fished on or within five miles of shoal A6. Fishing took place year round using trawl nets, hook line, surf fish gear, and rod and reel.

Respondents were asked three questions related to direct, indirect, and other impacts that dredging may have on fishing. Thirty-five percent (35%) of the respondents answered there was no direct impact, while 65% thought there was a direct impact. Fifty-three percent (53%) of the respondents answered there was no indirect impact, while 35% thought there was an indirect impact, 6% had no response, and 6% commented, “dredge holes support ground fish.”

3.3.5 Seabirds, Sea Turtles, and Marine Mammals

Results of the seabirds, sea turtles, and marine mammals November 2005 and June 2006 field events differed in the total number of species observed and the diversity of species encountered. Between the two surveys, nearly 151 hours of visual observation for marine fauna and avian species and approximately 10 hours of passive acoustic monitoring for marine mammals were conducted. Table 3.11 contains a summary of species observed and the number of individuals from the 2005 and 2006 surveys.

3.3.5.1 November 2005 Field Event Protected Species Observations

Forty-six hours of observation were completed during the November 2005 survey. Species observed were dolphins, loggerhead and leatherback sea turtles, and on November 6, an unconfirmed sighting of a green sea turtle (Table 3.11). The most common seabirds spotted were Royal Tern and members of the Laridae family. Completed data sheets for marine mammal and sea turtle sightings are provided in Appendix B.

The passive acoustic monitoring for marine mammals system was deployed for a total of 7 hours. No vocalizations were recorded. Recording logs of dates and times are in Appendix B.

3.3.5.2 June 2006 Field Event Protected Species Observations

Protected species observations were conducted during daylight hours of June 3–9, 2006. Observations occurred on the deck and above the wheel house. Due to good weather, 105 hours of observation were completed. Twenty-seven protected species that were documented included bottlenose dolphins, pantropical spotted dolphins (*Stenella attenuate*), and loggerhead sea turtles. Various forms of gulls including Laughing Gulls (*Larus atricilla*) and Herring Gulls (*Larus argentatus*), Royal Terns, Brown Pelicans (*Pelicanus occidentalis*), a Double-crested Cormorant (*Phalacrocorax auritus*), and an unconfirmed Black-legged Kittiwake (*Rissa tridactyla*) were seen.

Acoustic monitoring for marine mammals was conducted June 4–8, 2006, in an attempt to record marine mammal vocalizations. The hydrophone was deployed for a total of three hours. No marine mammal sounds were recorded during the monitoring period.

Table 3.11. November 2005 and June 2006 Protected Species Observations

November 2005	June 2006
Marine Mammals (11) Bottlenose dolphins, *Tursiops truncates*, possible hydrophone signals	**Marine Mammals** (12) Bottlenose dolphins, *Tursiops truncatus* (3) Pantropical spotted dolphins, *Stenella attenuata*
Sea Turtles (3) Loggerhead sea turtles, *Caretta caretta* (1) Leatherback, *Dermochelys coriacea* (1) Green sea turtle, *Chelonia mydas* [1]	**Sea Turtles** (12) Loggerhead sea turtles, *Caretta caretta*
Seabirds Royal Tern, *Sterna maxima* Gull family members Laridae Warbler	**Seabirds** Royal Tern, *Sterna maxima* Brown Pelicans, *Pelecanus occidentalis* Herring Gulls, *Larus argentatus* Laughing gulls, *Larus atricilla* Black-legged Kittiwake, *Rissa tridactyla* [1] Double-crested Cormorant, *Phalacrocorax auritus*

1. Unconfirmed

4.0 POTENTIAL ENVIRONMENTAL IMPACTS OF DREDGING

4.1 Introduction

A review of dredging methods, equipment, and best management practices for dredging is provided below. Also in this section, potential impacts of different dredging scenarios from the numerical modeling with respect to nearshore erosion and alteration of the shoals are discussed as they relate to the physical environment of the study areas and to the biological resources. Model test cases were examined to calculate potential nearshore impacts from dredging different volumes of sand under normal and extreme weather conditions over time. Potential harm to biological resources is assessed for immediate affects that result from dredging and for the potential cumulative impacts that may occur.

4.2 Dredging Overview

4.2.1 Equipment

As described by W.F. Baird & Associates, Ltd. & Research Planning, Inc. (2004) and based on previous dredging projects conducted in federal waters, the most likely equipment of choice for dredging sand in federal waters for beach nourishment projects will be the trailer suction hopper dredge (TSHD). For example, Bean Stuyvesant dredged on shoal A4 offshore Duval County in 2005 with a hopper dredge with capacity of 6,000 yd^3 (USACE 2008).

TSHDs are self-propelled ships suitable for operations in an ocean environment and capable of mining sand and loading a self-contained hopper while the ship is underway. Most TSHDs are twin screw and have bow thrusters that provide a high degree of maneuverability. Loading takes place as the ship moves ahead at a speed of 2–3 knots. Unloading for beach nourishment projects is typically by pump discharge.

The main advantages of the TSHD are
- performance in high-seas conditions with the use of heave-compensated dragarms,
- independent operation without tender vessels,
- the ability to transport materials over long distances,
- the high rate of production, and
- operation in relatively deep water.

A large proportion of the internal space of the TSHD is occupied by the hopper space into which the material is loaded by one or two large centrifugal pumps. The pumps are usually inboard but may not be fitted into the trailing suction pipe (submerged pump). Submerged pumps are a necessity for all deep-water dredges. The suction pipe is stowed inboard when the ship is in transit between the dredging site and the discharge or off-loading site. The maximum operating depth to which a hydraulic dredge can operate is limited by the vacuum head generated by the dredge pump. If the pump is mounted within the hull of the vessel, the maximum economical dredging depth is about 100 ft. By mounting the dredge pump externally in the trailing suction pipe close to the draghead, a much greater depth may be achieved along with improved production. Dredging production from a 400-ft depth is now achievable economically.

4.2.2 Operations

Most modern, high-capacity dredges are of the hydraulic type, employing suction produced by high-speed centrifugal pumps to excavate the sediment and dispose of it, either through a pipeline or to a storage hopper. Material dislodged from the ocean floor by the suction is suspended in water in the form of a slurry and then passed through the centrifugal pump and discharge pipeline to the nourishment or disposal site. The types of dredges likely to be used in obtaining offshore sand for beach nourishment projects are cutterhead and hopper dredges. Hydraulic dredges have very high production rates when the materials to be dredged are relatively soft and contain a high ratio of water.

The trailer suction pipe with draghead attached is swung outboard and lowered by means of winches and davits. If inboard pumps are installed, the inboard end of the suction pipe is lowered in a fixed track to mate, below the waterline, with the pump suction intake, which is open in the side of the hull. Pipe works from the discharge side are routed to the hopper where discharge is conveyed to launders (chutes) to minimize turbulence. If the dredging pumps are located within the trailing suction pipe, there is a fixed connection of suction and pressure pipe systems.

The intake end of the suction pipe is fitted with a draghead, the function of which is to strip off a layer of sediment from the seabed and entrain those sediments into the suction pipe. The draghead is lowered from the vessel, which is proceeding forward at a speed from 1 to 5 knots. The bearing pressure of the draghead on the seabed is controlled by an adjustable pressure compensator system, which acts between the draghead and the hoisting winch that supports the trailing pipe. This same system acts as a heave compensator that accumulates and smoothes out the vertical forces resulting from induced wave motions of the dredge. Because of this heave compensation, the TSHD can dredge effectively in sea states much higher than those that would limit the effectiveness of a cutter-suction dredge.

The trailer suction pipes are usually operated along portside of the barge by means of an articulated link that supports a hose connection between adjoining lengths of rigid pipe. This articulation permits relative movement between the draghead and the vessel. As the vessel pumping continues, the sediment particles settle in the hoppers, and the excess water passes overboard through overflow troughs. The volume ratio of solids to water is generally around 15%–20%. To reduce surface turbulence, overflow water is conducted along weirs and conveyed along the sides of the dredges opposite to where the dredged material is discharged into the hopper. In addition, to help reduce the effect of a surface plume, the overflow is conveyed down along the side of the vessel hull to discharge below the waterline. This allows sufficient time for the particles to settle before overflowing.

The primary source of suspended sediment is the hopper overflow. Sediment suspended at the draghead is generally local and close to the bed. The hopper overflow usually produces a dynamic plume phase (where highly turbid water forms a turbidity plume or current through the water column), a passive phase, and sometimes, a near-bed "pancaking" and laterally spreading turbidity current phase (W.F. Baird & Associates, Ltd. & Research Planning, Inc. 2004). "Pancaking" describes the effect of the vertical momentum of the dynamic plume phase impacting the bed and, with the subsequent transfer of this momentum, to spreading in the horizontal plane (W.F. Baird & Associates, Ltd. & Research Planning, Inc. 2004).

The maximum hopper size of TSHDs is in excess of 35,000 m^3. TSHDs have highly accurate positioning and control systems, allowing them to be operated with considerable precision in the dredging area.
Over the last few years, two other areas of development in TSHDs that have been adopted almost industry-wide are the under-hull release of overflow sediment (except for screening operations) and the use of anti-turbidity valves (Tsurusaki et al. 1988, Pennekamp and Quaak 1990, LaSalle et al. 1991). The purpose of these operational changes is to reduce the extent of suspended sediment plumes generated by the overflow process.

4.3 Numerical Modeling of the Physical Environment

4.3.1 Numerical Modeling Analysis

A numerical model simulation was applied to quantify the potential impacts of sand excavation from the B12, B11, A9, A9, A6, A5, and A4 shoals (Figure 4-1). The model simulation combines a wave-energy model and a two-dimensional, vertically averaged, circulation model. Four model grids were developed to cover the total of seven shoals. Applying several grids rather than one large model domain over the Northeast Florida coastal ocean was required to reduce the total calculation to a practical limit. Model runs for the separate domains could be conducted simultaneously at higher spatial resolution than would be practical over one large regional model grid. The wave model was driven by a combination of hind cast wave data and wind stress for local wave generation. Boundary conditions to drive the circulation and sediment transport model included wave conditions from the wave model, wind stress, and water-level time series containing oscillations at tidal and subtidal frequencies. In operation, the wave model was run to force the circulation and sediment transport models as well as to provide predictions of wave heights over the study area. Once the wave field was predicted, the resulting forces were combined with wind to drive the circulation model. The circulation model included sub-models to predict sand transport and erosion.

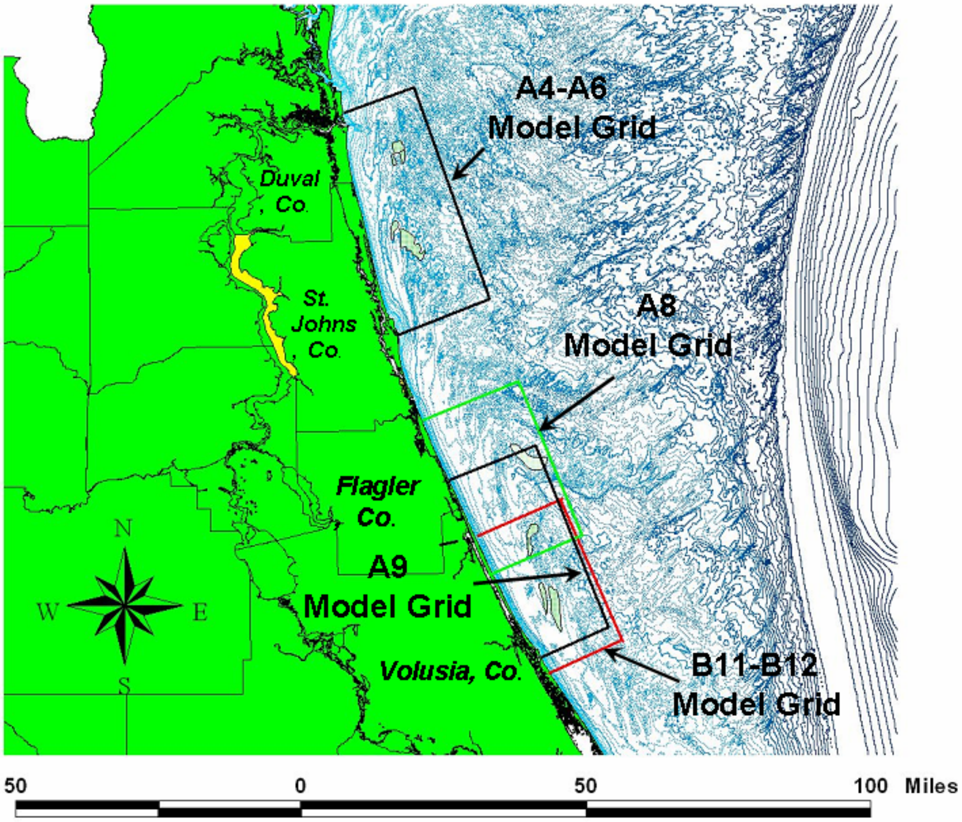


Figure 4-1. Location of the target shoals with the model grid boundaries in Northeast Florida, offshore St. Johns and Volusia counties.

The combined wave, circulation, sand transport, and topographic change modeling scheme was run for a two-year period from the beginning of January 1998 through the end of December 1999. This corresponds with the most recent availability of high-quality hind cast wave data from the Wave Information Study (WIS). Tables 4.1 and 4.2 compare characteristics of the hind cast wave climate the 1990–1999 decade as well as the 1995–1999 and 1998–1999 periods. The comparison shows that the distribution of significant wave height, peak period, and the distribution of energy by directional bin are similar through each period. The hind cast wave regime for the 1998–1999 period was specifically chosen for the model tests because it included the occurrence of record wave events associated with an active hurricane season. Results of the model runs were compared to determine predicted changes in wave patterns, sand transport patterns, and net topographic changes on the shoreface on both a regional and local basis with respect to the proposed sand borrow sites. The following sections provide the details of model setup and results of the model simulation.

4.3.2 Numerical Modeling Methods

The modeling methods are based on the USACE Coastal Modeling System (CMS), which was developed by the Coastal and Hydraulics Laboratory (CHL) of the Engineering Research and Development Center (ERDC) at the Waterways Experiment Station (WES) located in Vicksburg, Mississippi. This modeling system was chosen because of its widespread use within the U.S. coastal engineering community in a number of well-calibrated and validated applications. In addition, the CMS is largely in the public domain and available through a well-supported software platform known as the Surface Water Modeling System (SMS).

Table 4.1. Comparison of the occurrence of hind cast significant wave heights and peak periods over the decade of the 1990s.

Sig. Wave Height (m)	**Percent Occurrence**		
	1990-1999	**1995-1999**	**1998-1999**
0-0.49	5.7	7	6.9
0.50- 0.99	40.6	40	40.6
1.0-1.49	29.8	29.3	30.2
1.50-1.99	14.5	15.8	15.3
2.00- 2.49	6.0	5.3	4.3
2.50- 2.99	2.0	1.3	1.1
3.00-3.49	0.7	0.5	0.5
3.50-3.99	0.4	0.4	0.3
2.50- 2.99	0.2	0.2	0.3
4.00-4.49	0.1	0.1	0.1
4.50-4.99	0.1	0.2	0.3
5+	5.7	7	6.9
Peak Wave Period	**Percent Occurrence**		
	1990-1999	**1995-1999**	**1998-1999**
3-3.9	6.7	7.4	7.7
3-4.9	12.7	12.2	12.0
5-5.9	17.5	18.4	18.3
6-6.9	16.8	17.4	17.2
7-7.9	12.6	11.3	12.9
8-8.9	9.8	7.8	7.8
9-9.9	7.2	6.4	6.8
10-10.9	5.1	5.1	4.8
11-13.9	9.7	11.4	10.3
14+	1.9	2.7	2.0

4.3.2.1 Wave Model

The CMS wave model (CMS-WAVE) is based on the Wave-Action Balance Equation with Diffraction model (Mase et al. 2005). CMS-WAVE is a steady-state, spectral, finite-differencing model that simulates wave shoaling, wave refraction, wave breaking, and wave growth due to wind. CMS-WAVE is a new-generation wave model developed by ERDC to couple with two- and three-dimensional hydrodynamic models designed for high-resolution predictions in coastal waters. CMS-WAVE uses a forward-marching, finite-difference method to solve the wave action conservation equation. The capabilities of CMS-WAVE include wave shoaling, refraction, diffraction, forward reflection, depth-limited breaking, dissipation, and wave-current interaction. Wave diffraction is implemented by adding a diffraction term derived from the parabolic wave equation to the energy-balance equation. CMS-WAVE includes prediction of local wind-wave growth and white capping to redistribute and dissipate energy in a growing wave field.

Table 4.2. Comparison of the distribution of hind cast significant wave energy by directional bin over the decade of the 1990s.

Directional Bin Degrees*	Percent Occurrence		
	1990-1999	1995-1999	1998-1999
0.0	4.3	4.7	4.0
22.5	5.7	5.8	4.6
45.0	12.7	12.7	11.9
67.5	21.0	20.4	17.5
90.0	24.2	23.6	27.0
112.5	17.8	17.4	19.6
135.0	4.8	4.4	4.4
157.5	2.4	2.3	2.5
180.0	0.9	1.2	0.8
202.5	0.5	0.5	0.5
225.0	0.5	0.6	0.7
247.5	0.3	0.4	0.5
270.0	0.4	0.4	0.5
292.5	0.7	0.9	1.0
315.0	1.3	1.6	1.6
337.5	2.7	3.2	3.0

For the analysis of the potential effects from hypothetical borrow cuts in the northeast Florida shoals, the CMS-WAVE model was coupled with the CMS circulation and transport (CMS-FLOW) model to resolve wave radiation stresses and currents due to wave interactions. A two-way interaction between CMS-FLOW and CMS-WAVE was applied, allowing the circulation model to be updated with the wave stresses and wave-current interactions computed by CMS-WAVE. The wave calculation was also updated using changes in topography and wave-current interactions. CMS-WAVE includes options to dissipate frictional energy in shallow water and to reflect energy at the shoreline and coastal structures.

4.3.2.2 Circulation Model

The CMS-FLOW circulation model provides predictions of wave, tide, and wind-driven currents and sediment transport. CMS-FLOW is based on a finite-volume circulation and sediment transport model that solves the two-dimensional (2D) continuity and momentum equations as well as the sediment continuity equation (Buttolph et al. 2006). CMS-FLOW has recently been updated to apply an implicit calculation approach for solution of the hydrodynamic equations. This advancement enables rapid computation of water level and current velocity. CMS-FLOW calculates current velocity and water level at each hydrodynamic time step. First developed at the Florida Institute of Technology in 1994, the model code has been maintained and upgraded by the CHL. A newer CMS-FLOW feature is the ability to include hardbottom areas in the grid so that shore protection structures, reef rock outcrops, and artificial reefs can be represented in the model. During model calculations, the CMS-WAVE spectral wave model interacts with the CMS-FLOW circulation model by passing wave-produced radiation stresses to the circulation model at user-specified intervals. Similarly, current information can be returned to the wave model to provide full current–wave interaction between the models, which is an important process in shallow, nearshore areas dominated by waves and tides.

4.3.2.3 Sand Transport and Topographic Change Calculations

The simulation of sand transport is based on a submodel in the CMS-FLOW model code. Developed for CHL of WES at Lund University in Sweden, the sand transport subroutine is called the "Lund Formulation." The Lund Formula considers processes that can be important in shallow water under the influence of waves. Processes in the formulation relevant to dynamics of shoal features in the coastal ocean include bed load and suspended load, waves and current interaction, breaking and non-breaking waves, slope effects, initiation of motion, asymmetric wave velocity, and arbitrary angle between waves and current. Details of the formulation can be found in Camenen and Larsen (2005, 2006).

Topographic change is calculated from the predicted flux of sand movement through the model grid cells. The sand transport formulation provides predictions of sediment flux through the sides of each grid cell, and the topographic change at each time step is calculated according to a sediment continuity formulation that relates the change in topographic elevation to spatial and temporal flux of sand. Details of the sediment continuity formula can be found in Buttolph et al. (2006).

4.3.2.4 Model Grids and Boundary Conditions

The computational grids associated with the CMS-WAVE and CMS-FLOW resolve distances down to 80 m and 100 m, respectively. In model runs, calculations of wave forcing were completed on the wave model grid and interpolated onto the CMS-FLOW model grid, alternating the use of the two models under a model-steering module of the Surface Water Modeling System (SMS). Forcing for the wave model was provided by a time series of directional wind data from coastal meteorological stations in Northeast Florida and with data from NOAA C-Man Station SAUF1 in St. Augustine, Florida, and a similar station in Fernandina Beach near the mouth of the St. Johns River. Spectral wave forcing corresponding to the 1998–1999 model period was obtained from hind cast data from the ERDC WIS. Figure 4-2 shows the bottom topography used in the wave and circulation models, the location of shoals B12 and B11, and WIS Station 427 used to assemble spectral wave forcing for the southernmost model grid setup on the overall study area.

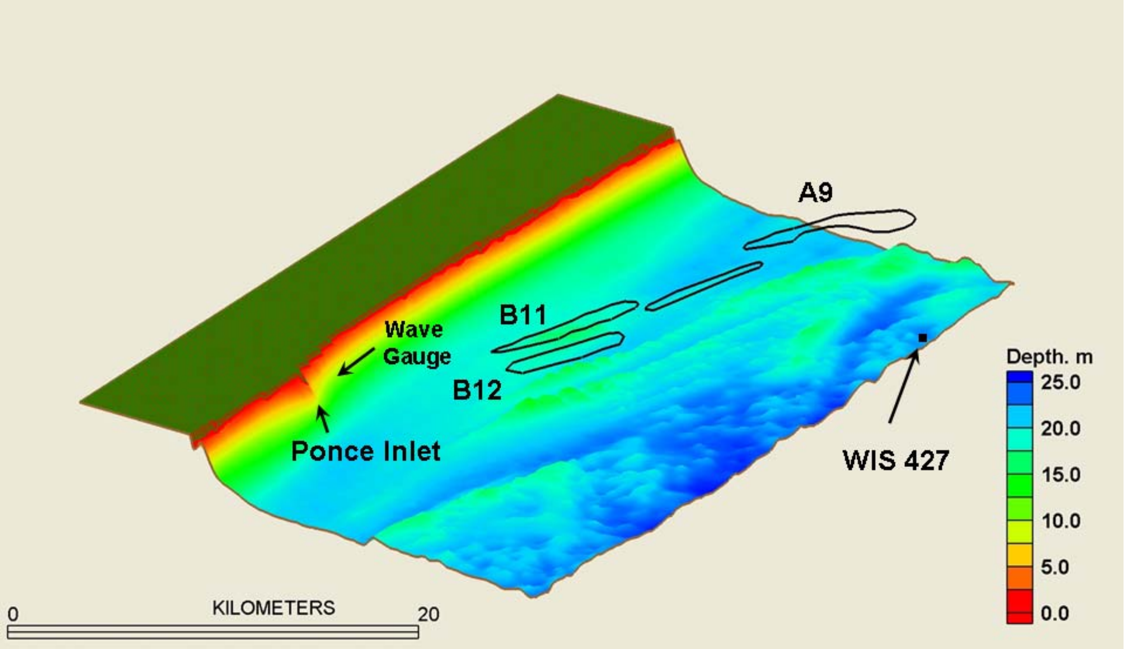


Figure 4-2. Location of the B11 and B12 shoals and bottom topography in the B12 and B11 model domain. WIS station 427 is shown at the seaward boundary of the model domain.

Water level forcing for the CMS-FLOW was obtained by combining predicted tides with the subtidal or low-frequency water level time series obtained by digital filtering the data from NOAA coastal water level stations at St. Augustine and Fernandina Beach. The tidal signal for each boundary cell in the CMS-FLOW model was extracted from the East Coastal Tidal Data Base (Mukai et al. 2001) created for the CHL for coastal modeling. Figure 4-3 shows the CMS-FLOW model grid for the B12 and B11 shoals along the boundary cell-string where water level forcing is applied. Also shown in this figure is series of numerical observation stations along the shoreline to record predicted time series of water level, flow, and sand transport rates.

Figure 4-4 shows the A9 shoal model grid and associated string of boundary cells established for calculations. Although the B12, B11, and A8 shoals are also included in the A9 model domain, calculations specific to possible excavations in B11 and A8 were conducted in separate model grids. Each model grid was designed to have the targeted shoal(s) located more or less in the central portion of each grid to avoid the slight numerical noise that can arise at the model boundaries. Thus, the A9 shoal is also present in the A8 shoal model grid. Figure 4-5 shows the northernmost model grid for the A6 and A4 shoals. In this case, the two shoals are in close proximity and can be included in one calculation.

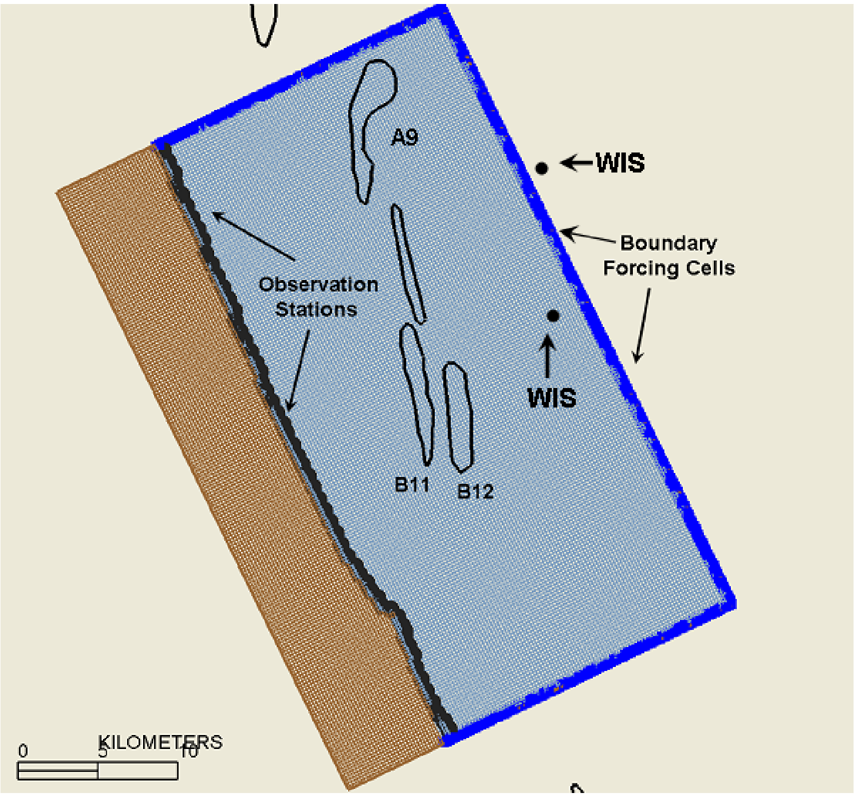


Figure 4-3. The CMS-FLOW model grid for the B11 shoal. The locations of the boundary forcing cells, shoreline numerical observation stations, and WIS wave hind cast stations are also shown.

For each model domain, three two-year runs were completed. The base model case used the existing topography to determine wave patterns over the shoal and at the shoreline without any excavations in the targeted shoals. The second case for each shoal included a typical or planned borrow area of limited dimensions in the target shoal topography. The simple or single borrow cuts range in total volume from about 1 million to several million cubic meters of sand. A third test case for each shoal represented the removal of a large volume from the crest of each target shoal. This case was aimed at examining the potential for cumulative impacts of repeated dredging of a borrow site that might occur over the life of a long-term beach restoration project or that might be permitted for multiple beach renourishments. Each alternative was run for a two-year period using wave patterns, sand transport rates, and predicted topographic changes.

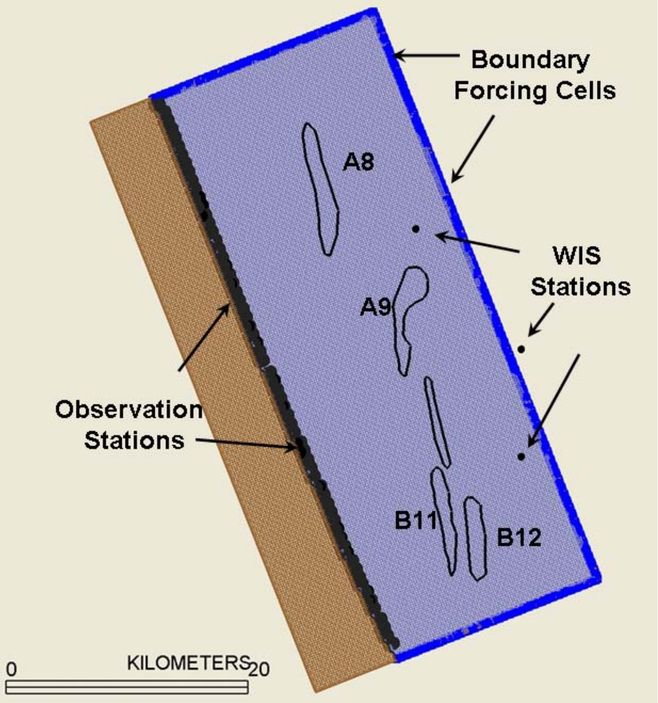


Figure 4-4. The CMS-FLOW model grid for the A9 shoal. The locations of the boundary forcing cells, the shoreline numerical observation stations, and the WIS stations are shown.

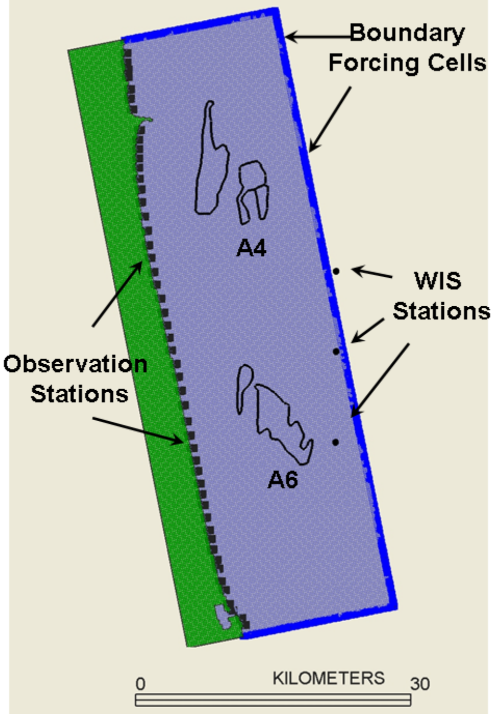


Figure 4-5. The CMS-FLOW model grid for the A6 and A4 shoals. The locations of the boundary forcing cells, the shoreline numerical observation stations, and the WIS stations are also shown.

During operation of the modeling scheme, the SMS steering module allowed the runs of the circulation and wave models to alternate. The initial model run consisted of two sweeps of CMS-WAVE to provide wave-orbital velocity and wave-generated radiation stresses to the CMS-FLOW. After the initial CMS-WAVE model runs, the steering model started the circulation model run, which continued to the next scheduled update of the wave field. Throughout the two-year model runs, updates of the wave field data file were scheduled at six-hour intervals. Wave data used to generate the spectral input at this interval were derived from the appropriate WIS stations. The modeling period extended from January 1998 through December 1999 and was based on the most recent comprehensive WIS data available and the occurrence of several major storms. Major boundary input data included the low-frequency components of water level variation, water level time series at the tidal frequency calculated from the tidal constituent database (Mukai et al. 2001), and spectral wave data from the WIS database. Wind forcing was also included among the forcing processes for each model grid.

There are very limited data available from the northeast Florida inner continental shelf for model calibration. In addition, there are no reliable current velocity data available for the locations represented by the model grids. However, local measurements of the nearshore directional wave field were conducted from 1995 through 1997 (King et al. 1999). The measurement method of the directional wave field was based on spectral analysis of co-located, high-frequency measurements of sea surface elevation and current velocity. These measurements were used to extract significant wave height, peak period, and the direction of wave energy associated with the peak period. While there are some drawbacks to this method that limit the accuracy of measuring energy from spectral bins outside the peak period and direction, the method is considered to provide a good estimate of significant wave height. A description of the measured data set can be found in King et al. (1999). The data are available from the CHL web site at http://sandbar.wes.army.mil/.

The location of the directional wave gauge used to check the calibration of the wave model (CMS-WAVE) is shown in Figure 4-2 and also in Figure 2-27. This location is within the B12 and B11 model grid just offshore of Ponce de Leon Inlet, where water depths are about 8 m (24 ft). The wave climate of Northeast Florida was discussed in Section 2.3.6 of this report. Although measured data for model calibration is limited in duration, it is important to demonstrate that the wave model produces predicted data that are close to the measured significant wave height. This is especially true for the nearshore and littoral zone where breaking waves are responsible for driving the littoral currents that transport sand and cause deposition and erosion. To examine the skill of the CMS-WAVE model for prediction, nearshore wave regime comparisons were made with measured data from the CHL gauge acquired in 1997. The CMS-WAVE model was run on the B12 and B11 model grid using WIS hind cast data for 1997, and results were compared to portions of the measured data set that are free of gaps in the record. Overall, the match between model and measured data was good, as shown in Figures 4-6 and 4-7. The model slightly over-predicted significant wave height derived from the Ponce Inlet directional wave gauge. With wave heights larger than about 50 cm (1.5 ft), the match was very close. In Figure 4-7, it can be seen that the linear regression between measured and model data resulted in a correlation coefficient of 0.93. The comparison between predicted and measured wave periods that represent the spectral energy peak was also very good. Figure 4-8 shows this comparison in which the match was generally within 1 to 2 seconds. The correlation coefficient between the measured and predicted period was not as high as the correlation between the wave height time series (Figure 4-9). This was due to the difficulty in establishing a representative wave period from the both the gauged data and hind cast data that were equivalent. The average wave period and the period of the peak spectral energy bin are available from the WIS hind cast data. In gauged data the period is reported only from the peak energy bin.

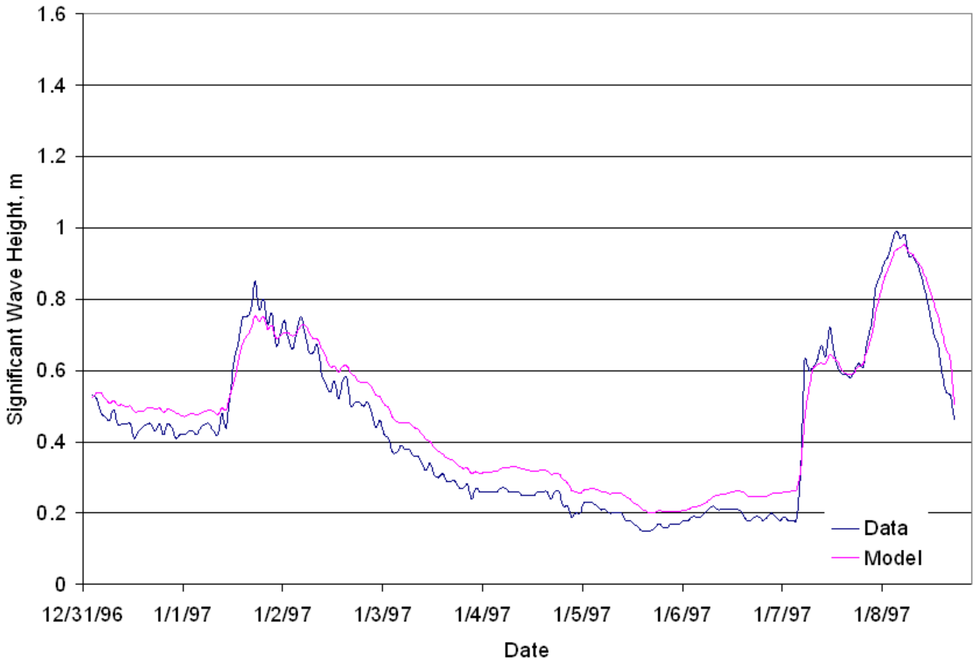


Figure 4-6. Comparison between modeled and measured significant wave heights for the first 10 days of 1997. Gauge location is shown in Figure 4-2.

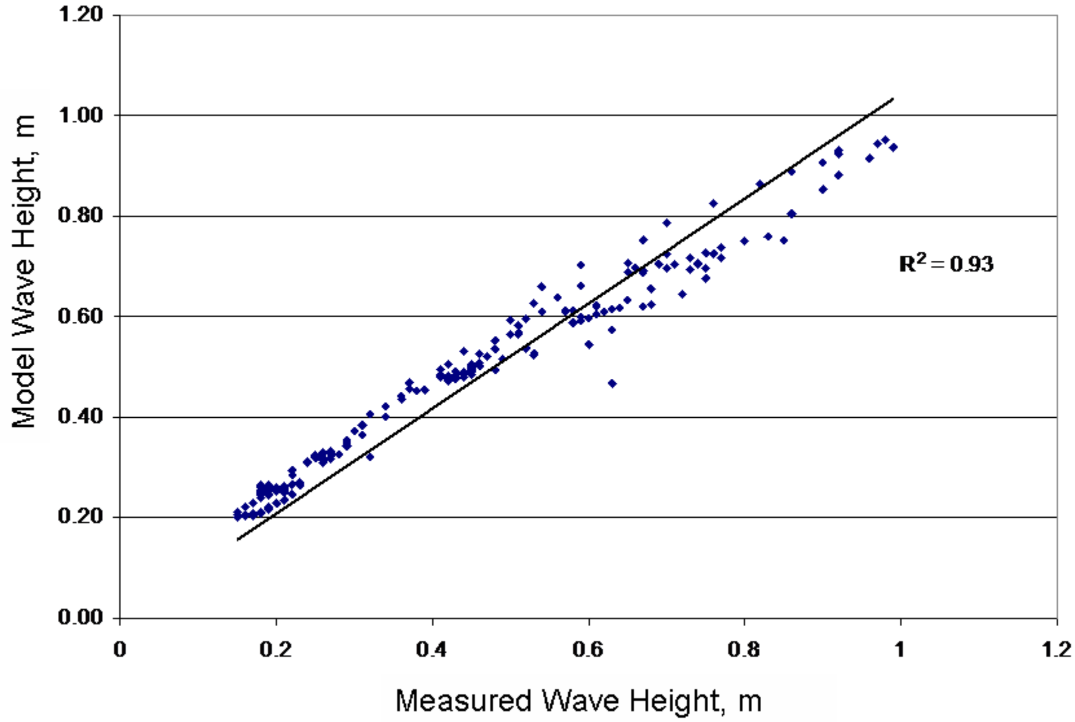


Figure 4-7. Correlation between measured and predicted significant wave height at the location of the CHL Ponce Inlet wave gauge.

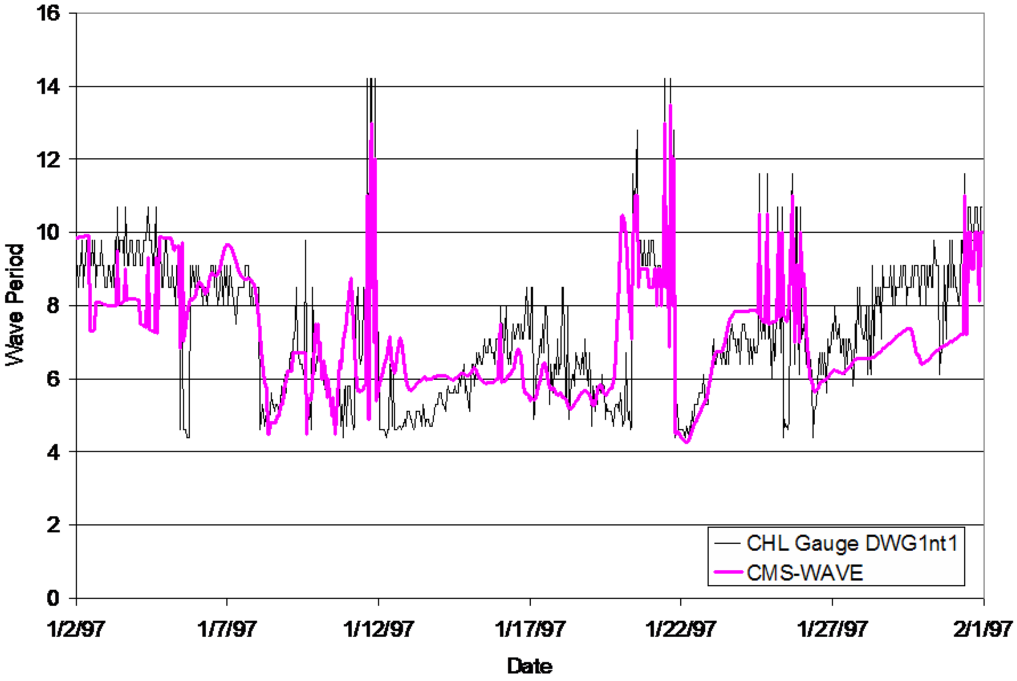


Figure 4-8. Comparison between gauged and modeled wave period near Ponce Inlet, Florida for the month of January 1997.

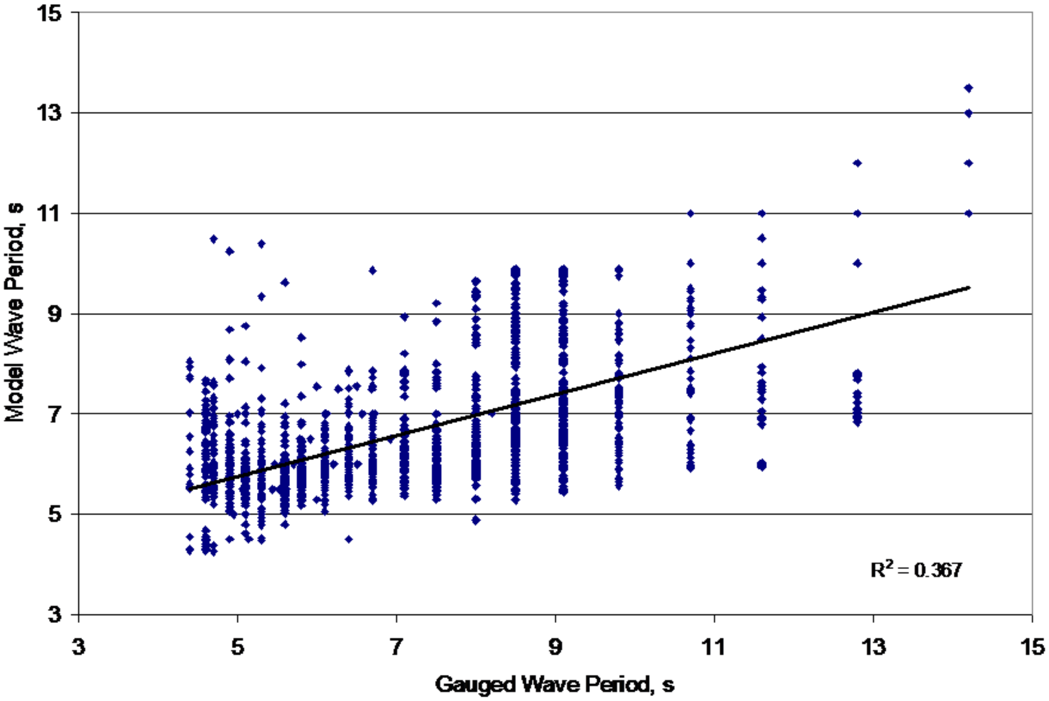


Figure 4-9. Correlation between measured and predicted wave period at the location of the CHL Ponce Inlet wave gauge.

The period of the peak energy bin is typically reported but can be ambiguous and not representative if multiple spectral energy peaks are present. Although there is scatter between the time series, the pattern of change is closely matched between the gauged and modeled data. Figure 4-10 and 4-11 compare the gauged and predicted wave direction at the location of the Ponce Inlet nearshore directional wave gauge. Considering the smoothing of the real bottom topography when interpolated onto the wave model grid, the match between the measured and predicted data is considered to be very good. Similar to the other statistical eave parameters that are extracted from the analysis of wave gauge data, there can be some ambiguity in representing wave directions.

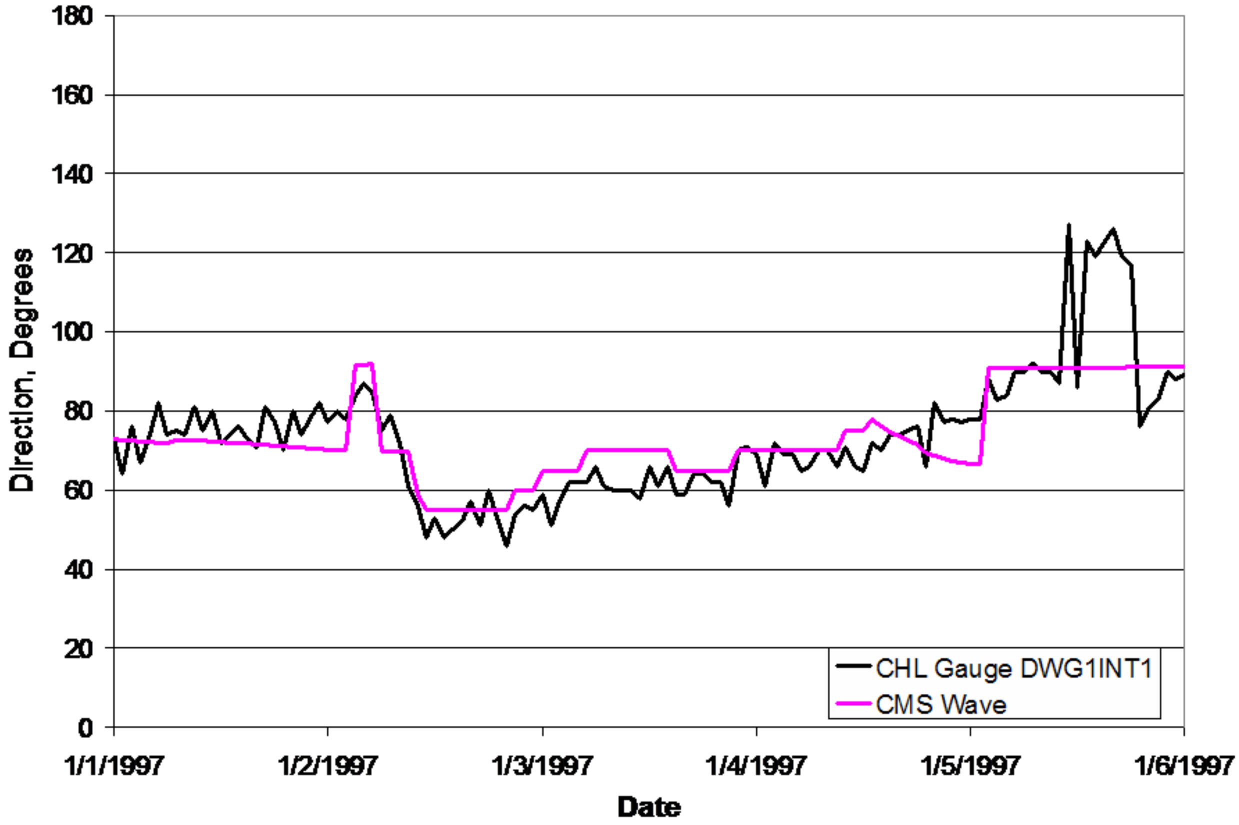


Figure 4-10. Comparison between gauged and modeled wave direction near Ponce Inlet, Florida for the month of January 1997.

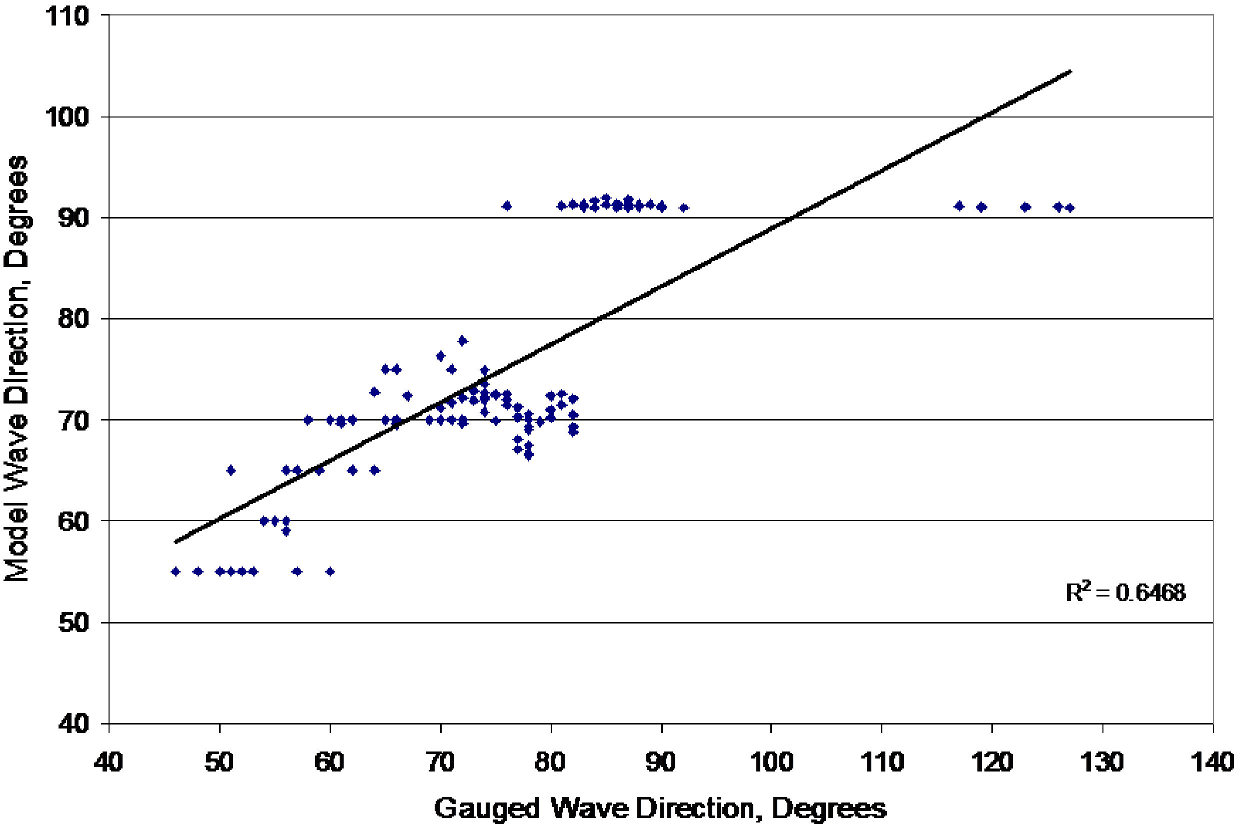


Figure 4-11. Correlation between measured and predicted wave period at the location of the CHL Ponce Inlet wave gauge.

4.3.3 Numerical Model Results

The goal of the model simulation is to quantify the potential for significant physical influence at and near the shoreline as a consequence of dredging large volumes of sand from shoals B11, A9, A8, A6, and A4. The results of the model simulations are presented with respect to wave patterns, littoral transport near the shoreline, and predicted topographic changes on the shoreface in littoral water depths. Model results are provided for before and after dredging in borrow sites on the shoals of single borrow cuts and of large dredge cuts designed to represent removal of sand for multiple beach-fill projects. The model bathymetry for each shoal area was adjusted to pre-dredge conditions and for two additional cases consisting of a single borrow cut and multiple borrow cuts. A total of 12 model test cases were examined. Table 4.3 summarizes the model test cases that were performed in each of the study sites. The volume of the hypothetical single or initial cut for each shoal or group of shoals ranged from approximately 2.8 to 14.4 million cubic meters (3.6 to 18.7 million cubic yards) in the case of the A6, A5, and A4, which are included in the same model grid. The expanded and multiple borrow cuts range from 10.8 to more than 84 million cubic meters (14 to 109 million cubic yards) for the A6–A4 shoal system.

Table 4.3. Summary of Model Test Cases

Model Test	Location	Borrow Cut	Volume (cubic meters)	Test Duration
Case 1	B12–B11 Shoals	None	0	2 years
Case 2	B12–B11 Shoals	Single/Planned	4.1 million	2 years
Case 3	B12–B11 Shoals	Expanded/Multiple	17.4 million	2 years
Case 4	A9 Shoal	None	0	2 years
Case 5	A9 Shoal	Two	1.7 million	2 years
Case 6	A9 Shoal	Expanded/Multiple	10.8 million	2 years
Case 7	A8 Shoal	None	0	2 years
Case 8	A8 Shoal	Single	2.8 million	2 years
Case 9	A8 Shoal	Expanded/Multiple	12.9 million	2 years
Case 10	A6–A4 Shoals	None	0	2 years
Case 11	A6–A4 Shoals	Existing/single	14.4 million	2 years
Case 12	A6–A4 Shoals	Expanded/Multiple	84.5 million	2 years

Model Results: B12 and B11 Shoals

Predicted Changes in Wave Patterns

The configurations of single borrow cuts listed in Table 4.3 for the B12–B11 shoals are shown in Figure 4-12. The locations of core borings used to identify beach-quality sand are also shown in this figure. Figure 4-13 shows multiple hypothetical cuts placed in these shoals that could be part of a multiyear beach renourishment project. The initial cuts as shown in Figure 4-13 total 4.1 million cubic meters of sand. The extended borrow cuts for the multiyear replenishment project approximate 17.4 million cubic meters and result in lowering the topography of both shoals by 2.5 m over an area of about 7 sq km.

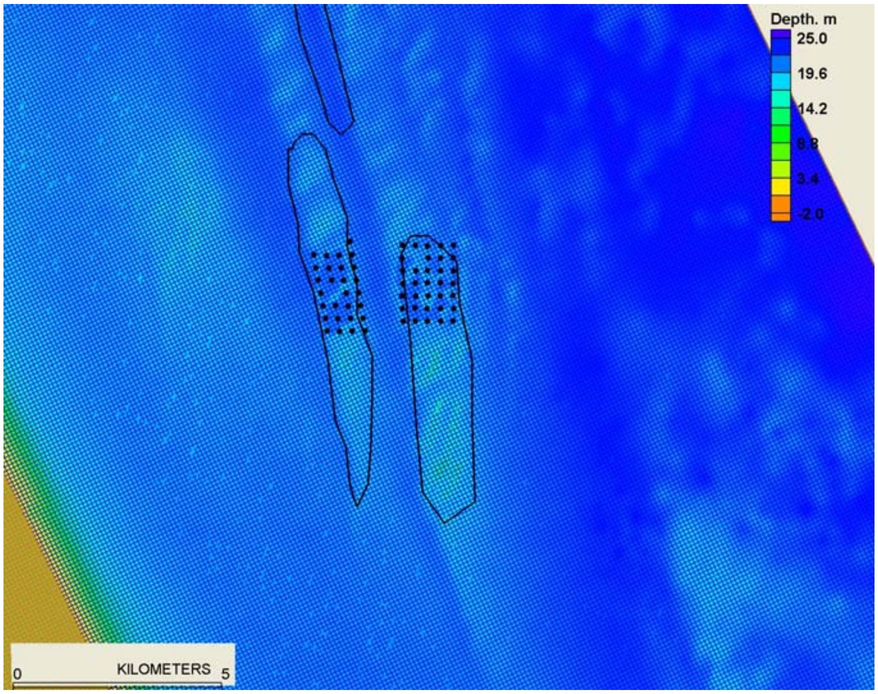


Figure 4-12. Location of single borrow cuts in the B12 and B11 shoals based on geotechnical information developed by Volusia County, Florida. Vibracore locations marked with black circles.

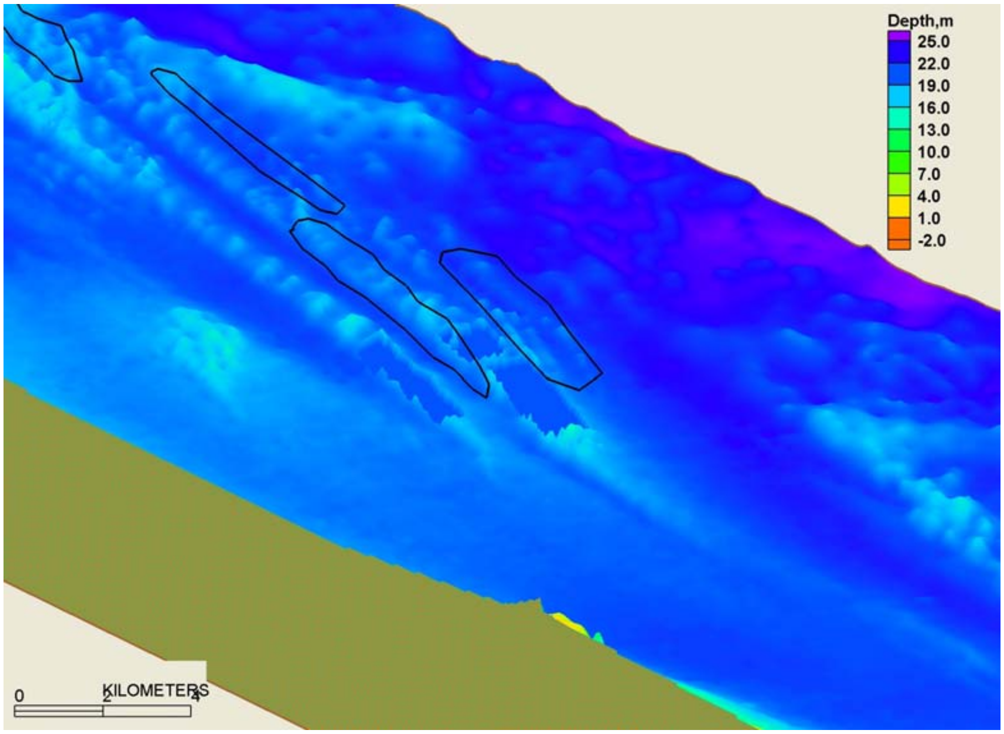


Figure 4-13. Perspective view from the southwest of multiple borrow cuts in the B12 and B11 shoals representing a multiyear beach renourishment plan.

Model tests indicate that detectible changes in the wave regime from the hypothetical excavations over B12 and B11 occurred only during storm events. During the 1998–1999 period, several events occurred that included a combination of long-wave periods and high-wave heights. The maximum episode of this kind was related to Hurricane Floyd in mid-September 1999 (Figure 4-14). According to the WIS hind cast data, the highest and longest period waves affecting the study area coast occurred several days after the storm transited the northeast Florida continental shelf. In mid-September, a long fetch that was developed when the storm was well to the northeast of Florida resulted in waves of 6 to 8 m high and periods between 10 and 14 sec.

The predicted wave field over the B12 and B11 shoals showed distinctive differences among the three cases that were examined (Cases 1, 2, and 3, Table 4.3). The most apparent differences occurred during storm conditions. Long-period waves propagating across the shoals and borrow areas were slightly influenced by shoal topography. Figure 4-15 shows the predicted wave height and direction over the shoals during the passing of Hurricane Floyd off Florida’s east coast in September 1999. Figure 4-16 provides the details of wave refraction as waves 4 m high and approximately 14 sec in period passed over shoals B12 and B11. Figure 4-17 depicts model results for Case 2 in which only a portion of the crest area of the shoals has been cut away. Thus, change in wave direction shown by the vectors occurred over the highest elevations where water depths were approximately 13 to 14 m. In the borrow cut areas, water depths over the crest of both shoals was nearly 19 m.

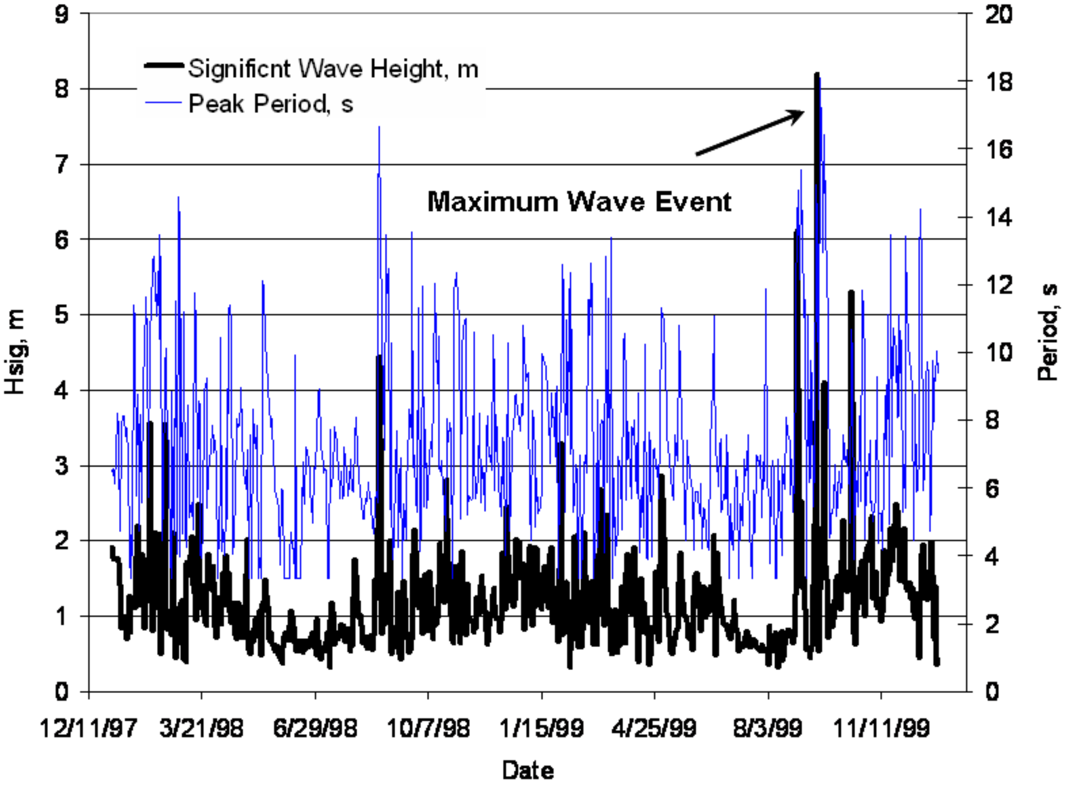


Figure 4-14. Hind cast of the significant wave height and peak wave period for the northeast Florida inner continental shelf during 1998–1999. The peak wave event is related to the passage of Hurricane Floyd.

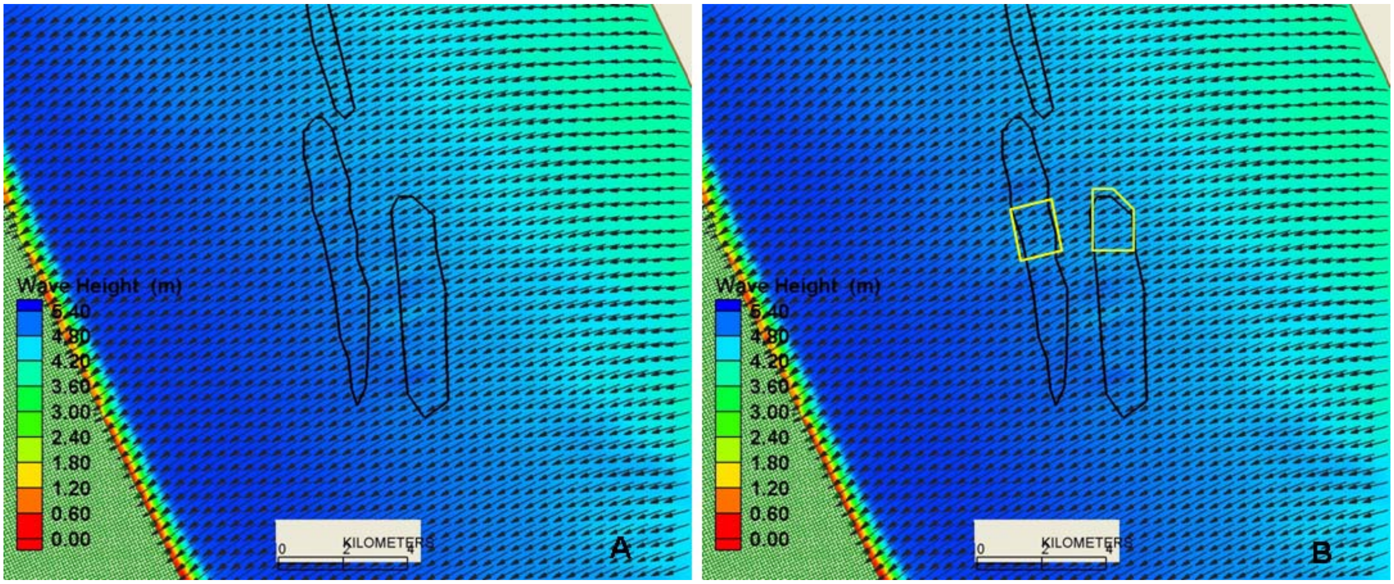


Figure 4-15. Predicted wave height and direction over Shoals B12 and B11 during Hurricane Floyd, September 1999. Wave patterns over the existing topography are shown in panel A, and predicted patterns with borrow cuts in place are shown in panel B (Case 2, Table 4.3). The perimeters of the proposed borrow excavation areas in panel B are marked with a yellow line.

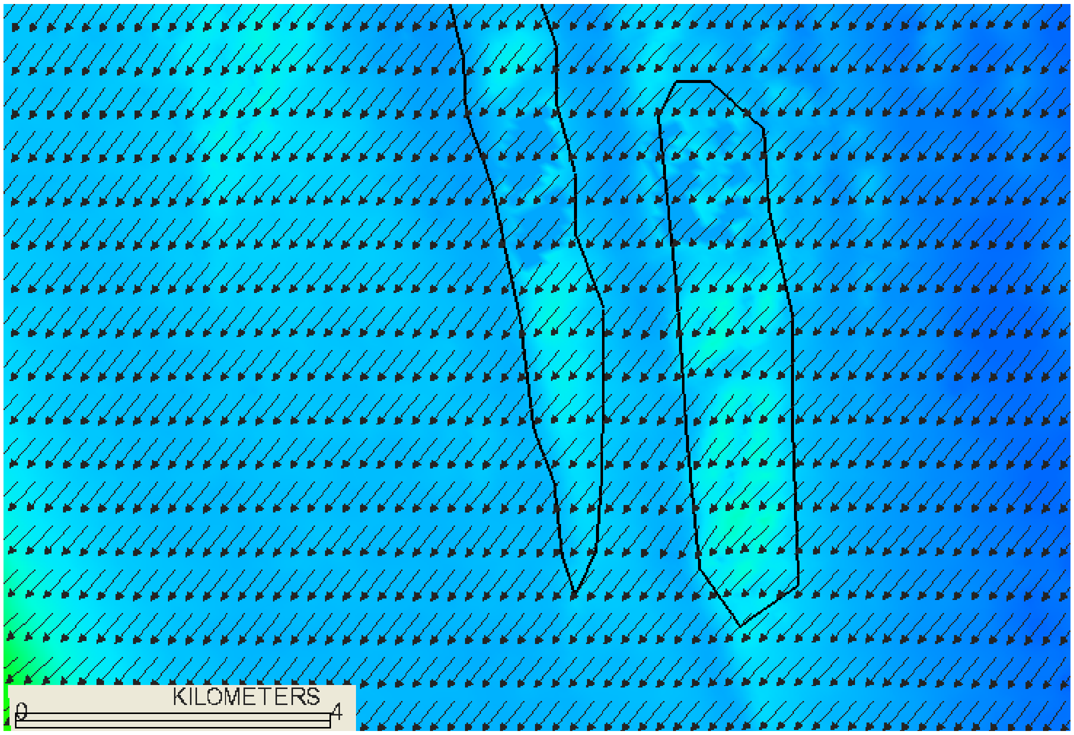


Figure 4-16. Wave refraction patterns over B12 and B11 as predicted for single borrow cuts proposed for Volusia County, Florida. Model prediction corresponds to Case 2 listed in Table 4.3.

The smaller borrow cut (Case 2) shown in Figure 4-12 result in small variations in wave height as shown in Figure 4-17, which depicts net differences in wave heights with and without the initial borrow cuts in place. With the smaller borrow cuts placed in the model grid, a localized decrease in wave height of 22 cm occurred over the borrow areas. A slight increase in wave height is predicted at the lateral borders of the borrow cuts. Overall, the magnitude of wave height increase due to shoaling of long-period waves over the borrow areas is predicted to be reduced once the borrow cuts are excavated. Figure 4-18 shows the influence of a more extensive set of borrow cuts that could be placed in B12 and B11 over the life of multiple excavations (Case 3, Table 4.3). Under Case 3, the decrease in wave height over the crest of the shoals was more widespread, owing to the much larger excavation area. Near the shoreline, the difference in wave height for Cases 1, 2 and 3 reduced to less than 1 cm. This minimal difference occurred within the surfzone, where breaking waves drive longshore currents and transport sand both along the shore and in the cross-shore direction. Thus, model results for conditions consistent with a category 2 hurricane estimated minimal potential for large changes in the wave regime at the shoreline due to major excavations over the B12 and B11 shoals.

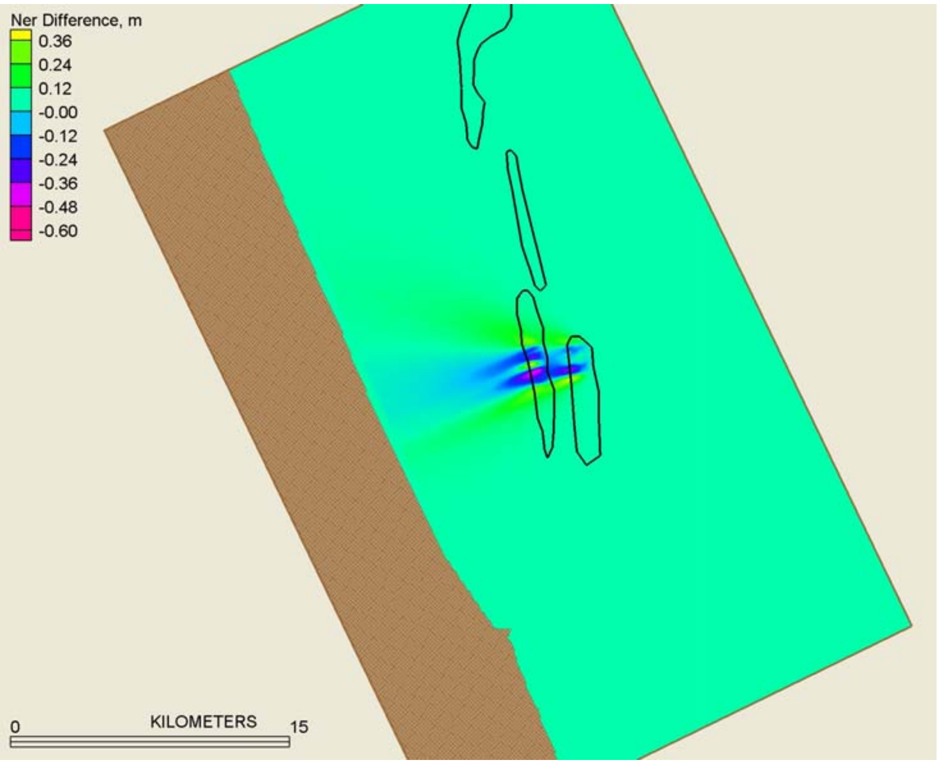


Figure 4-17. Predicted net differences in wave height after completion of proposed borrow excavation Case 2 in B12 and B11 shoals. Applied wave conditions were hind cast for Hurricane Floyd, August 1999.

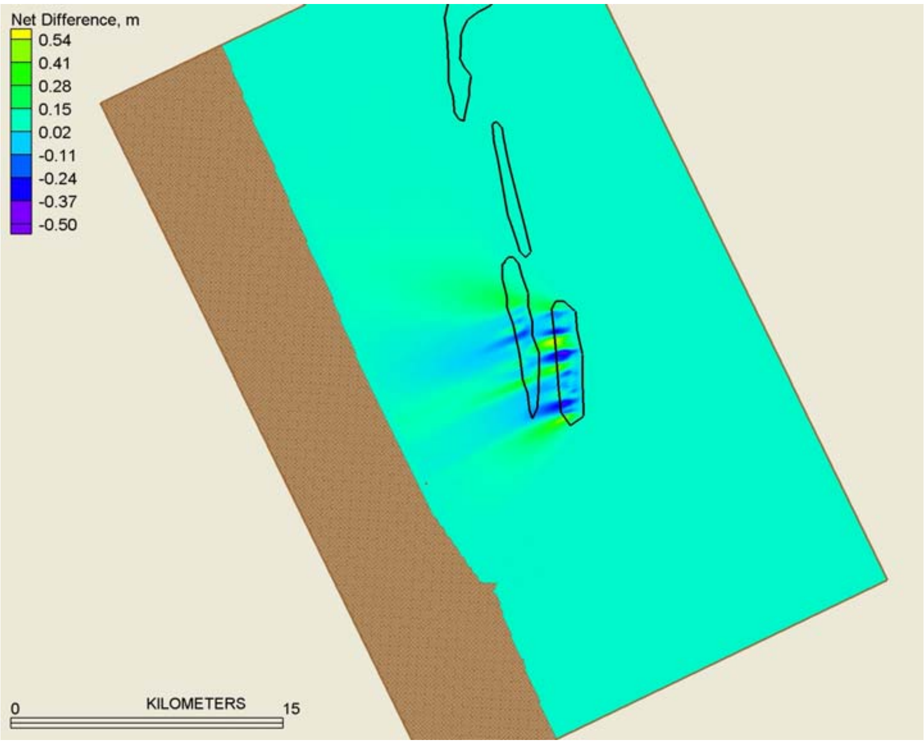


Figure 4-18. The influence of a more extensive set of borrows cuts (Case 3, Table 4.3) in B12 and B12 shoals, representing multiple excavations.

Figure 4-19 depicts the predicted difference in wave heights resulting from a long-period swell arriving from the east–northeast in April 1999. In Case 2, maximum wave heights over the shoals exceeded 3 m and wave height differences with the initial cuts in place were between 15 and 25 cm over the crest of the shoals. Similar to the predicted wave conditions generated by Hurricane Floyd, the influence on wave height near and at the shoreline was less than 1 cm. Figure 4-20 illustrates model results for the same long-period swell for Case 3 (Table 4.3). The results were similar to those of Case 2 but included more wide-spread reductions in wave height due to the greater water depth over the excavated areas. Near the shoreline, the difference in predicted height was less than 1 cm. These results are similar to those for Hurricane Floyd. Again, the potential for impacts on the littoral wave regime nearshore due to offshore borrow excavation is very small. The following sections further examine the potential for changes in the sand transport rates and topographic changes.

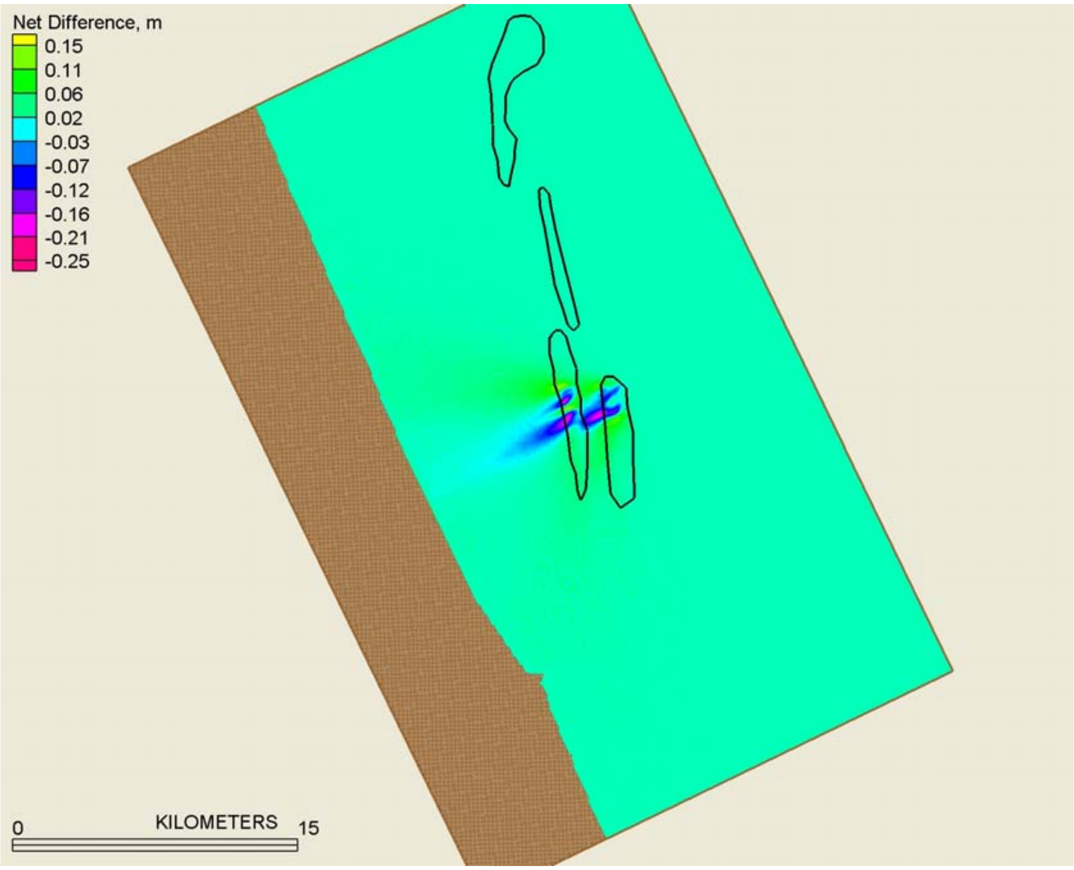


Figure 4-19. Predicted difference in wave height after Case 2 excavations with respect to a long-period, high-energy swell arriving from the east–northeast in April 1999.

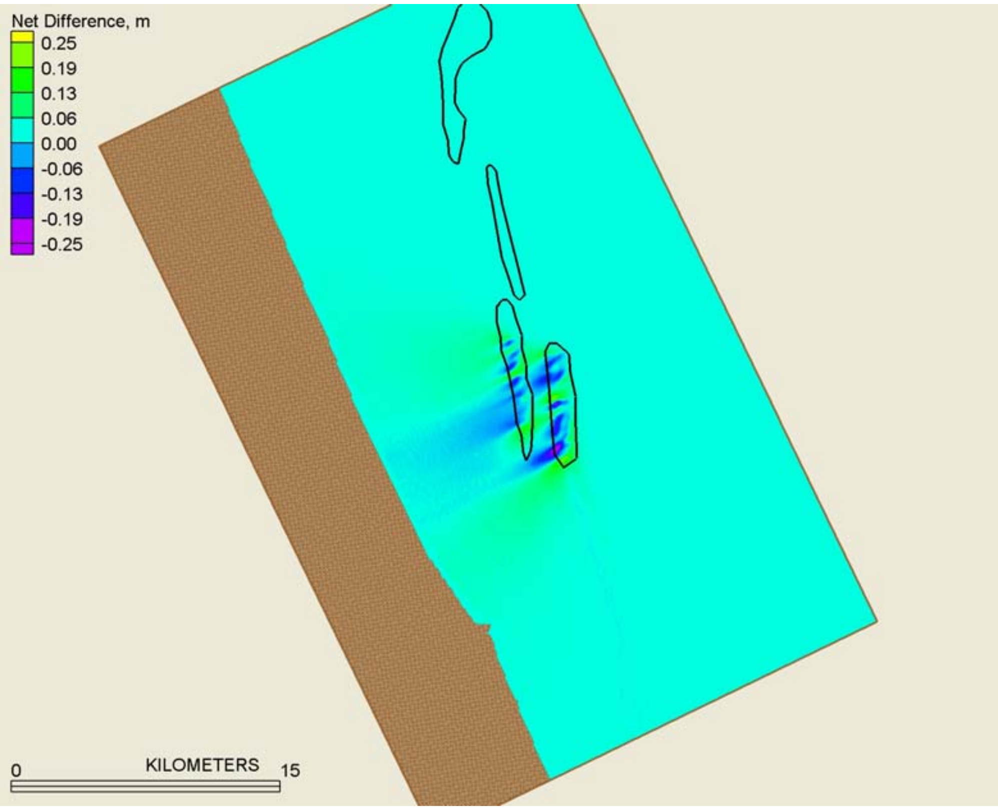


Figure 4-20. Predicted difference in wave height after Case 3, multiple excavations, with respect to a long-period, large swell arriving from the east–northeast in April 1999.

Predicted Sediment Transport and Topographic Change: B12 and B11

Figure 4-21 shows the predicted total instantaneous sand transport for September 22 when offshore wave heights reached a maximum of about 6 to 7 m as a result of Hurricane Floyd. Generally, sand transport is weak in the coastal ocean under most wave conditions. During higher energy conditions associated with storms, as shown in Figure 4-21, portions of the inner shelf can be subject to some transport. The most intense transport was expected to occur in the nearshore and surfzone as shown in Figure 4-21, which corresponded to the passing of Hurricane Floyd. Also apparent in Figure 4-21 is transport driven by waves breaking over the ebb shoal of Ponce Inlet. Figure 4-22 shows transport patterns associated with the passing of a mild northeaster in February 1999. The most intense transport was confined to the upper shoreface near the shoreline.

Most of the predicted topographic change over the 1999 simulation period occurred episodically as a result of specific storms or higher energy wave conditions. Figure 4-23 depicts results for Case 3, net topographic change with the passing of Hurricane Floyd. The largest changes occurred on the nearshore zone and shoreface along the north section of the model domain. Here a continuous band of erosion was predicted on the upper shoreface along with corresponding nearshore zone of deposition. Maximum topographic change over the 100-m model cell resolution was +/- 0.5 m. In reality, local changes are likely to be larger over smaller spatial scales.

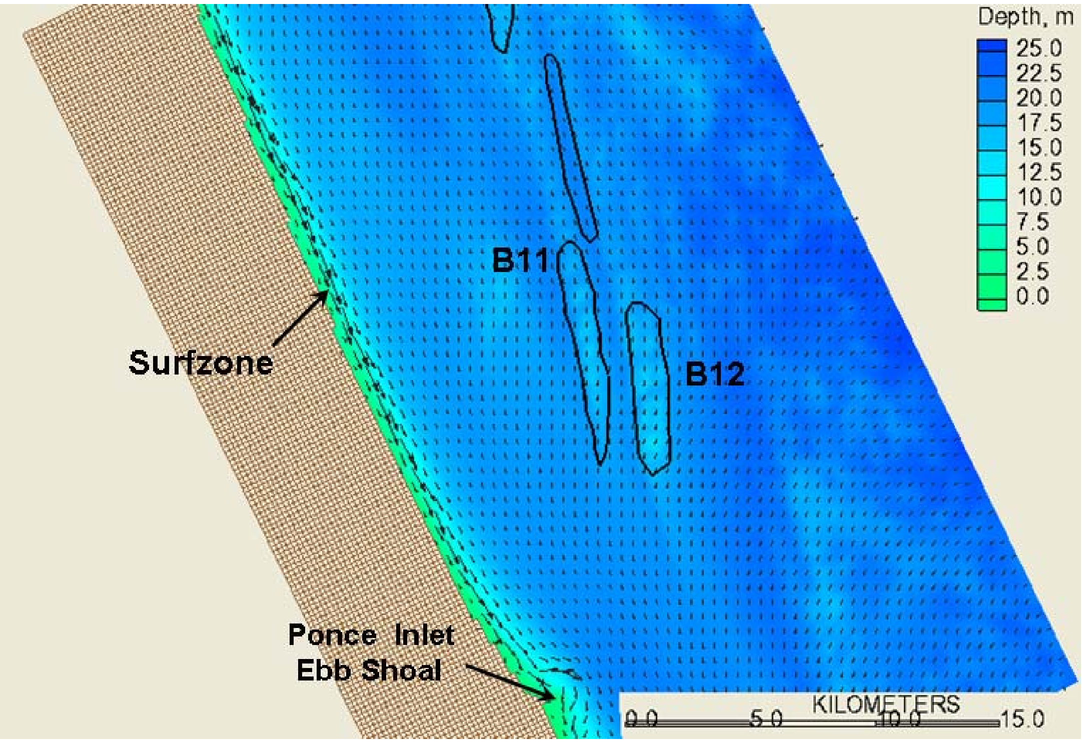


Figure 4-21. Instantaneous sand transport predicted during wave conditions produced by Hurricane Floyd in September 1999.

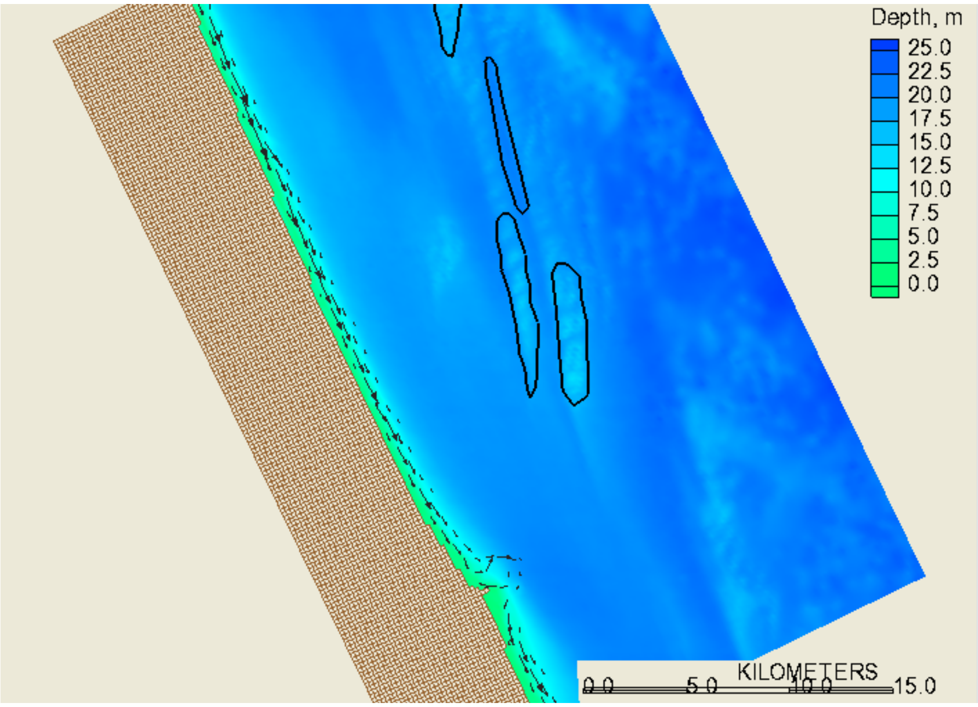


Figure 4-22. Predicted instantaneous sand transport on February 10, 1999.

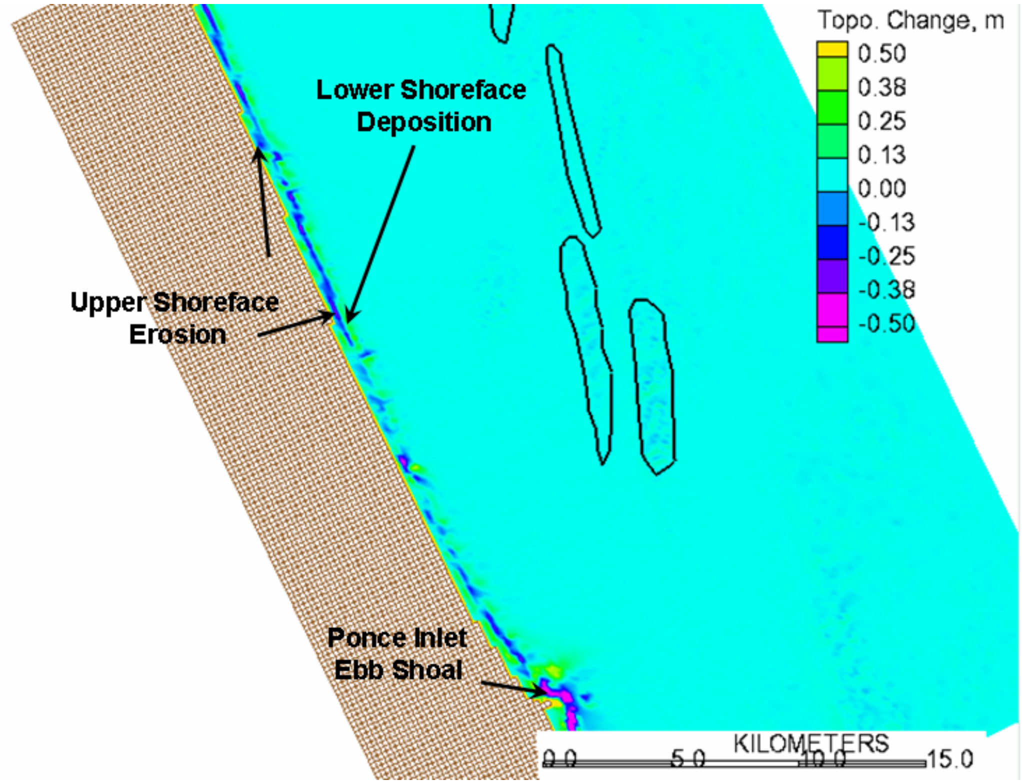


Figure 4-23. Predicted net topographic changes under Case 3 as a result of Hurricane Floyd, September 1999.

Figure 4-24 shows the net topographic change after 24 months of simulation (Case 2). Under Case 2, the range of change over this period was +/-2 m. Most of the predicted changes occurred on the shoreface close to the shoreline.

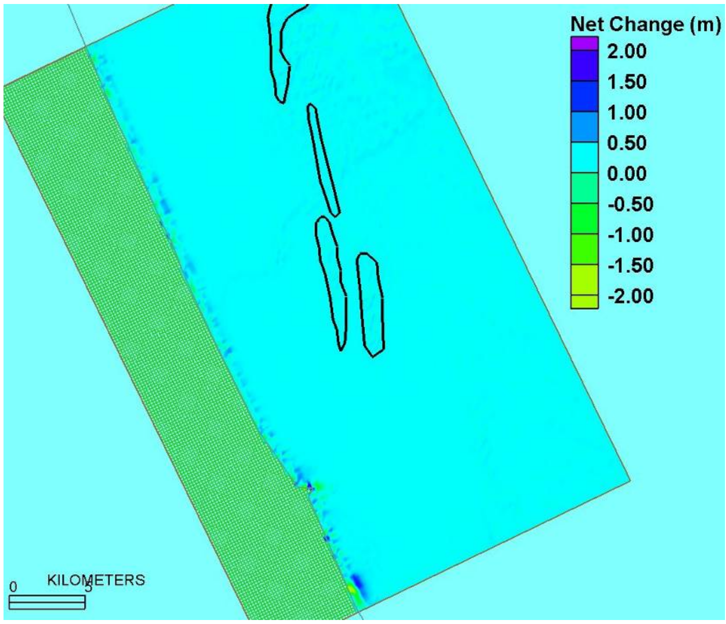


Figure 4-24. Predicted net topographic change after 24-months of simulation.

Figure 4-25 shows the predicted net topographic change in the areas of the B12 and B11 shoals after 24 months of simulation under Case 2 (see Figure 4-9). The deposition and erosion patterns over the crest of the shoals more or less corresponded to the topographic variations in the original model topography. Thus, over the 24-month period of the simulation, the model topography underwent some smoothing as the hydrodynamic conditions were applied. When the excavated borrow cuts were included in the model topography, the deposition and erosion patterns reflected the presence of the cuts. For instance, in the presence of the cumulative borrow cut (Case 3, Table 4.3), predicted topographic changes were more abrupt around the rim of the cut, as shown in Figure 4-26. The pattern included an outer zone of erosion and an inner zone of deposition. As seen in Figures 4-26, 4-27, and 4-28, the predicted net changes over the two-year period are small. The reality of this predicted change is uncertain since detailed time series observations of topographic changes over shelf sand ridges are not available. However, the results of the simulation may indicate that in the post-borrow-cut period, some topographic smoothing may occur. To fully understand the topographic response of sand ridges that have been excavated, both long-term observations and model simulation would be required. Model simulations on the decadal time scale or longer may be required.

The maximum predicted topographic change over the crest of the B12 and B11 shoals during the model run was +/- 0.2 m. Most changes occurred during storms or higher energy conditions that could mobilize the higher crest areas of the shoals at water depths of 13–14 m.

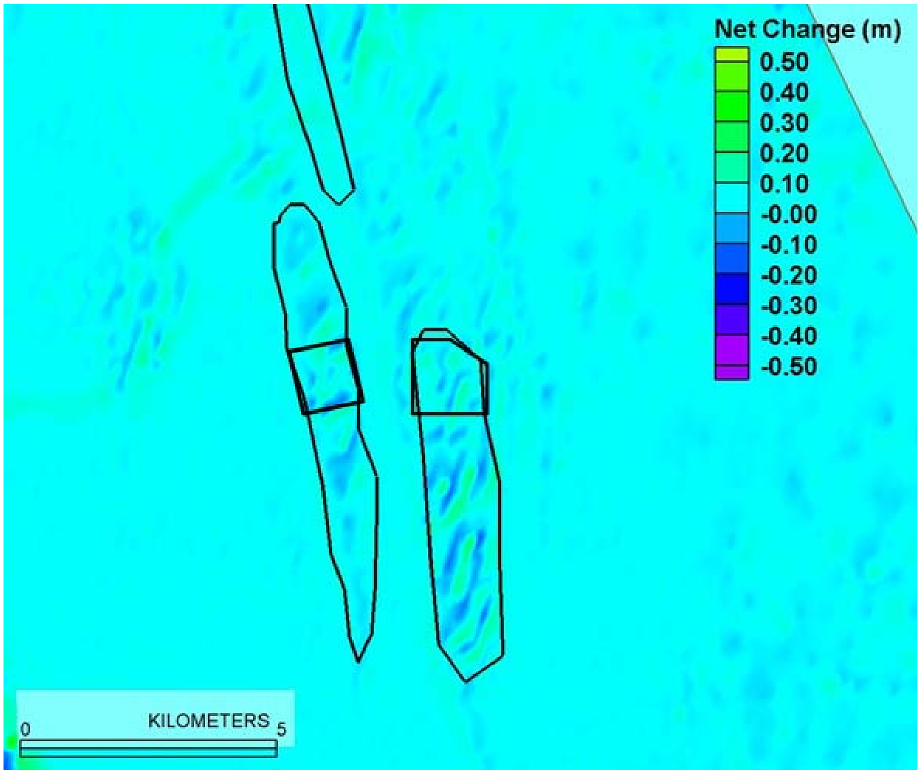


Figure 4-25. Predicted net topographic change near B12 and B11. Heavy lines show the positions of the borrow cut configuration planned by Volusia County, Florida.

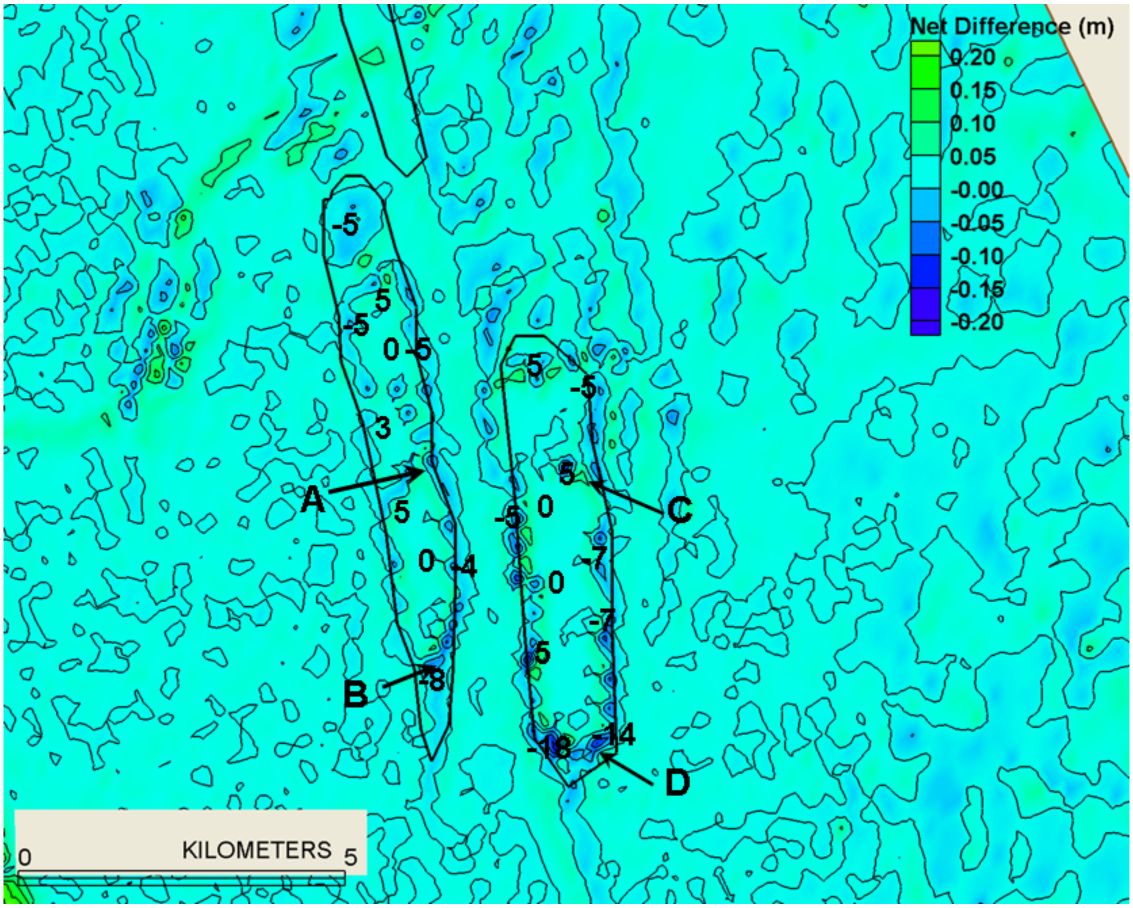


Figure 4-26. Predicted topographic changes over the cumulative borrow excavations of the B12 and B11 shoals after 24 months of simulation. Numbers indicate topographic change in cm. Time series of topographic change were recorded at Stations A, B, C and D.

When comparing predicted topographic changes near the shoreline for the pre- and post-borrow-cut model simulations, the difference among the three cases (Cases 1, 2, and 3) was near zero. Net predicted topographic differences among the three test cases were detectible in the areas directly onshore of the shoals containing the borrow sites and for approximately 10 km to the south along the shoreface. Figure 4-29 shows the difference in net topographic change between Cases 1 and 2, which includes the current excavation plan proposed by Volusia County. The main difference between test Cases 1 and 2 occurred as a result of the effects from Hurricane Floyd during the 1999 run. The differences were relatively small in area and magnitude, amounting to a maximum of +/- 0.04 m, as shown in Figure 4-29. In other areas of the model, the net topographic difference between Case 1 and Case 2 along the shoreline was near zero and within the limits of numerical noise of the model calculation. Figure 4-30 makes a comparison between Case 1 and Case 3 (Table 4.3), which includes excavation over much larger areas of shoals B12 and B11 as shown in Figure 4-13.

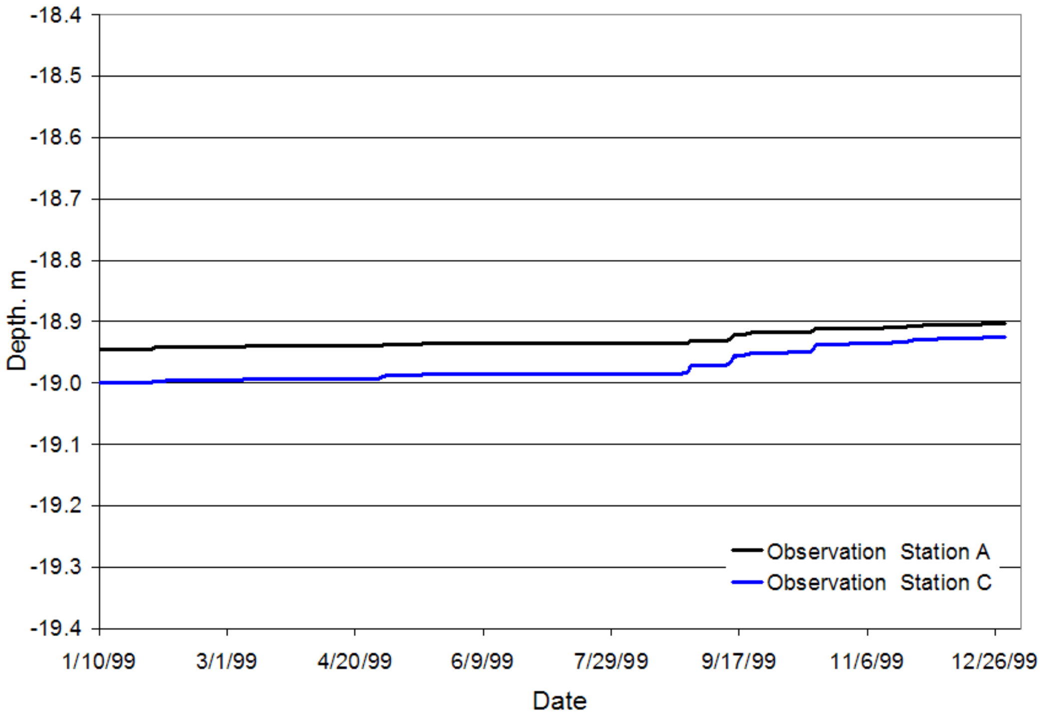


Figure 4-27. Time series of topographic change at model observation stations A and C on the rim of the cumulative borrow excavation in shoal B11. Locations are shown in Figure 4-26.

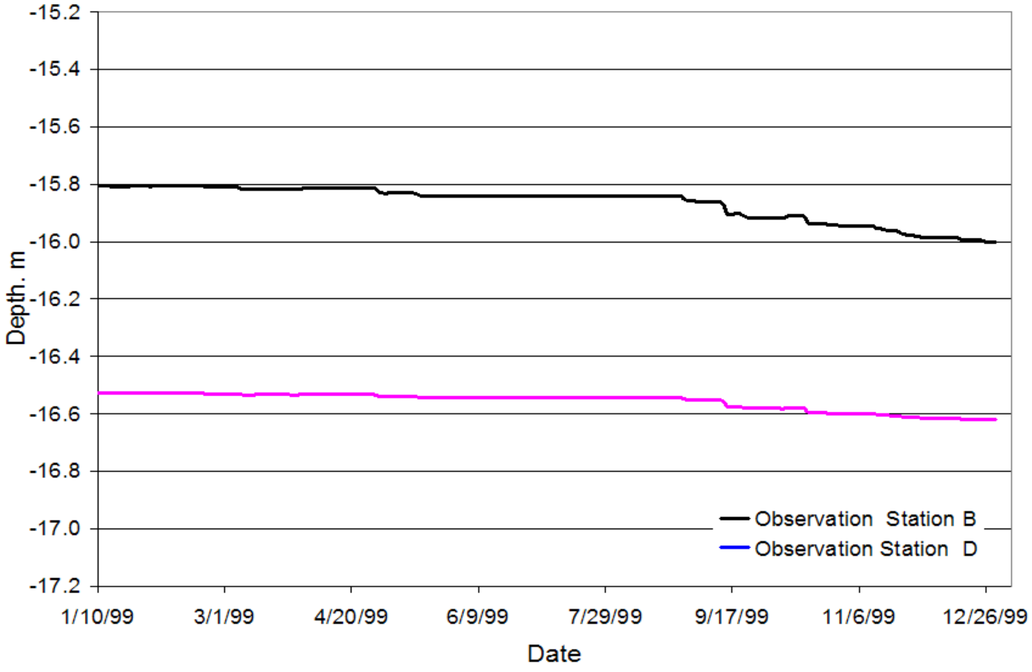


Figure 4-28. Time series of topographic change at model observation stations B and D on the rim of the cumulative borrow excavation in shoal B11. Locations are shown in Figure 4-26.

The history of topographic change for individual model cells can be examined to illustrate the small differences among the three test cases. This analysis also emphasizes the episodic changes in topography that are related to storm events. Figure 4-31 shows the location of four observation stations on the upper shoreface landward of the B12 and B11 shoals from which the time series of topographic changes were extracted and plotted. Figure 4-32 shows the time series of topographic change for 1999 at these four stations and for each of the model cases (Cases 1–3). The differences among the predicted topographic changes at each of the four stations were less than 3 cm among the three cases. In addition, at each station shown in Figure 4-31, the largest of topographic change was episodic in association with storms or higher wave energy events.

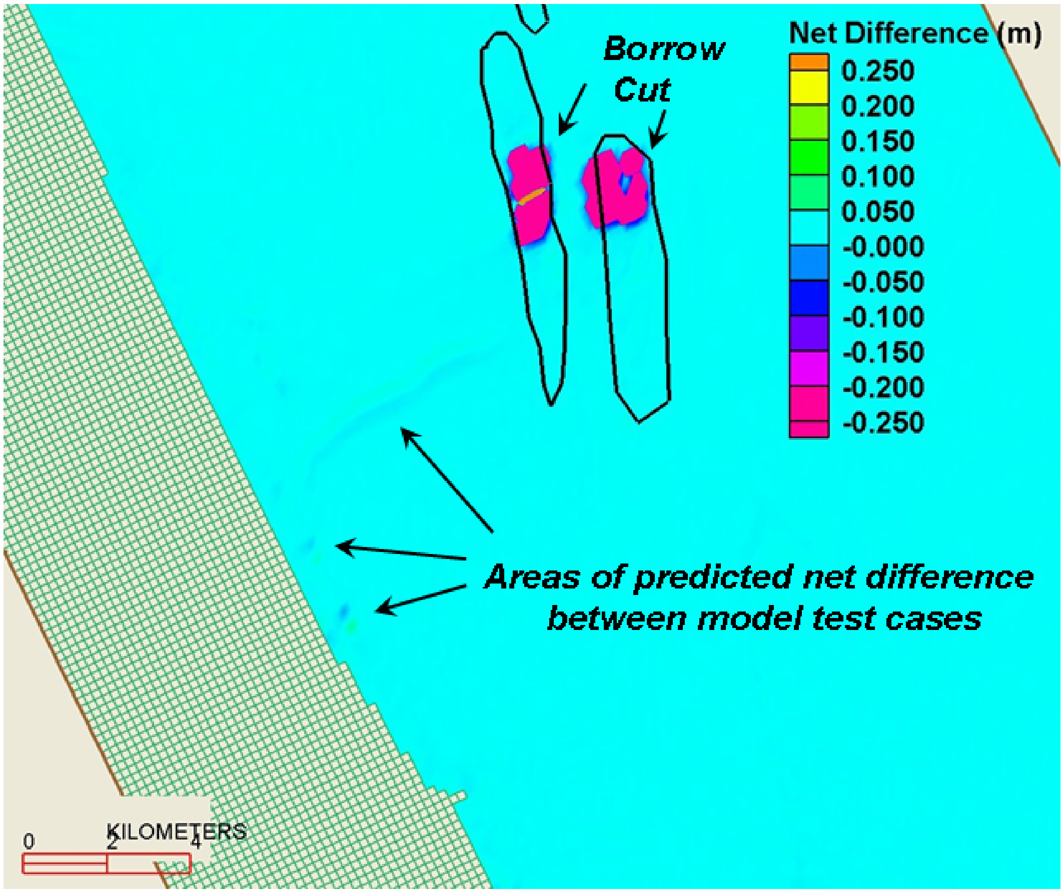


Figure 4-29. Calculated difference in net topographic change for model Case 1, without excavations, and model Case 2, with borrow cuts placed in the model topography.

Figures 4-33 and 4-34 show details of predicted topographic change of Cases 1 and 3 for 1999 at Stations 18 and 24, respectively. Although the vertical resolution on the plots has been expanded, it is still difficult to view the differences among these cases, which was 1 cm or less. Note the predicted topographic change at the shoreline from the impact of Hurricane Floyd during early September 1999.

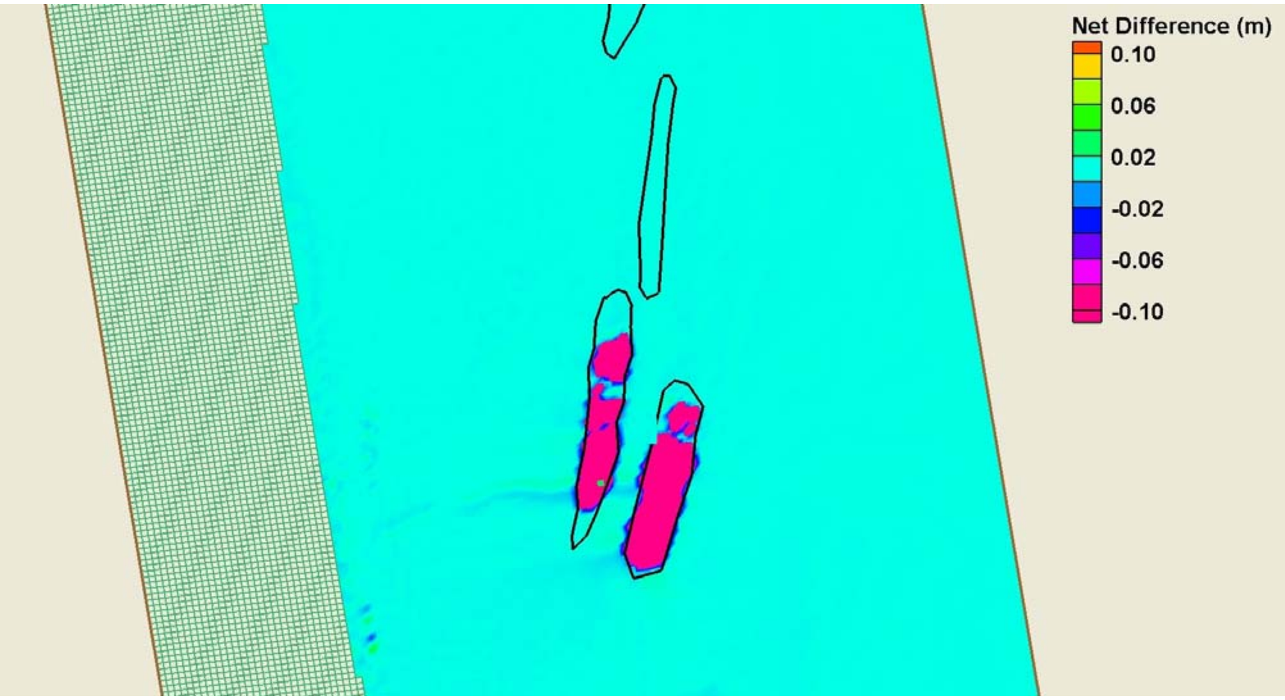


Figure 4-30. Differences in net topographic change for model Cases 1 and 3, without borrow cuts and with multiple cuts, respectively, placed in the model topography.

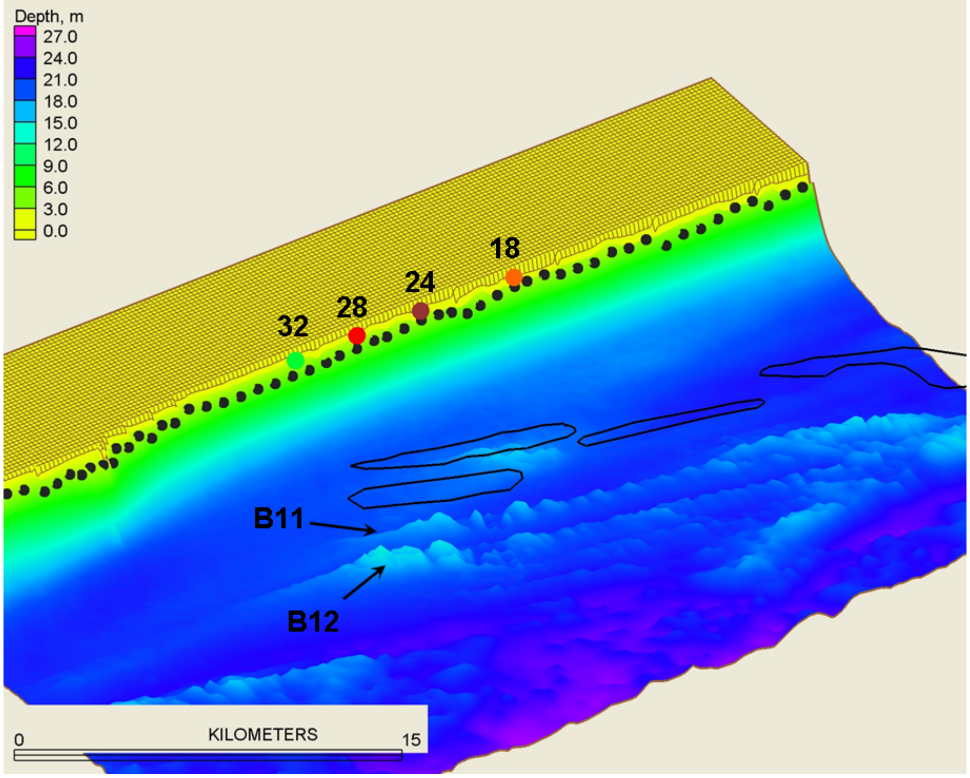


Figure 4-31. Location of numerical observations stations in the littoral zone used to extract the time series of topographic changes.

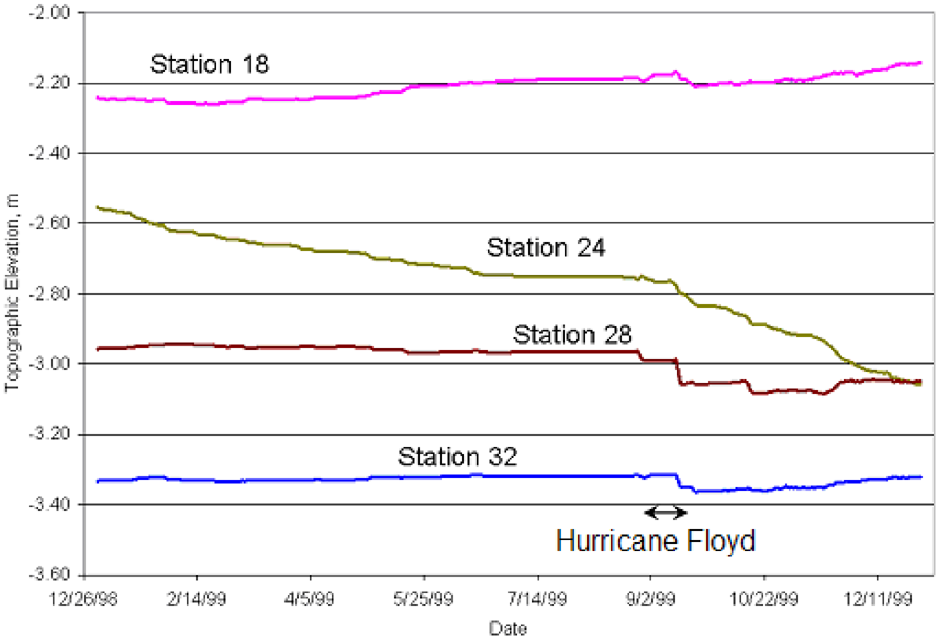


Figure 4-32. Predicted topographic changes for 1999 at numerical monitoring stations 18, 24, 28, and 32. Model test Cases 1, 2 and 3 are plotted for each station but not resolved due to the minimum differences among the results. Station locations are shown in Figure 4-31.

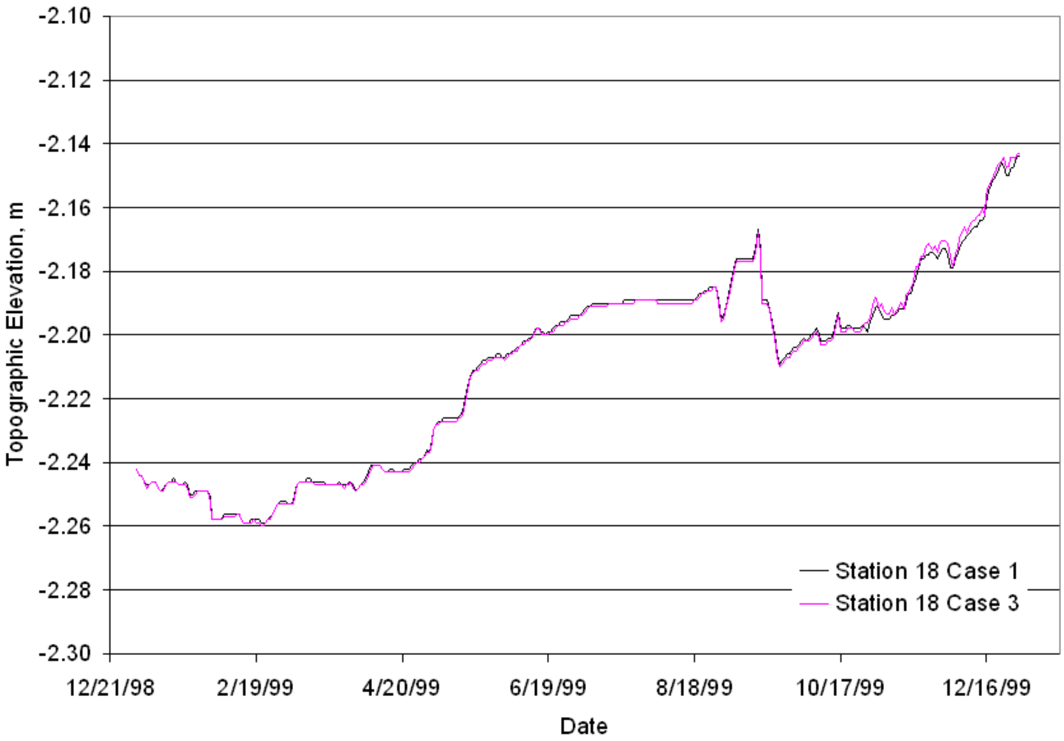


Figure 4-33. Predicted change in elevation at numerical observation Station 18 during 1999 for Cases 1 and 3. Station locations are shown in Figure 4-31.

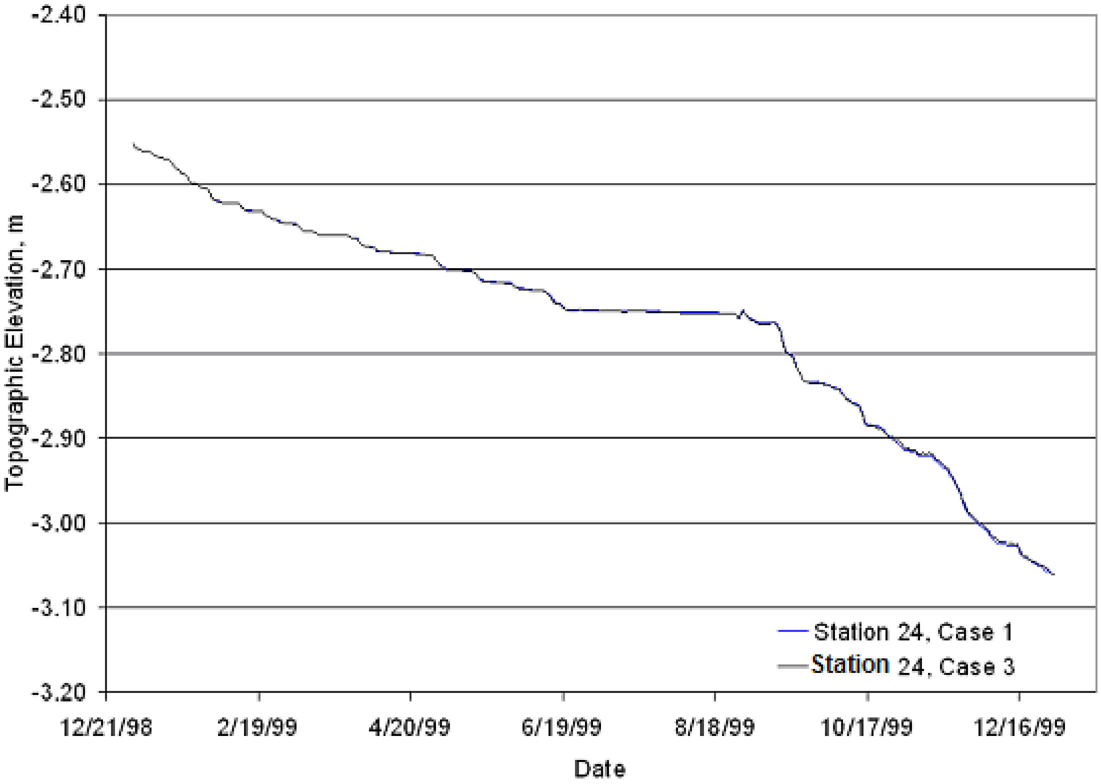


Figure 4-34. Predicted change in elevation at numerical observation Station 24 during 1999 for Cases 1 and 3.

Predicted Littoral Transport: B12 and B11

In this section of the analysis, predicted net littoral transport is compared among model runs with and without the borrow cuts placed in shoals B12 and B11. Using the time series of sand transport rates predicted in model cells (see Figure 4-31) covering the nearshore area of shoaling and breaking waves, a total net annual rate of longshore transport was calculated for model runs with and without borrow cuts in shoals B12 and B11 for 1998–1999. (Figure 4-35). In Figure 4-36, the difference between the net annual rates of littoral transport calculated at each numerical recording station was minimally detectible when comparing Case 1 with model test Case 3. Overall, the rates were reasonable when compared to previous estimates for the Florida's east coast. The dominant net littoral sand direction directions from north to south. The maximum annual rate of approximately -130,000 m^3/year occurred south of Ponce Inlet near the southern boundary of the model. A transport minimum occurred on the north side of Ponce Inlet where sand was impounded by the north jetty. Strong variation in the rate and direction of sand transport around the entrance of the inlet was consistent with the current knowledge that trapping sand at the jetty structures and refraction of wave energy around the ebb shoal are common inlet features. It is noted that tidal flushing though the inlet throat was not calculated in the model, nor did it include back-barrier bays, estuaries, or lagoons. In reality, local net littoral drift at finer spatial resolution is likely to be higher. The direction and order of magnitude of the predicted net littoral transport along Florida's east coast was consistent with previous estimates by Dean and O'Brien (1987).

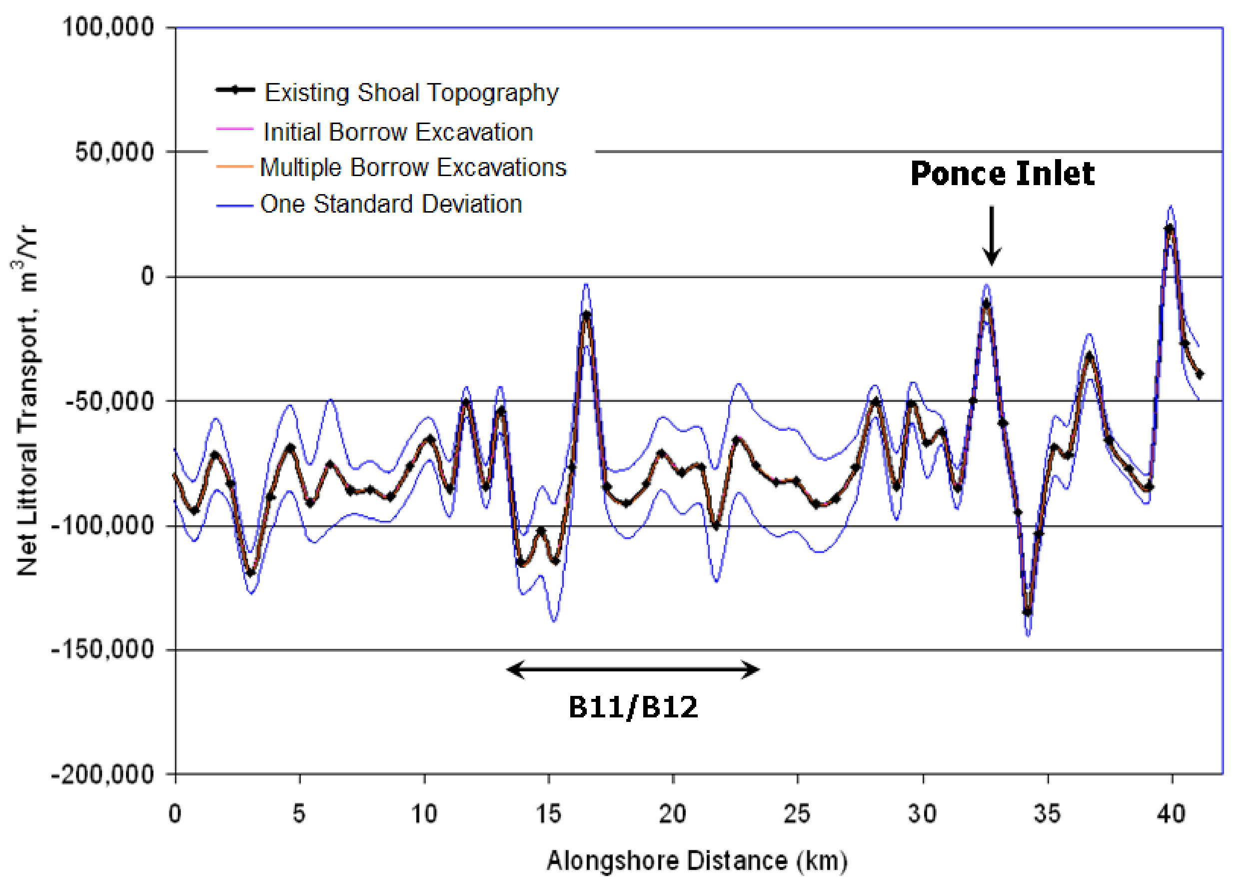


Figure 4-35. Annualized predicted net sand transport with/without the borrow cuts in shoals B12 and B11. The positions of Ponce Inlet and longshore extent of the shoals are shown.

Figure 4-36 shows the annual difference between the net littoral drift calculations along the shoreline for model test Cases 1 and 3. The zone of influence at the shoreline in response to the two borrow areas placed in the model topography was clearly detectable in the results. In the area immediately onshore of the borrow sites, the increase in net littoral drift reached a maximum of about +/- 500 m^3/year higher in comparison to the pre-borrow case. The reduction in net drift between 18 and 25 km indicated that the predominant southerly directed net drift in this section was reduced by 500 m^3/yr. On the other hand, from about 13 to 18 km, the higher negative values indicated a slight increase in the annualized drift rate.
Thus, presence of the borrow cuts on the crest of the B12 and B11 shoals produced a small but detectable zone of influence.

Although the influence of two borrow areas on B12 and B11 was detectable in the results of the model simulations, the magnitude of the changes should be considered with respect to the natural variability of transport rates on the shoreface. Figure 4-37 compares the temporal standard deviation determined from predicted sand transport to the annual net transport rate. The standard deviation characterized the temporal variability of predictions at each station that were integrated over time to arrive at the annual net transport. The maximum difference in annual net transport (Figure 4-36) is at least one order of magnitude less than the standard deviation. The net difference in predicted littoral transport between existing topographic conditions over the B12 and B11 shoals and Case 3 is detectible and related to several storms and high-energy wave conditions occurring in 1998–1999. However, the signal was small compared to the annual sediment budget and the variability in transport that can be expected in the northeast Florida littoral zone.

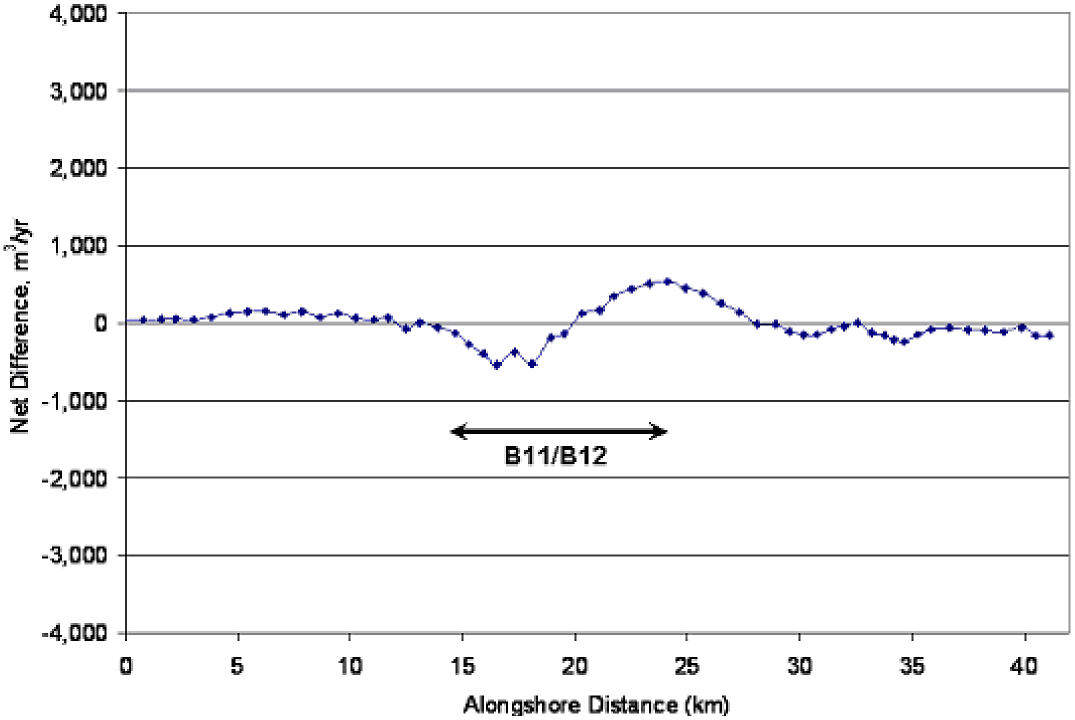


Figure 4-36. Predicted differences in the annual net littoral transport rate with and without the Case 3 borrow excavations present in the B12 and B11 shoals.

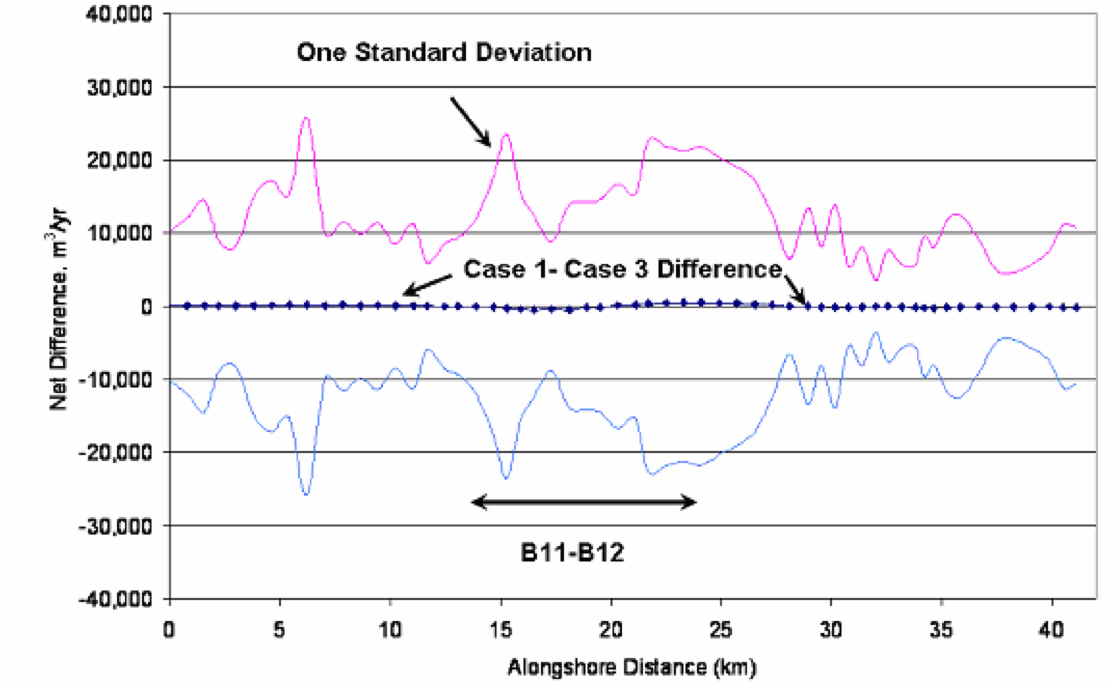


Figure 4-37. Standard deviation (blue) compared to the difference between annual littoral sand transport (dark blue) predicted for model Case 1 (no cut) and model Case 3 (cumulative cuts).

Model Results: A9 Shoal

Location and Model Test Cases

A perspective of the A9 shoal, as viewed from the southeast, is provided in Figure 4-38. This shoal was first identified during the ICONS study (Meisburger and Field 1975) and later reviewed by the Florida Geologic Survey (Phelps et. al. 2004). According to these studies, the A9 shoal may hold more than 24 million cubic meters of sand. Figures 4-39 and 4-40 show the configuration of hypothetical borrow cuts in the A9 shoal offshore of northern Volusia County. The highest topographic elevation of the A9 shoal is found near the north end where minimum depths are approximately 13 m along the crest line of the A9 shoal, depths increase to the south and drop to nearly 15 m. As indicated in Table 4.3, the model tests for the A9 shoal include Cases 4, 5, and 6. Case 4 included no modifications to the model topography. Case 5 included a limited cut area at the north end of the shoal, whereas Case 6 included borrow cuts distributed over a much wider area of the shoal. All the cases were run for a 24-month period with water level, wind, and wave boundary conditions of 1998–1999.

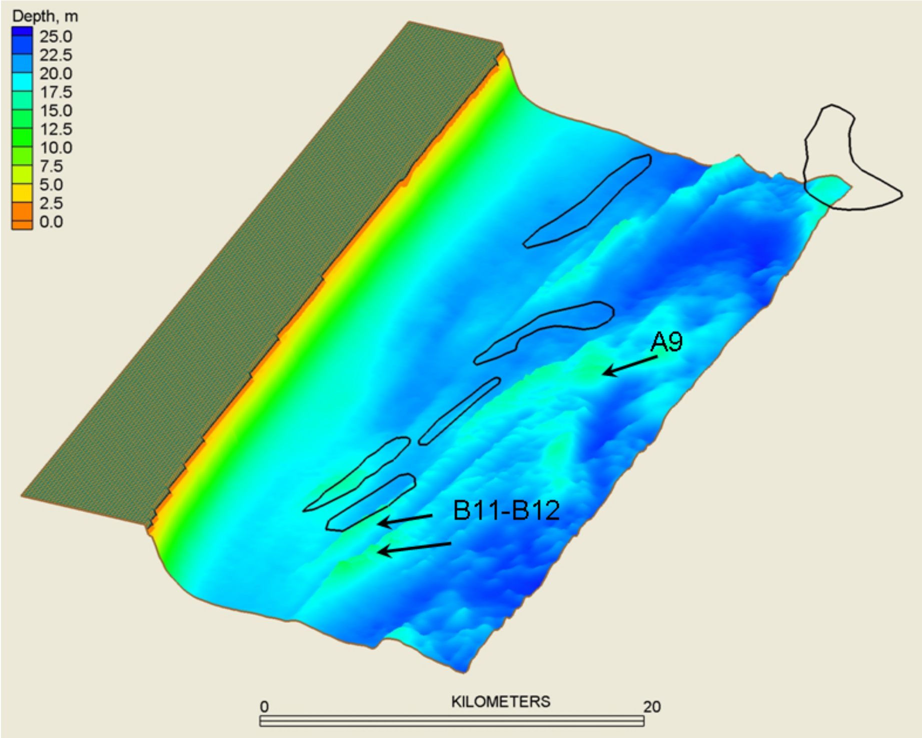


Figure 4-38. Perspective view of the A9 shoal and other nearby shoals offshore of Volusia County, Florida.

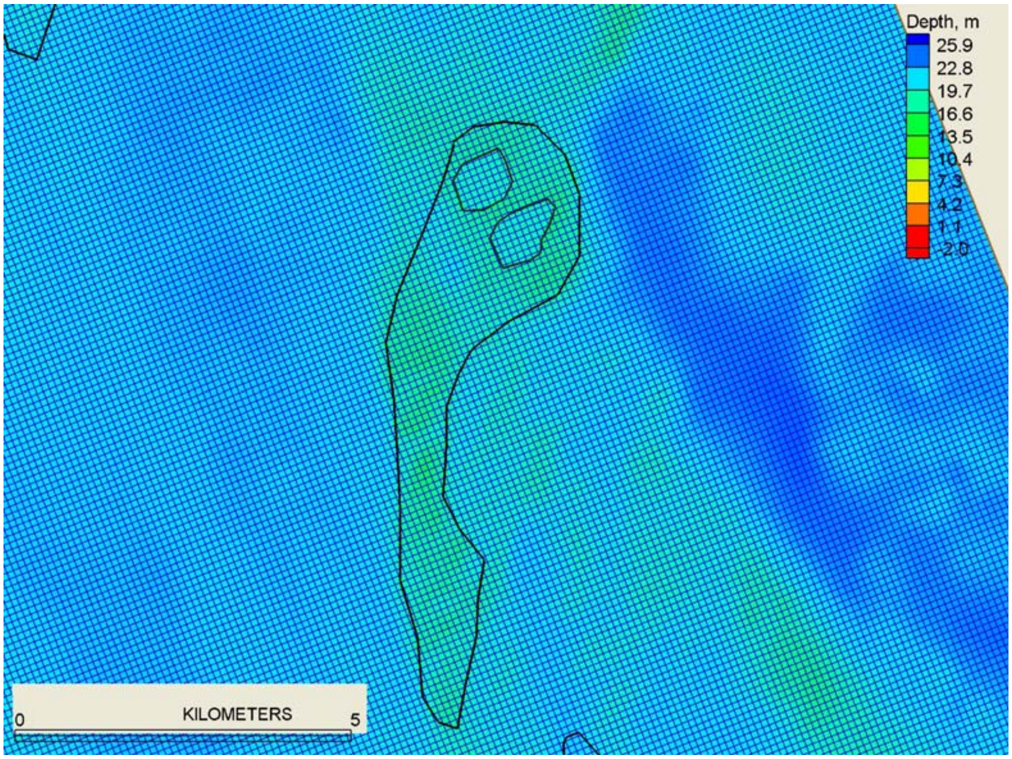


Figure 4-39. Plane view of hypothetical borrows excavations at the north end of the A9 shoal. The borrow cut as shown represents removal of approximately 1.2 million cubic meters of sand.

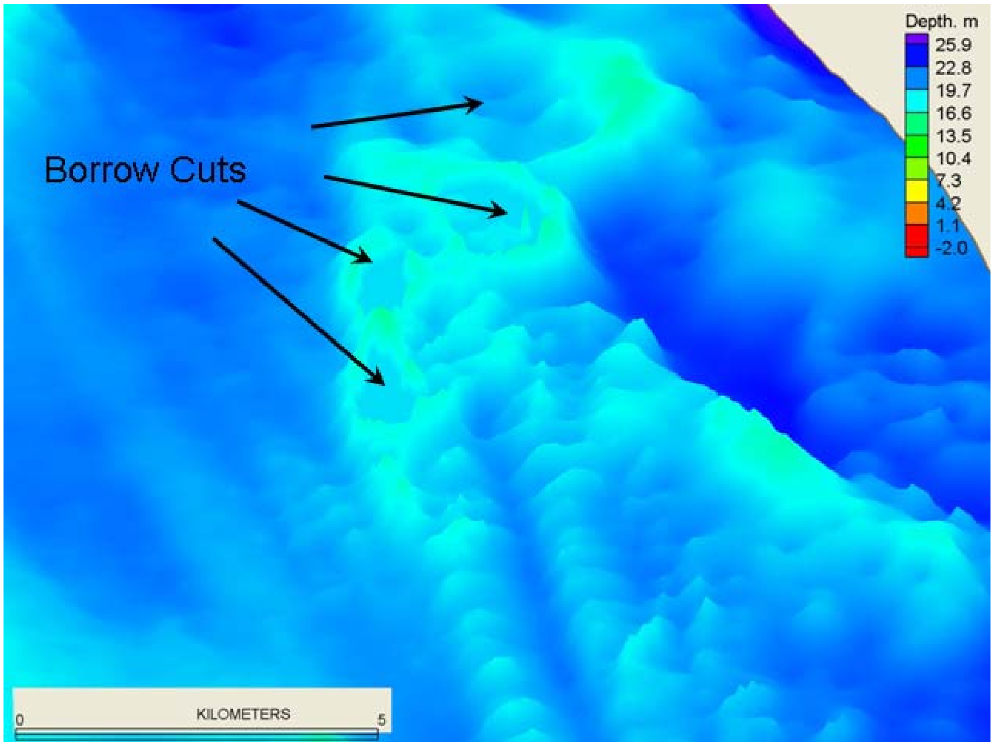


Figure 4-40. Perspective view of hypothetical excavations in the A9 shoal. Multiple borrow cuts having a total volume of 5.3 million cubic meters are represented here.

Predicted Changes in Wave Patterns: A9

Model tests for the B12 and B11 shoals indicated that detectible changes in the wave regime from the hypothetical excavations over these shoals occurred only during storm events. Model tests for the A9 shoal under conditions of 6- to 8-m high and 10- and 14-sec waves did not show detectable wave refraction (Figure 4-41). Long-period waves traveling more parallel to the crest of the A9 shoal (Figure 4-42) also were not refracted. Although wave energy was not refracted for even extreme waves, the influence on the borrow cuts in the A9 shoal were detectable for the height and longer period waves associated with storm. Figure 4-43 shows the predicted change in wave height associated with the maximum wave event when the hypothetical borrow cuts of Case 5 (see table 4-3) were placed in the model. Likewise, Figure 44 makes the same comparison for the more extensive hypothetical cuts of Case 6 in which a large area of the A9 shoal was excavated.

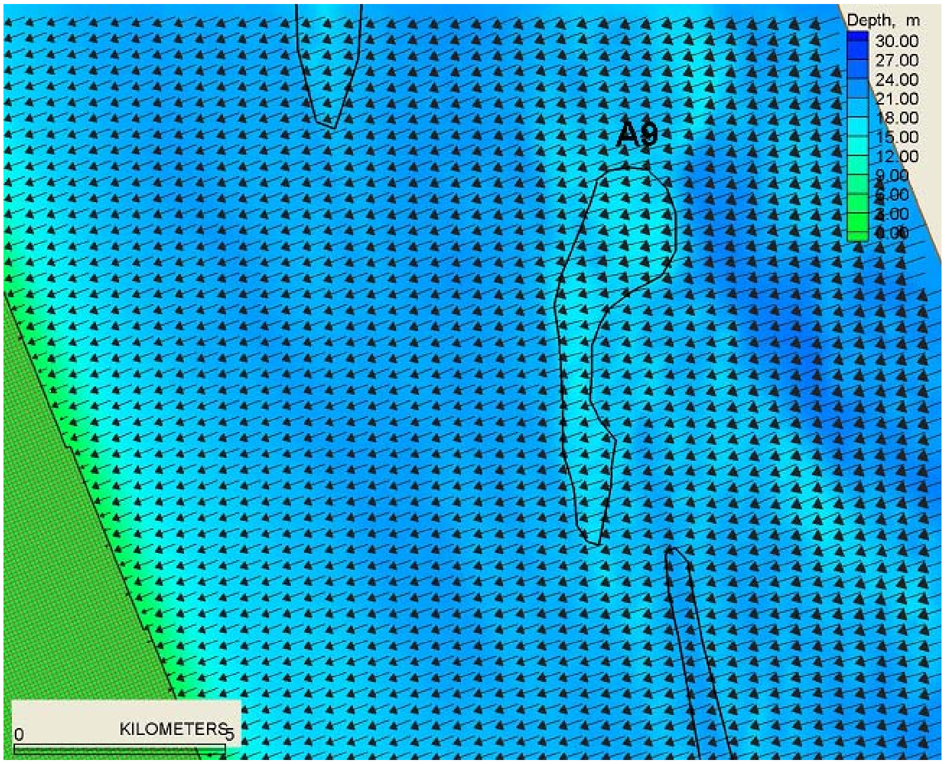


Figure 4-41. Propagation of wave energy produced by Hurricane Floyd across the inner continental shelf of Northeast Florida over A9.

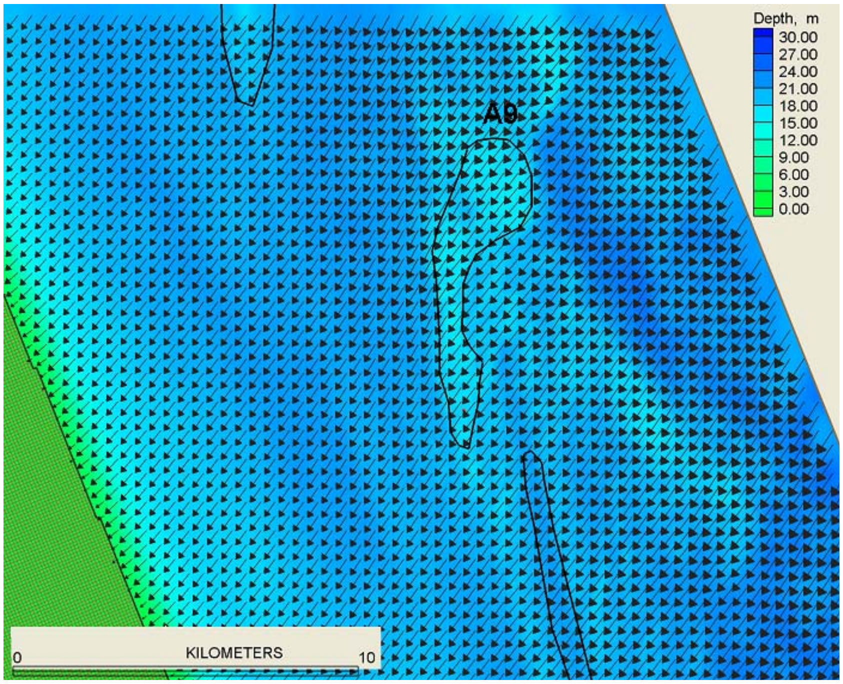


Figure 4-42. Hypothetical extreme wave conditions from the north–northeast, propagating over the A9 shoal but not refracted. Wave direction at the model boundary is from N40^o East.

Predicted wave heights were reduced over the borrow pits where the water depth was increased due to the excavation. The maximum wave height reduction was approximately 20 cm (0.6 feet). Some increase in wave height was predicted to occur at the excavation boundaries. As shown in Figures 4-43 and 4-44 alterations in the wave height field extended landward of the A9 shoal. In the nearshore zone at water depths of less than about 5 m (16.4 feet), the wave height difference was less than 1 cm.

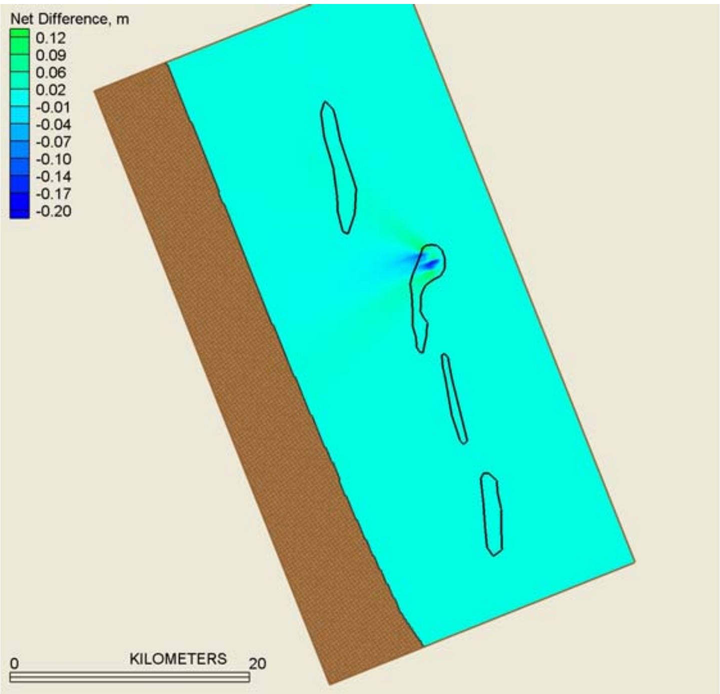


Figure 4-43. Results of model test Case 5, showing predicted net differences in wave height after completion of hypothetical excavations in shoal A9. Applied wave conditions were hind cast for Hurricane Floyd, August 1999.

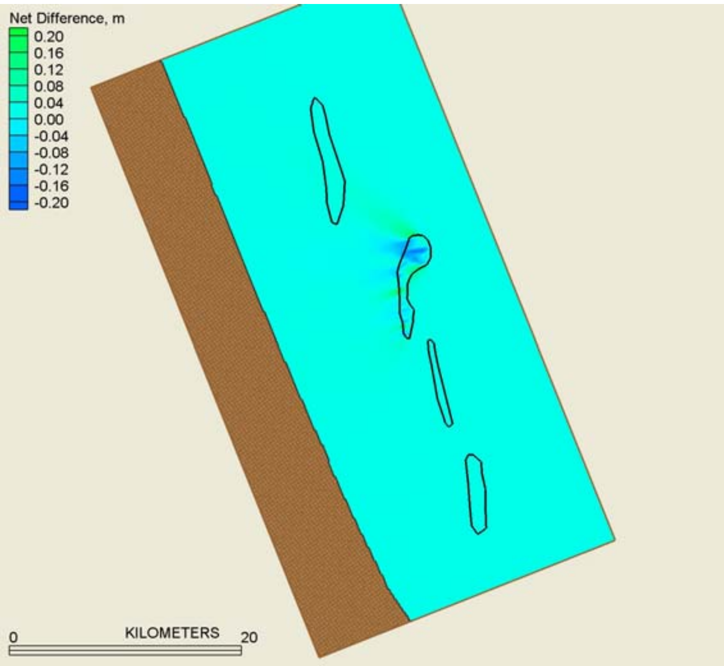


Figure 4-44. Results of model test Case 6, showing predicted net differences in wave height after completion of multiple hypothetical excavations in shoal A9. Applied wave conditions were hind cast for Hurricane Floyd, August 1999.

Predicted Sediment Transport and Topographic Change: A9

In Figure 4-45, the predicted instantaneous sand transport for September 15, 1999 over the A9 model grid is shown. The most intense transport was within the surfzone where breaking waves generated strong littoral currents. Some transport is predicted over the shallowest portion of the A9 shoal. In this simulation period, the large waves generated by Hurricane Floyd, situated off the coast of North Carolina, moved to the south, propagating across the inner continental shelf of Northeast Florida. The wave-generated littoral drift shown in Figure 4-45 corresponds to wave conditions shown in Figure 4-41.

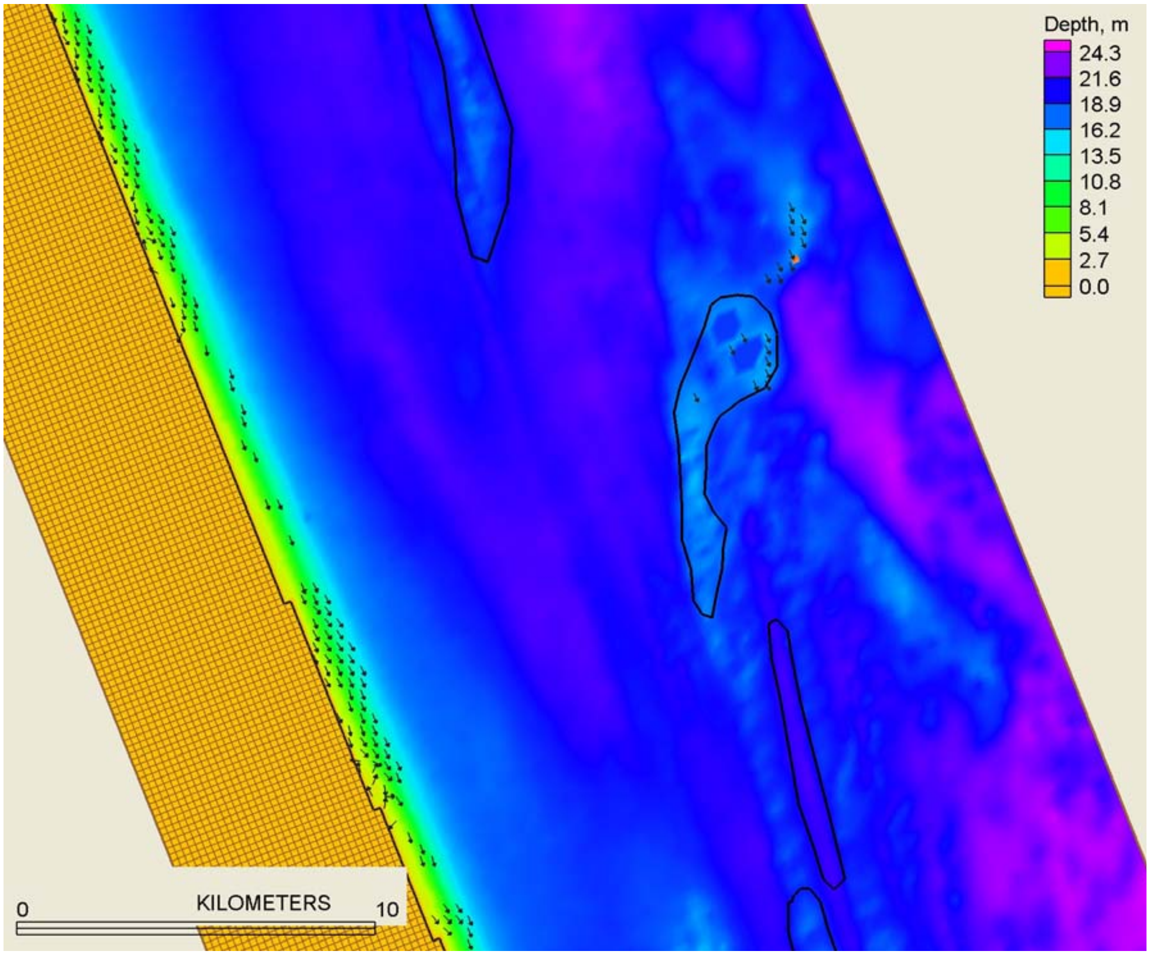


Figure 4-45. Predicted sand transport patterns for September 15, 1999. The model topography corresponds to Case 5, which includes two borrow cuts at the north end of the A9 shoal.

Figure 4-46 shows the current velocity field corresponding to the sand transport shown in Figure 4-45. The largest current speeds are predicted to occur in the surfzone on the upper shoreface. Offshore currents were small and mostly generated by wind shear.

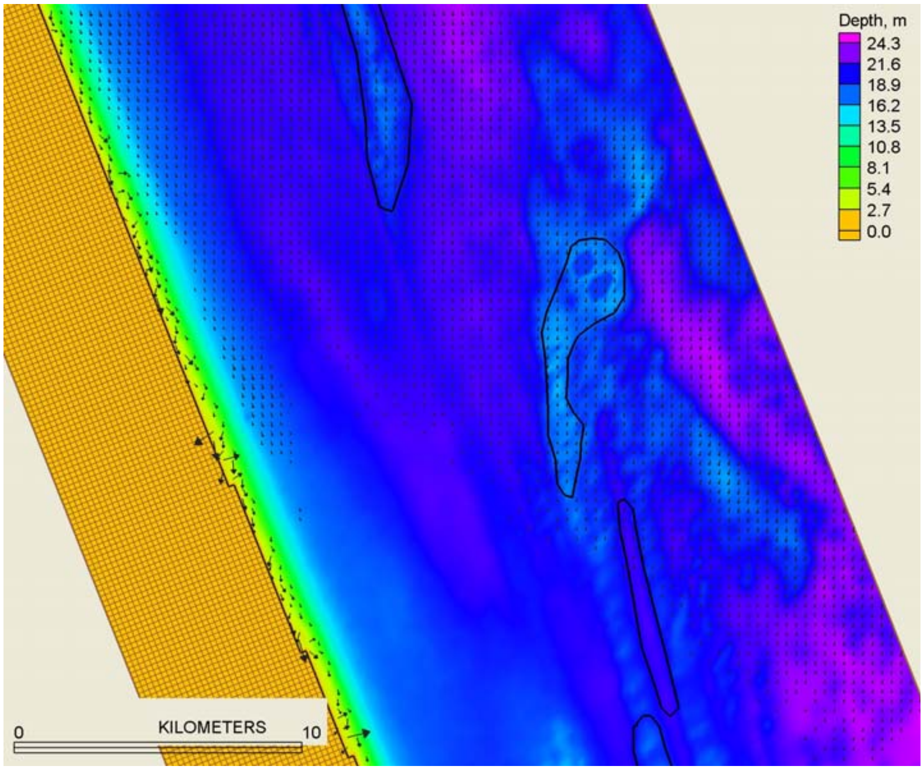


Figure 4-46. Predicted current velocity patterns for September 15, 1999. The model topography corresponds to Case 5, which includes two borrow cuts at the north end of the A9 shoal.

Figure 4-47 depicts model results under Case 5, single borrow cut, showing net predicted topographic change with the passing of Hurricane Floyd. Topographic changes occurred in the nearshore zone and shoreface along the north section of the model domain. Erosion dominated on the upper shoreface with corresponding erosion on the lower shoreface. Maximum topographic change over the 100-m model cell resolution was 1 m (3.28 ft).

Figure 4-48 shows predicted topographic change after 24 months of simulation. Significant changes in topography were confined to the shoreface at a depth of about 5 m (16 ft) or less. The alternating patterns of deposition and erosion were due, in part, to the smoothing of the initial bottom topography. When viewed on shorter time scales corresponding with individual storms, the typical deposition/erosion pattern was similar to that shown in Figure 4-47. Between storms, the shoreface adjusted back to fair-weather equilibrium.

Topographic changes over the crest of the A9 shoal are shown in Figure 4-49 for the initial condition (Case 4) prior to excavation of the borrow cuts. The mixed pattern of deposition and erosion indicated that the crest area of A9 was subject to reworking to depths of at least 25 cm (about 0.8 ft.). Topographic changes over the crest of A9 for the two-year simulation period are shown in Figure 4-50. Case 6 is shown in this figure and included extensive borrow excavations (see Figure 4-340. Erosion and deposition patterns are similar to those for Case 4 (no excavation) shown in Figure 4-49. However, 1 to 10 cm (0.1–0.3 ft) of deposition is predicted to occur within the borrow pits.

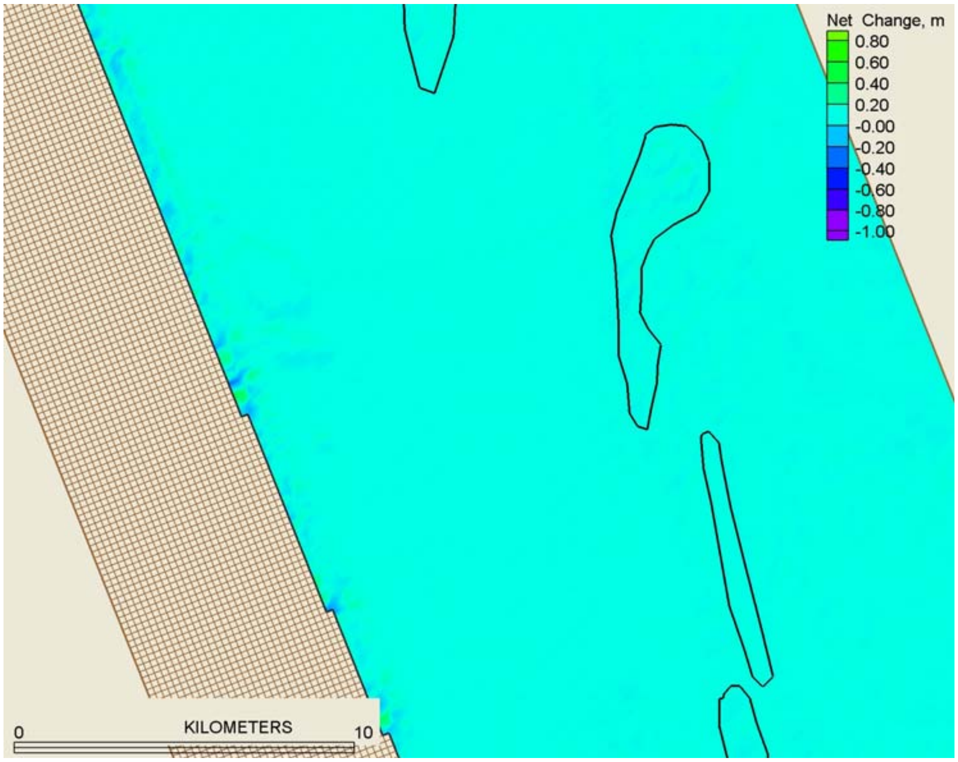


Figure 4-47. Predicted topographic changes between August 25 and September 15, 1999, accounting for the impacts of Hurricane Floyd.

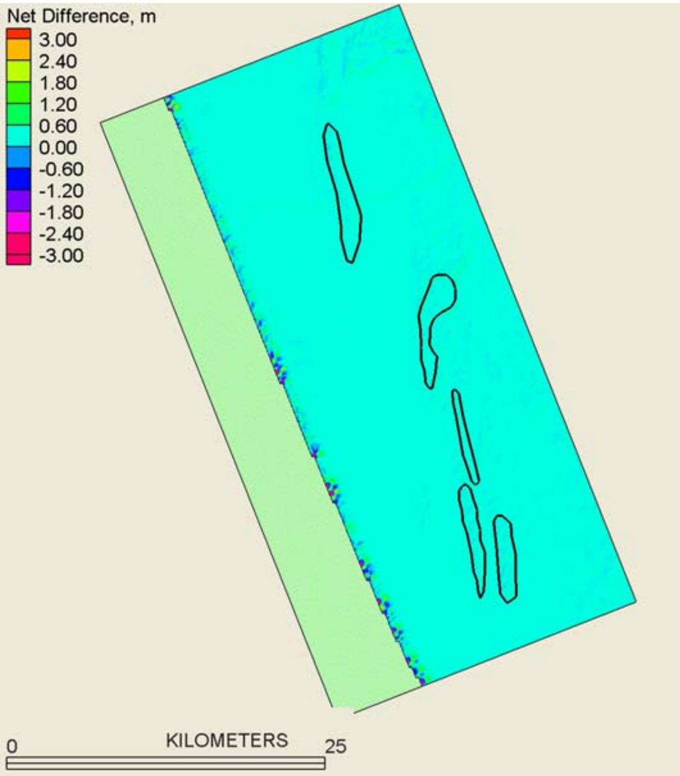


Figure 4-48. Net predicted topographic change over the A9 model domain after two years of simulation. Maximum changes in the nearshore area were +/- 3 m (9.8 ft.).

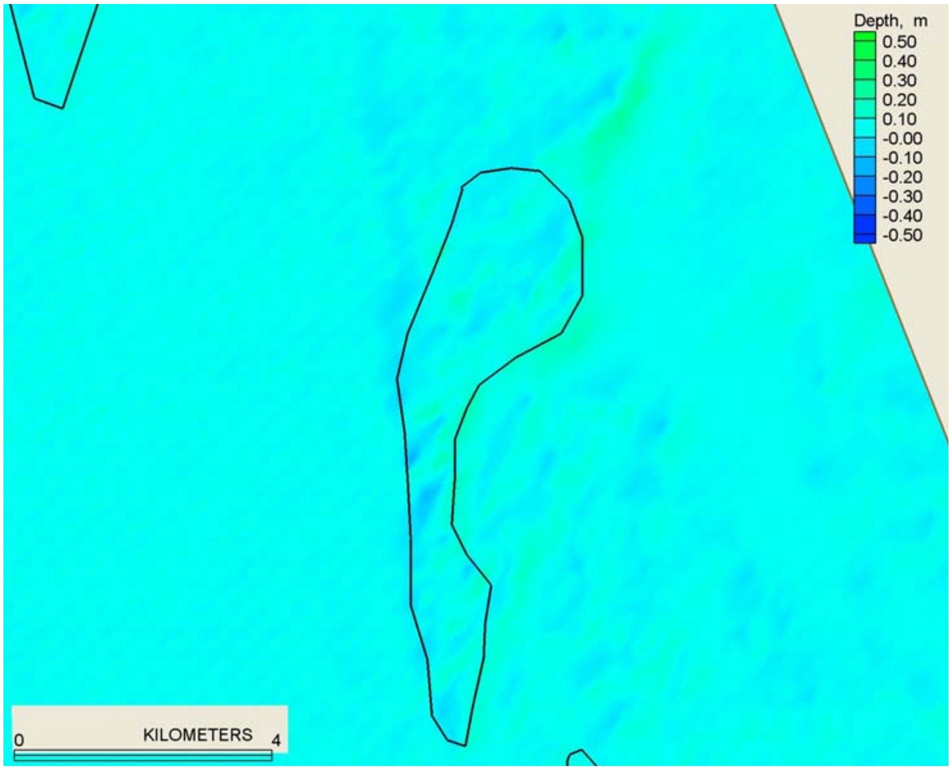


Figure 4-49. Net predicted topographic change over the crest of the A9 model domain after two years of simulation. Maximum changes were +/- 25 cm (0.8 ft.).

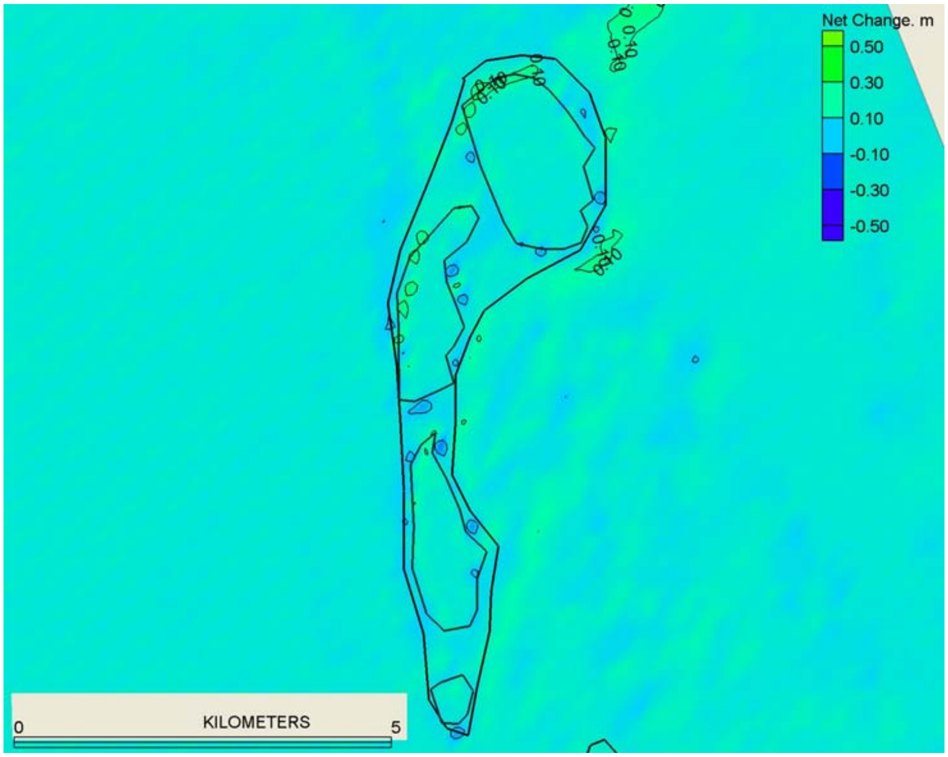


Figure 4-50. Net predicted topographic change over the crest of the A9 model domain after two years of simulation with multiple borrow cuts (Case 6).

Comparison of predicted topography among all three test cases for the A9 shoal showed that placement of the hypothetical single or multiple borrow excavation in the shoal had virtually no impact at the shoreline. This can be illustrated by comparing the evolution of topographic changes through the model runs for each test case involving borrow excavations. Figure 4-51 depicts the distribution of numerical monitoring stations setup on the upper shoreface of the A9 model grid. The predicted time series of topographic change at Stations 21, 29, 35 and 44 were extracted to illustrate the results for each case. Figure 4-52 includes plots of the topographic changes over the 1999 period at an upper shoreface location (Station 21) and at a mid-shoreface station (Station 29). The trend of decreasing in elevation at Station 21 indicated erosion, but at a variable rate that occasionally reversed to deposition. This pattern was likely to correspond to variations in wave energy and wave-driven littoral currents. The increase in elevation at Station 29 indicated deposition of about 0.4 m (1.3 ft). The difference between each of the tests with and without hypothetical borrow cuts was 1 cm (about 0.03 ft) and less. The signature of excavation from the A9 shoal was not detectable on the upper shoreface. The pattern of erosion on the upper shoreface and deposition on the lower shoreface was consistent with the regional patterns shown in Figure 4-48.

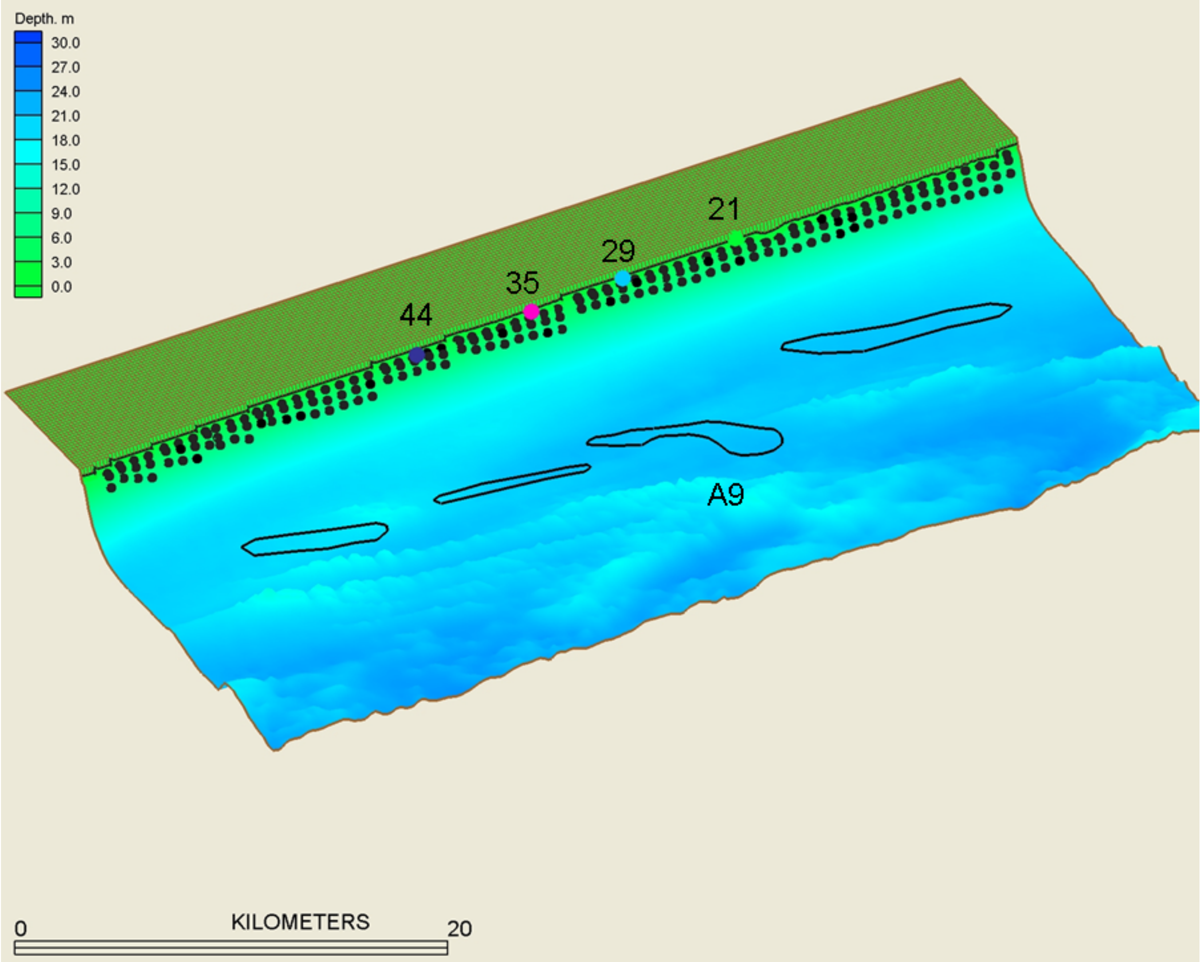


Figure 4-51. Location of the numerical monitoring stations placed in the A9 model grid. Predicted data at Stations 21, 29, 35, and 44 are shown in Figures 4-52 and 4-53.

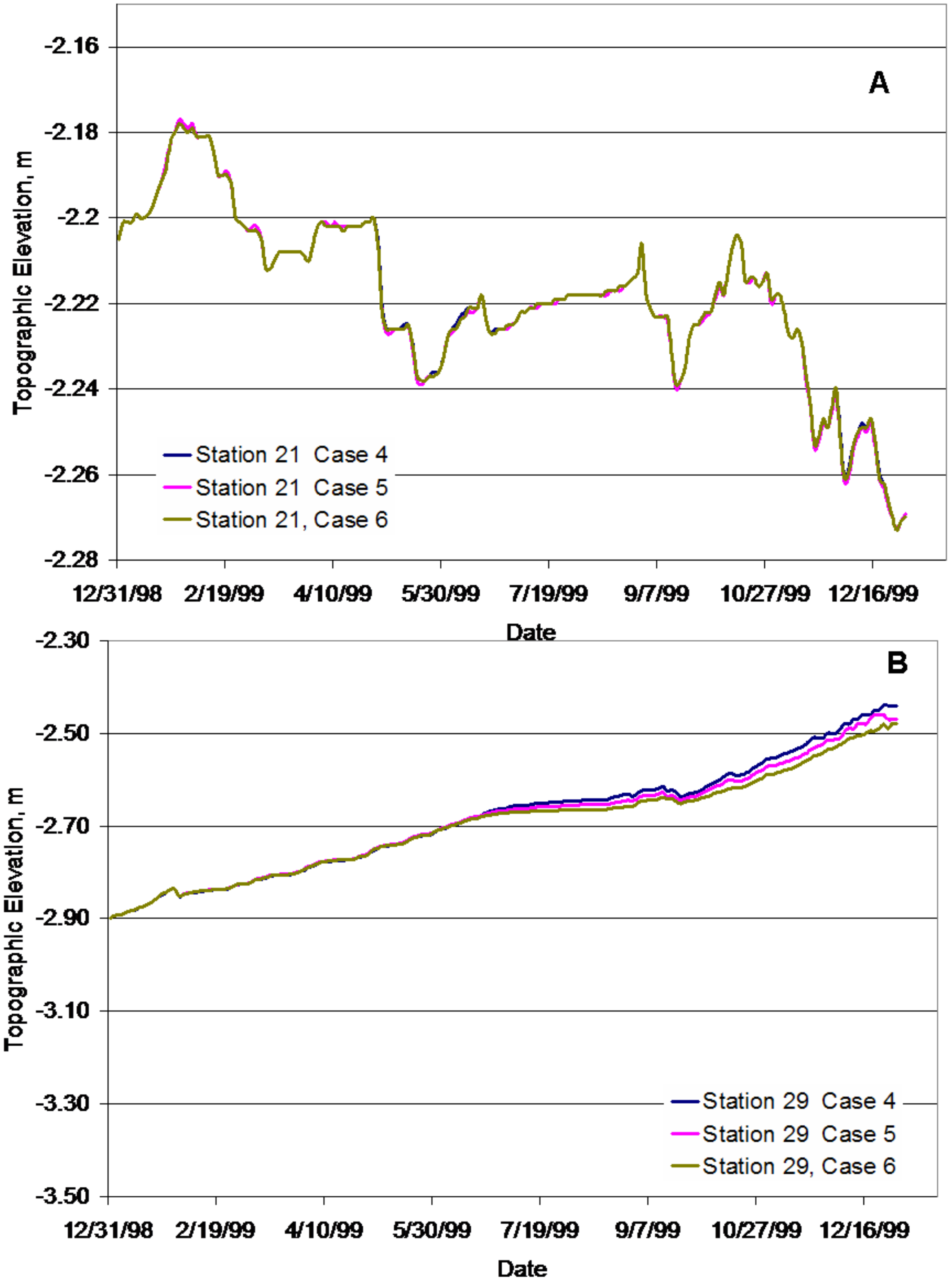


Figure 4-52. Topographic changes on the upper shoreface at Station 21 (A) and on the mid-shoreface at Station 29 (B). Cases having the existing topography (Case 4) are compared with model test Case 5 (initial borrow cuts) and Case 6 (multiple borrow cuts). Station locations are shown in Figure 4-51.

Figure 4-53 shows the topographic change at Station 35 and 44 during 1999. Both are located on the lower shoreface and deposition is indicated for each. The modeled differences between the three test cases with and without borrow cuts positioned in the A9 shoal were less than 1 cm.

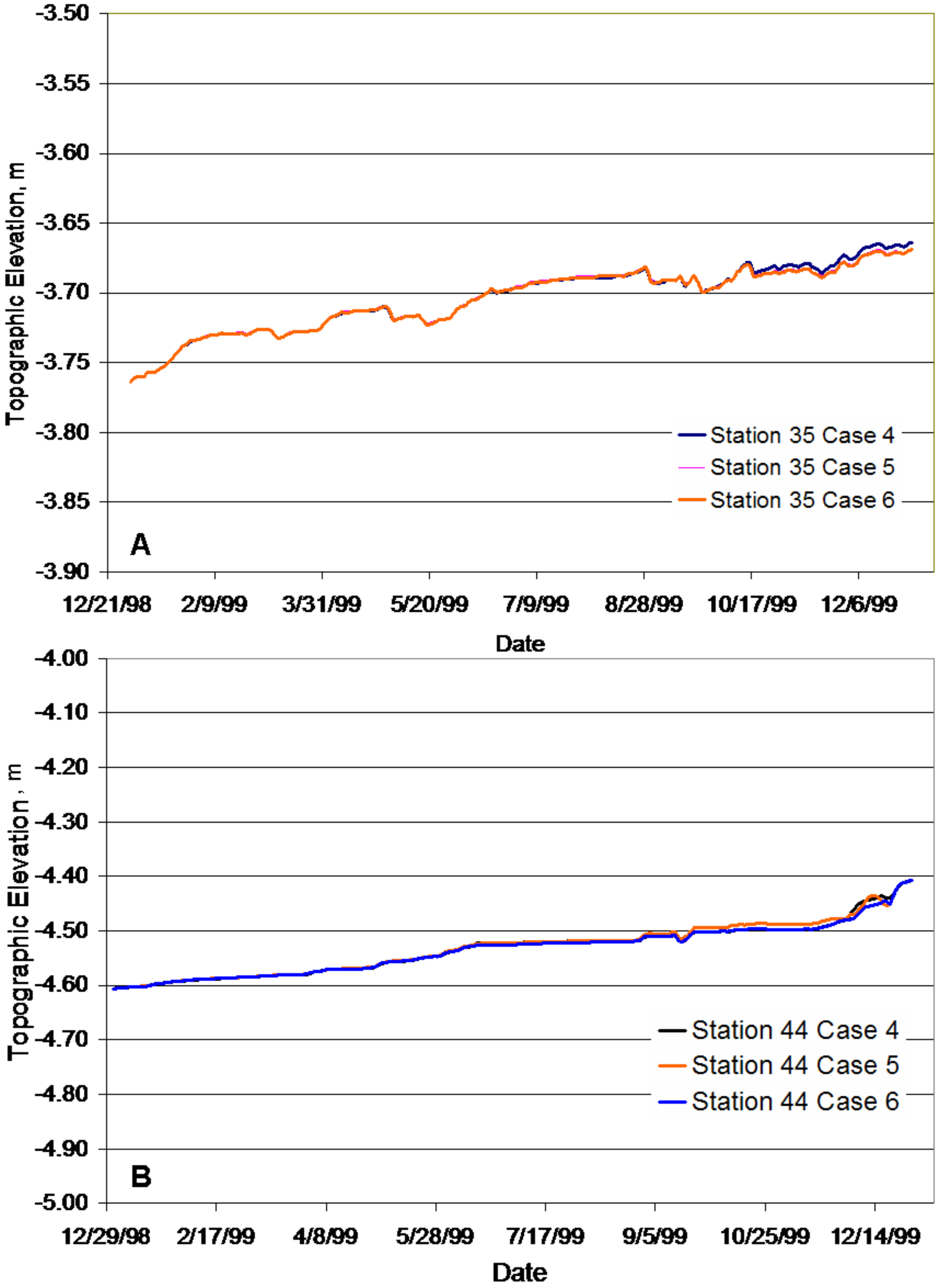


Figure 4-53. Topographic changes on the lower shoreface at Stations 35 (A) and 44 (B). Cases 4, 5, and 6 are compared. Station locations are shown in Figure 4-51.

Predicted Littoral Sand Transport: A9

The model results of annualized net littoral drift for the two-year simulation period were consistent with those of topographic change and the influence of the borrow cuts on the nearshore wave regime. The annualized net littoral transport rate over the shoreface landward of the A9 shoal for 1998–1999 can be seen in Figure 4-54. Net annual rates vary from 100,000 to 200,000 m^3/yr. The negative values indicated net south-directed transport. The values were calculated by summing and averaging hourly values of sand transport calculated at each of the numerical monitoring stations shown in Figure 4-51. The littoral transport rates for each of the test cases (Cases 4, 5, and 6) are included in Figure 4-55 but are not resolvable due to the minimal difference among the test cases.

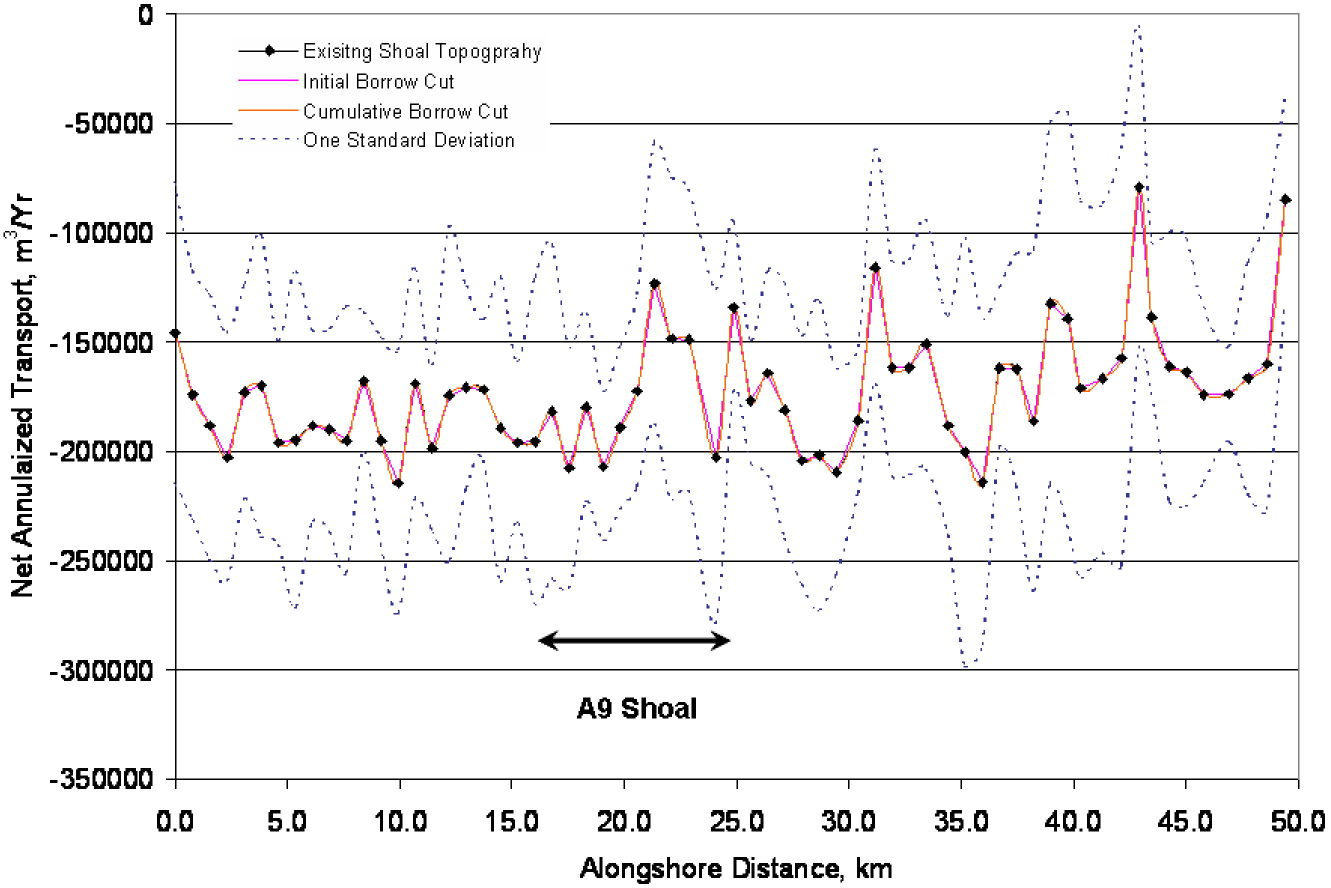


Figure 4-54. Net annualized littoral transport rate for the 1998–1999 period. Alongshore distance is from north to south. The relative position of A9 is indicated on the plot.

To more closely examine the potential for influence at the shoreline from the presence of excavations in A9, the difference between littoral sand transport predicted for Case 4 (existing shoal topography) and Case 6 (multiple borrow excavations) was compared to the standard deviation of the littoral transport calculated at each monitoring station. The difference in littoral transport for these two cases on an expanded vertical scale is presented in Figure 4-55. From this, it can be seen that the difference varies +/- 200 m^3/yr. When compared to either the annualized littoral drift rate or the standard deviation of predicted rates, the difference was very small and generally less than 2% of the standard deviation. Excavations of sand from the A9 shoal, even if extended over a large area of the shoal, are not predicted to have significant influence over littoral processes at the shoreline.

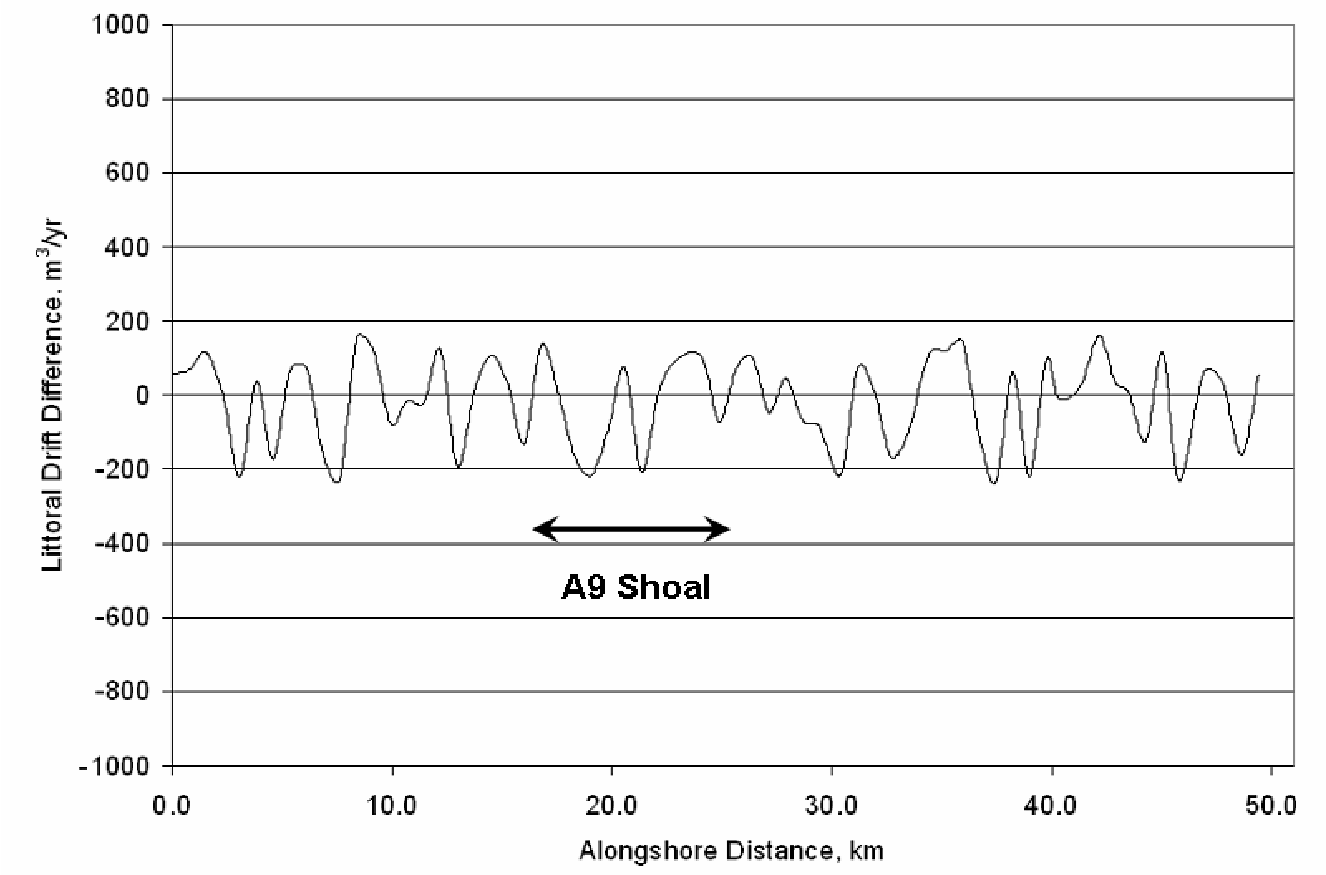


Figure 4-55. Predicted difference between annualized littoral drift for A9 shoal topography without borrow pit topography and with multiple borrow excavations (Case 4 and Case 6, respectively).

Model Results: A8 Shoal

Location and Overview

Shoal A8 is located about 12 miles offshore of Flagler County, Florida (Figure 4-56). This shoal was first identified by Meisburger and Field (1975 as part of the ICONS studies completed in the 1960s and 1970s. This area was further investigated in the Florida Geologic Survey reconnaissance study conducted in recent years under a cooperative agreement with MMS (Phelps et al. 2005). Based on these reconnaissance-level studies, it is estimated that as much as 39 million cubic yards of sand may be available from the A8 sand bank (shoal). Core samples from the ICONS study show that at least the crest area of the A8 shoal is characterized by clean, medium to fine, quartz sand (see Core 147 in Appendix D1). The highest elevation on A8 is approximately 12.4 m or about 41 ft.

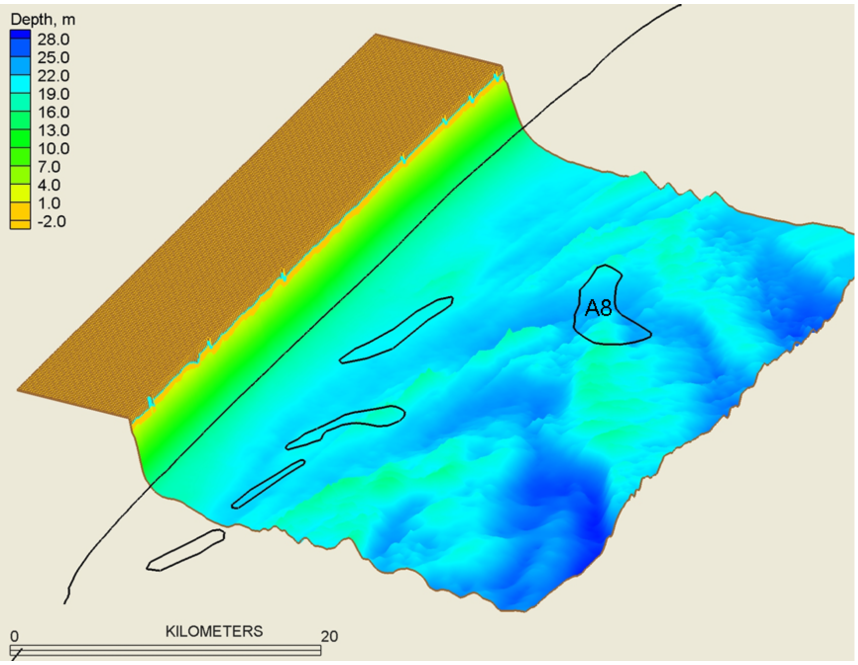


Figure 4-56. Perspective location view of the A8 shoal offshore Flagler County, Florida.

Predicted Changes in Wave Patterns: A8

The model test cases for the A8 shoal outlined in Table 4.3 include Cases 7, 8 and, 9. The hypothetical borrow cuts are shown in Figures 4-57 and 4-58. A single borrow cut placed at the north end of the shoal with respect to the model topography represented 1.2 million cubic meters of sand removed. Multiple borrow cuts equivalent to 12.9 million cubic meters of sand removal represented the potential for cumulative impacts of borrow excavations.

Figure 4-57. Location of a single, hypothetical borrow cut (Case 8, Table 4.3) at the north end of the A8 shoal.

Propagation of wave energy over the crest of the A8 sand bank was most influenced by topography when subjected to long-period, high waves generated by local storms or waves generated in the north Atlantic by storms in distal fetch areas. Model results indicated that some refraction of wave energy can take place for longer waves passing over A8 and the surrounding shoal. Wave direction over A8 was noticeably different in Figure 4-59 when compared to the direction of propagation in deeper areas just to the southeast of the shoal crest. Figure 4-60 shows the predicted difference in wave height with respect to Cases 7 and 8 (Table 4.3). The comparison was for a wave regime associated with the passage of Hurricane Floyd in September 1999. Figure 4-61 makes the same comparison for Case 9, which included multiple excavations over the crest of A8. A comparison of Case 7 to Case 8 wave heights under these extreme conditions were predicted to be reduced by 10 cm (0.3 ft) directly over the borrow pit, along with an increase of about 5 cm over the perimeter or rim of the borrow cut.

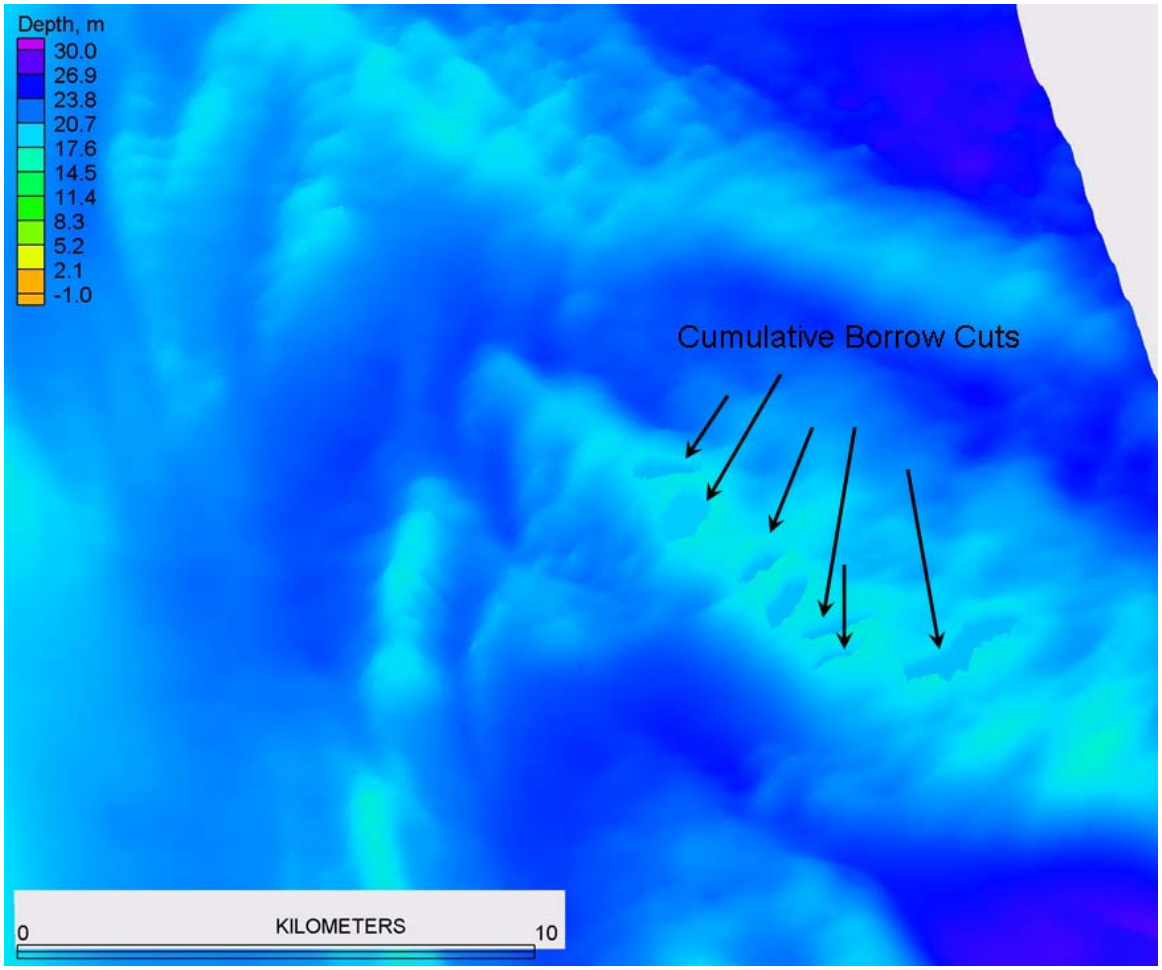


Figure 4-58. Cumulative model borrow cuts (Case 9) over the crest of the A8 shoal.

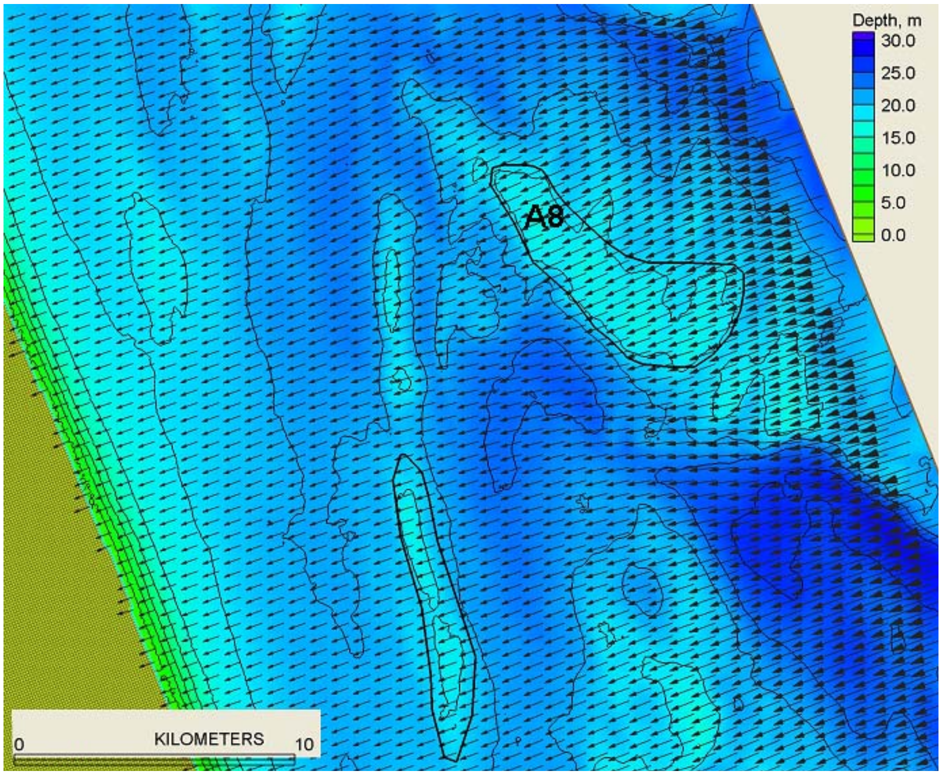


Figure 4-59. Refraction of wave energy over the crest of A8 can be identified by comparing it to the movement of wave energy in a deeper area to the southeast of the shoal crest.

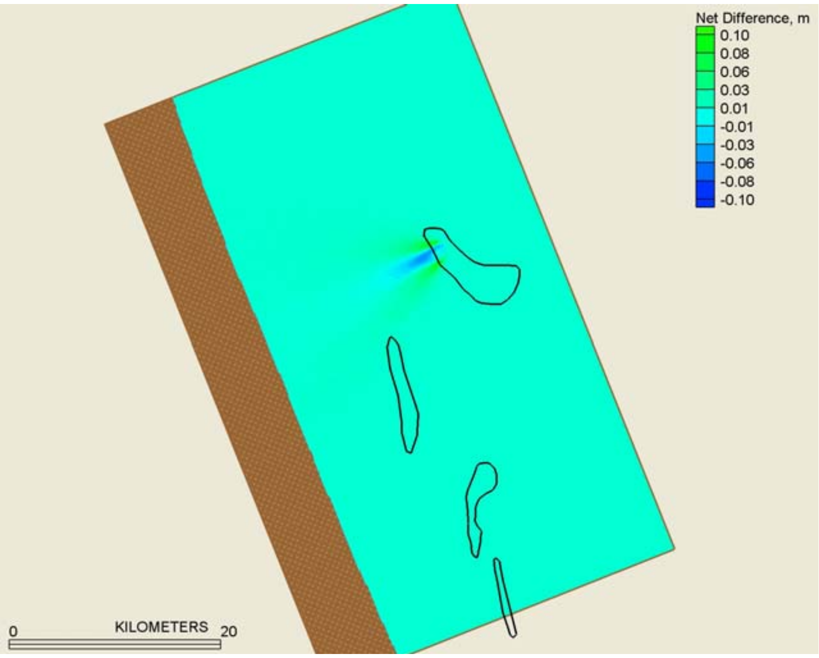


Figure 4-60. Difference between predicted wave height over the A8 model grid for Case 7 (existing topography) and Case 8 (single borrow cut). The wave regime corresponds to the passage of Hurricane Floyd, September 1999.

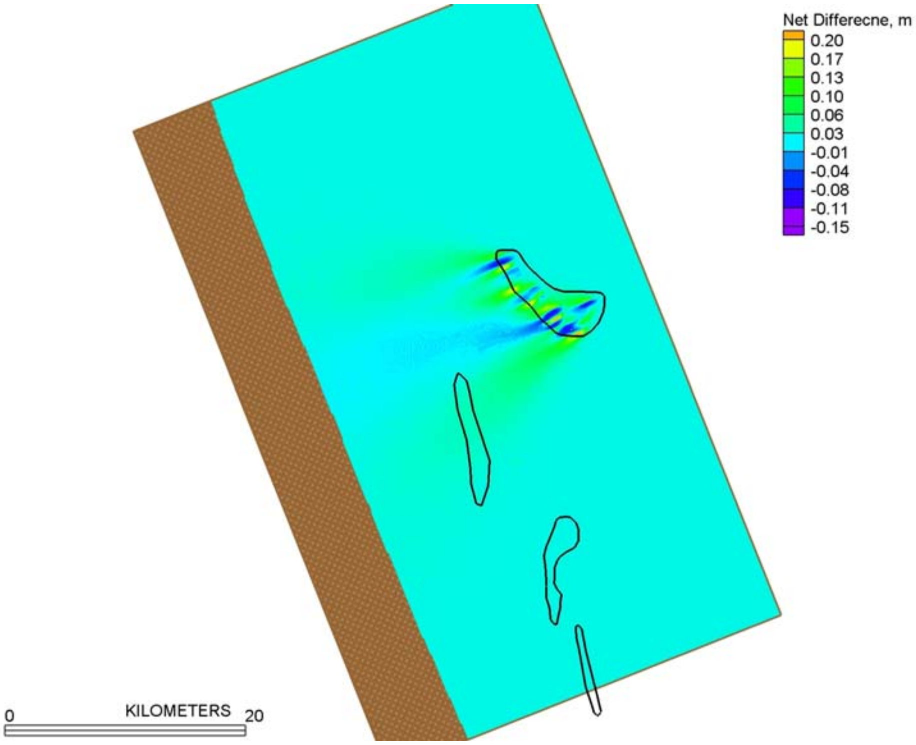


Figure 4-61. Difference between predicted wave height over the A8 model grid for Case 7 (existing topography) and Case 9 (multiple borrow excavation). The wave regime corresponds to the passage of Hurricane Floyd, September 1999.

The Case 7 to Case 9 comparison was more complicated to due to the multiple borrow cuts. Reduction in wave height of up to 15 cm (about 0.5 feet) occurred over the discrete borrow pits. An increase of wave height of similar magnitude occurred at the edges of and between the cuts. The re-distribution of wave energy across the excavated areas is thought to be, in part, due to wave diffraction over the irregular topography.

Predicted Sediment Transport and Topographic Change: A8

Sand transport and circulation patterns over the A8 model grid were similar overall to predictions for B12, B11, and A9 model cases. Intense sand transport occurred only during wave conditions generated by either local or regional storms. Sand transport patterns associated with the most energetic wave conditions that occurred as a result of the passing of Hurricane Floyd across the northeast Florida continental shelf in 1999 are depicted in Figure 4-62. Strong transport in the littoral zone to depths of about 10 m could be noted during storms. Shoaling and breaking waves stirred the sand with orbital motion and wave-generated littoral currents moved sand that had been set in motion. Offshore measurable, but weak, transport was seen over the crest of the A8 shoal.

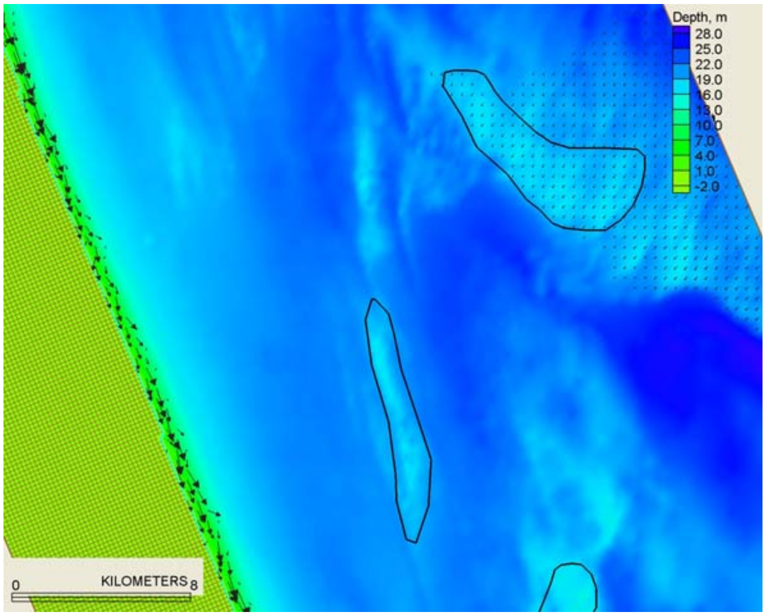


Figure 4-62. Predicted sand transport pattern over the A8 model grid under storm conditions of Hurricane Floyd.

Still shots from the November 2005 field survey video film taken along transects across A8 and other shoals often show wave- and current-generated bedforms that cover the shoal crest (see Figures 3-22 to 3-31 in Section 3). Although net transport is thought be small over the shoal, wave and current action was strong enough to create large-scale bedforms as shown in Figure 3-22 of Section 3. Current patterns shown in Figure 4-63 are similar to the sand transport vectors. The strongest velocities were found in the littoral zone due to breaking waves. Weaker currents offshore were driven by local winds and tides. The conditions depicted in Figures 4-62 and 4-63 are from mid-September 1999 after Hurricane Floyd moved to the north and continued to generate large waves that eventually crossed the northeast Florida shelf.

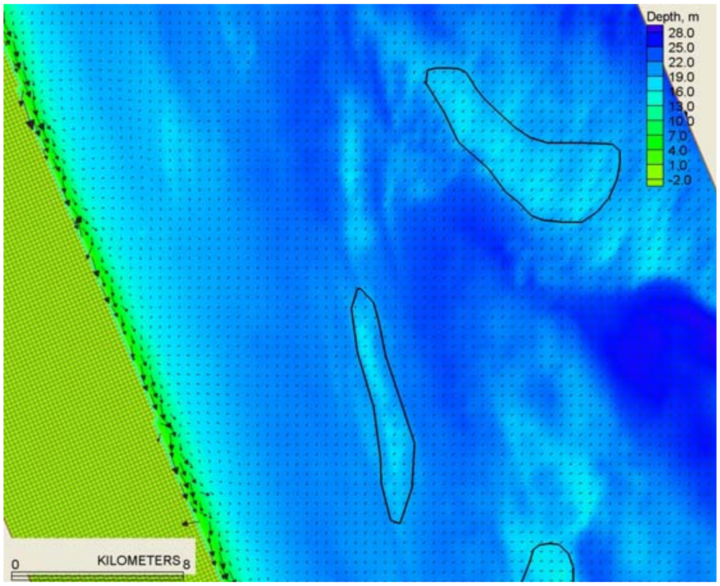


Figure 4-63. Predicted current pattern over the A8 model grid under storm conditions of Hurricane Floyd.

Modeled topographic changes over the two-year simulation were very similar to those of the B12, B11 and A9 areas. In general, erosion occurred on the upper shoreface at a depth of less than 3 m, and deposition occurred on the lower shoreface at a depth of 3 m and greater. Superimposed on these patterns were alternating zones of deposition and erosion in the alongshore direction. This may have been due to alongshore variations in the model topography that was smoothed as the simulation proceeded. Figure 4-64 shows the net topographic changes after two years of simulation. Maximum predicted alterations in the model topography were on the order of +/-3 m (about 10 ft). Changes on the shoreface were readily visible, but topographic changes over the A8 shoal, which were less than 30 cm (1 ft), were not discernable at this scale, as shown in Figure 4-64. Thus, changes over the shoal will be addressed separately.

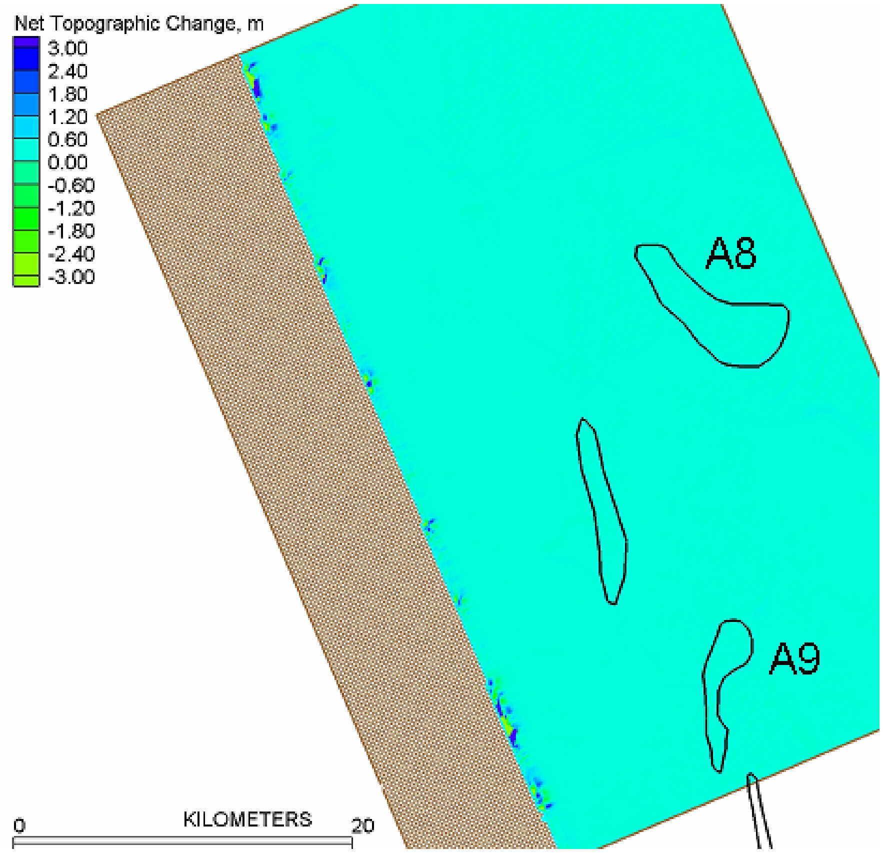


Figure 4-64. Net topographic change over the A8 model grid at the end of the two-year model simulation. Shoal A9 is also included in the A8 grid as well as being centered within the main A9 model domain.

The potential differences among the three model test cases, as listed in Table 4.3, can be best illustrated by examining topographic changes as discrete time series extracted from selected locations in the nearshore. Numerical monitoring stations set up to capture the details of topographic change are located in Figure 4-65. The topographic time series discussed here are identified in this figure as well. These include Stations 11 and 20, positioned onshore of the northern half of shoal A8, and Stations 29 and 38, positioned onshore of the southern half of the shoal. A plot of the time series of topographic change for Cases 7, 8, and 9 at Station 11 for 1999 is in Figure 4-66. The results for each of the three cases with and without borrow excavations in the crest of the A8 shoal are plotted simultaneously. Differences among the three cases at Station 11 were less than 1 cm. At the end of the model run, the topography associated with

Case 9 (multiple borrow cuts) was lower by nearly 2 cm compared to the model test Case 7 (no cuts) and Case 8 (one borrow excavation).

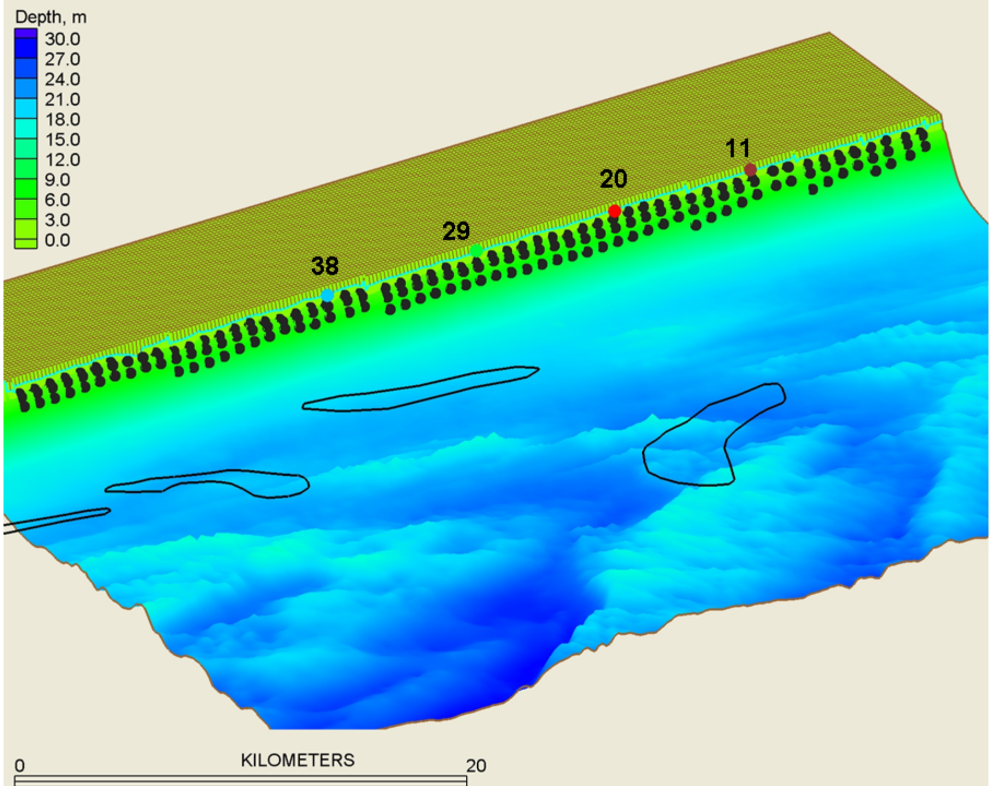


Figure 4-65. Location of numerical monitoring stations positioned along the shoreface in the littoral zone to capture individual time series of topographic change. Time series specifically discussed in this report are Stations 11, 20, 29, and 38.

Figure 4-67 shows the model results at Station 20, directly onshore of the center of the A8 shoal. At these locations, the difference among the three test cases remained less than 1 cm for most of the simulation period. At the end of 1999, the topographic elevation at Station 11 in the Case 9 model test became slightly lower compared to the other two predictions (Figure 4-66). Stations 29 and 35 were both located on the upper shoreface at locations usually subjected to erosion over the course of the model runs (Figures 4-68 and 4-69). Little net change occurred at Station 29, except for a period of erosion and recovery in response to the passing of Hurricane Floyd (Figure 4-68). The difference among the three cases at this station was less than 1 cm. Net erosion of 15 cm (0.5 ft) was predicted to occur at Station 35. Near the end of the simulation, the Case 9 results were about 1–2 cm lower than the other cases.

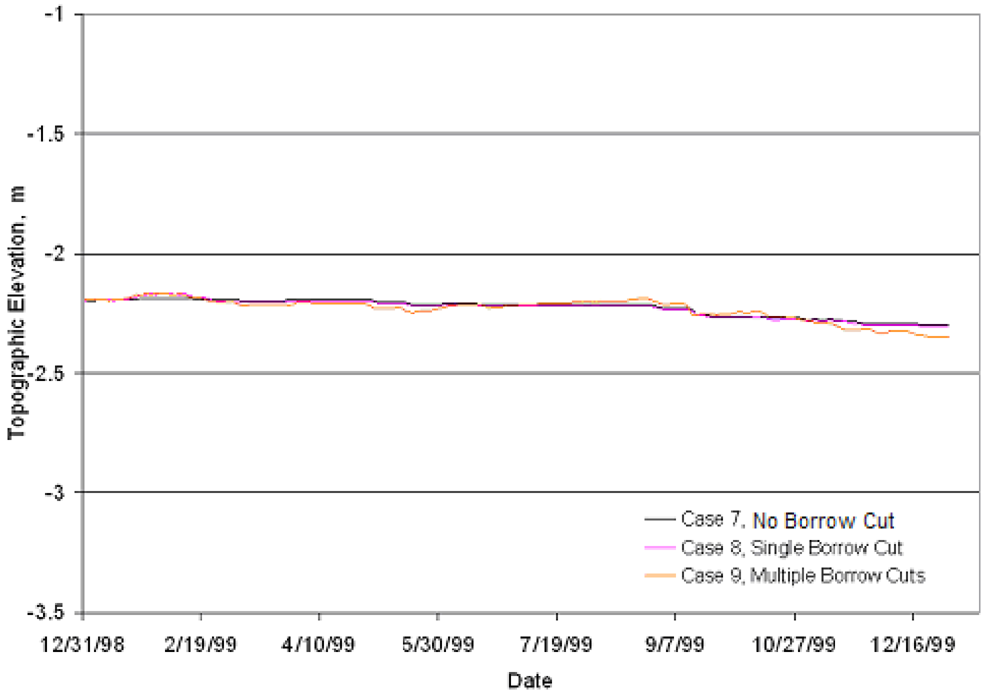


Figure 4-66. Topographic change at Station 11 for 1998 through 1999. Location of the station is shown in Figure 4-65.

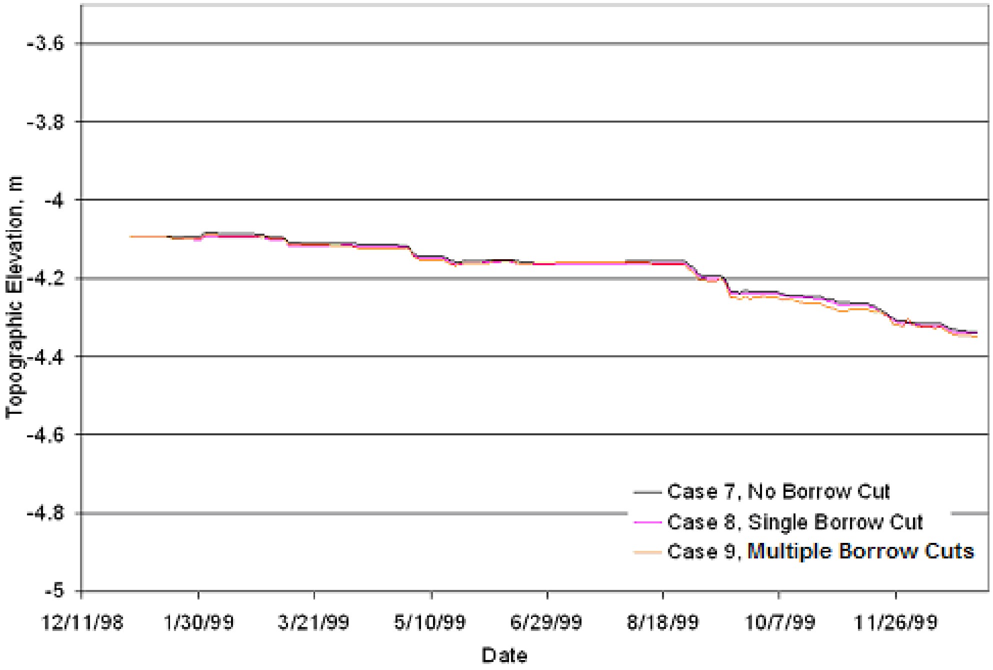


Figure 4-67. Topographic change at Station 20 for 1998 through 1999. Location of Station 20 in the A8 model is shown in Figure 4-65.

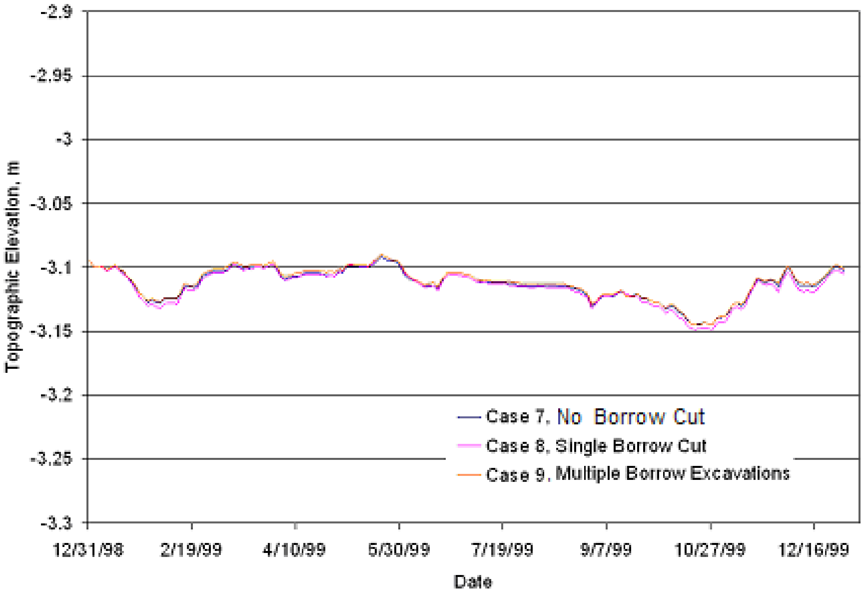


Figure 4-68. Topographic change at Station 29 for 1998 through 1999. Location of Station 29 in the A8 model is shown in Figure 4-65.

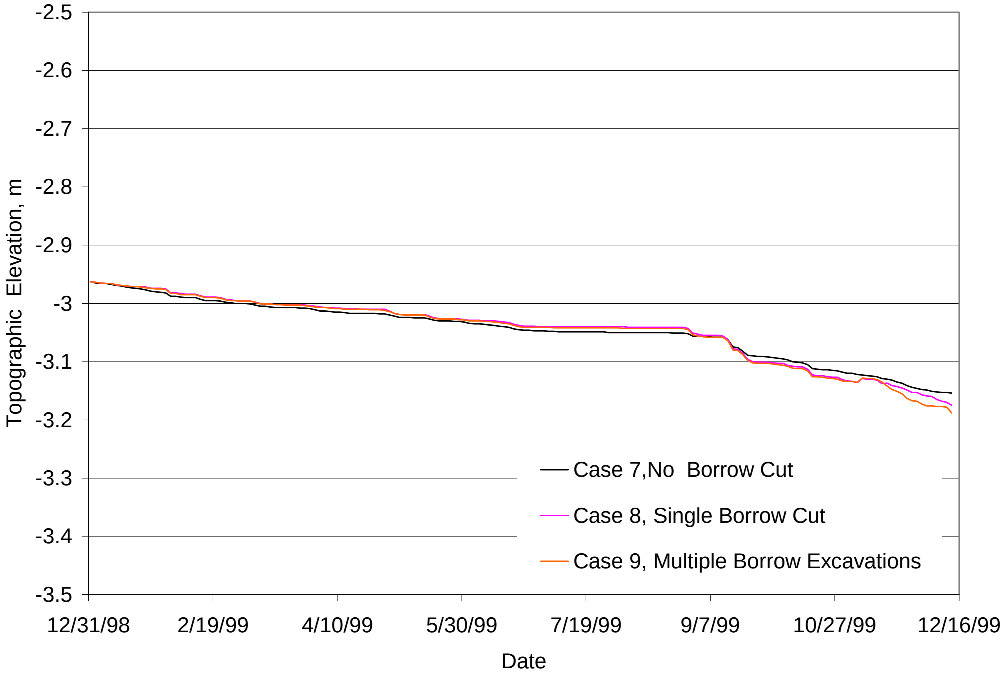


Figure 4-69. Topographic change at Station 35 for 1998 through 1999. Location of Station 35 in the A8 model is shown in Figure 4-65.

Topographic changes within the littoral zone of A8 among the model test Cases 7 and 8 indicated that the influence at the shoreline from offshore dredging was likely to be minimal. As noted in discussions of the B12, B11, and A9 shoals, there were distinctive differences among the model simulations over the crest of the A8 shoal. The occurrence of bedforms indicated that the shoals at higher elevations are dynamic and undergo topographic changes of 0.5 m (1.6 ft) over relatively short periods of time. Figure 4-70 shows the net topographic change on the top of shoal A8 and surrounding sand bank at the end of the two-year simulation. Approximately 5–10 cm (0.5–0.3 ft) of erosion occurred over the crest. Depositional areas occurred with the same magnitude after two years of simulation with a single borrow pit located at the north end of A8. Again, the average topographic changes were +/- 20 cm (Figure 4-71). Additional erosion and deposition values of up to 20 cm (about 0.6 ft) were concentrated along the perimeter of the borrow pit. This was consistent with complex wave height patterns that occurred over the borrow areas due to the irregular topography and possibly diffraction of wave energy. When multiple borrow cuts were located in the crest of A8 to identify potential cumulative impacts of continued dredging, the results included a background topographic change of 5–10 cm and larger changes of +/-30 cm (1 ft) focused around the rim of the excavations (Figure 4-72).

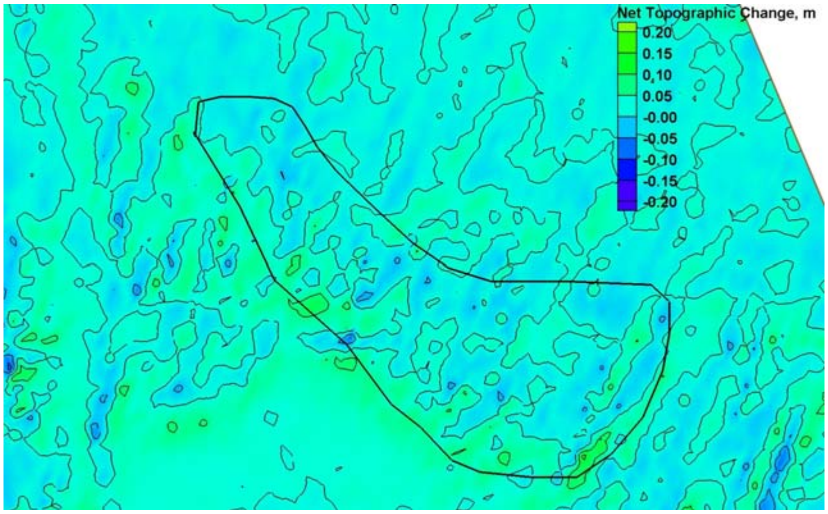


Figure 4-70. Modeled topographic change over shoal A8 after two years of simulation.

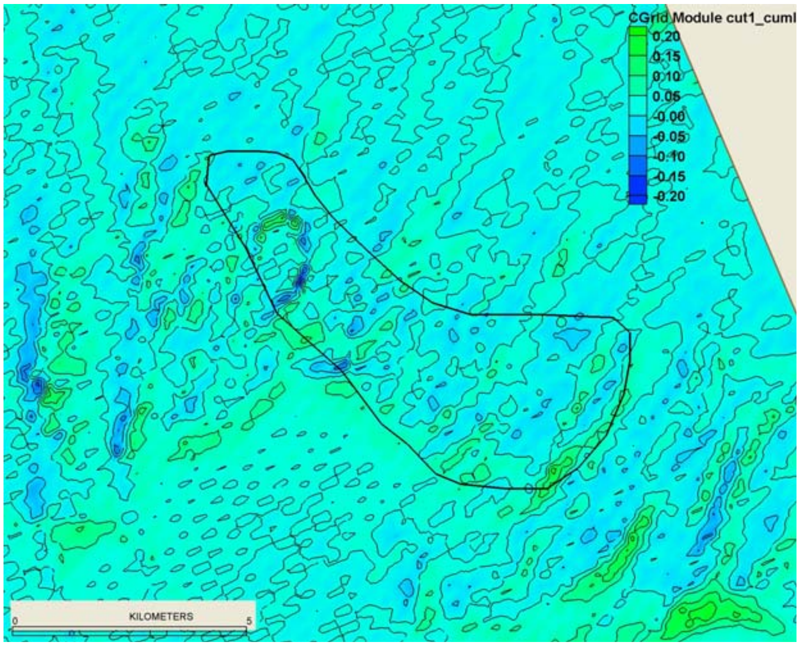


Figure 4-71. Topographic change over shoal A8 after two years of simulation with a single borrow excavation located on the crest (Case 8).

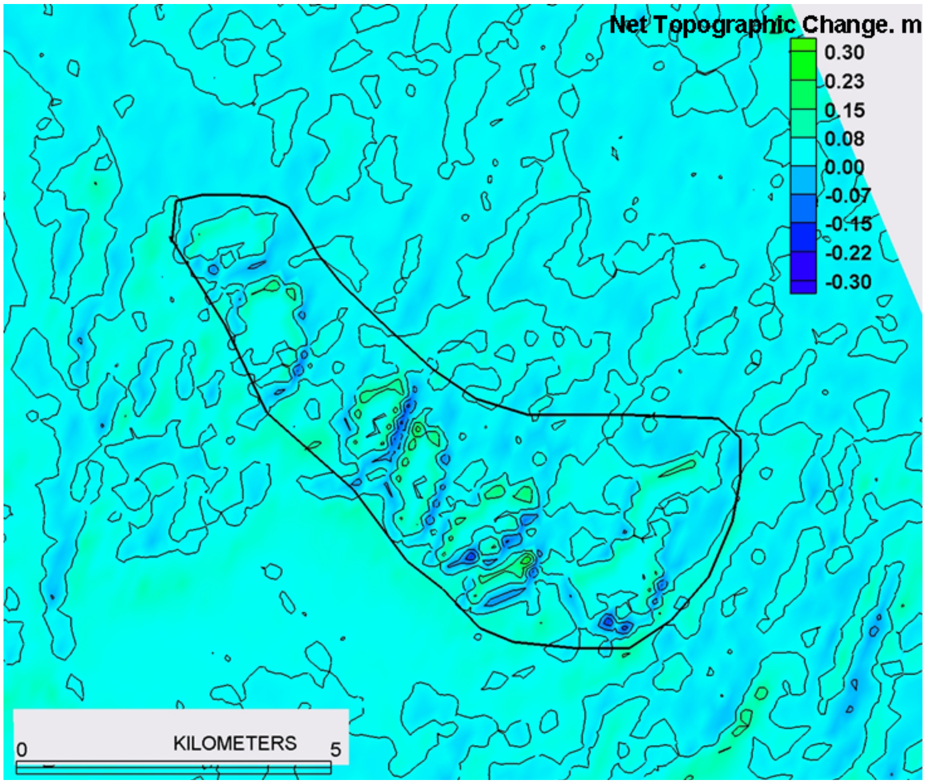


Figure 4-72. Topographic change over shoal A8 after two years of model simulation with multiple borrow excavations located on the crest (Case 9).

Predicted Littoral Sand Transport: A8

The model results of annualized net littoral drift for the two-year simulation period were consistent with the topographic change and the influence of the borrow cuts on the nearshore wave regime. The annualized net littoral transport rate over the shoreface landward of A8 for 1998–1999 is shown in Figure 4-73. Net annual rates varied from a south-directed -175,000 cubic meters per year to near zero in areas where the north and south gross rates were approximately balanced. The values were derived by summing hourly values of sand transport predicted at each of the numerical monitoring stations shown in Figure 4-65. The littoral transport rates for Cases 7 and 9 for A8 are included in Figure 4-74 but were not resolvable due to the minimal difference among the test cases.

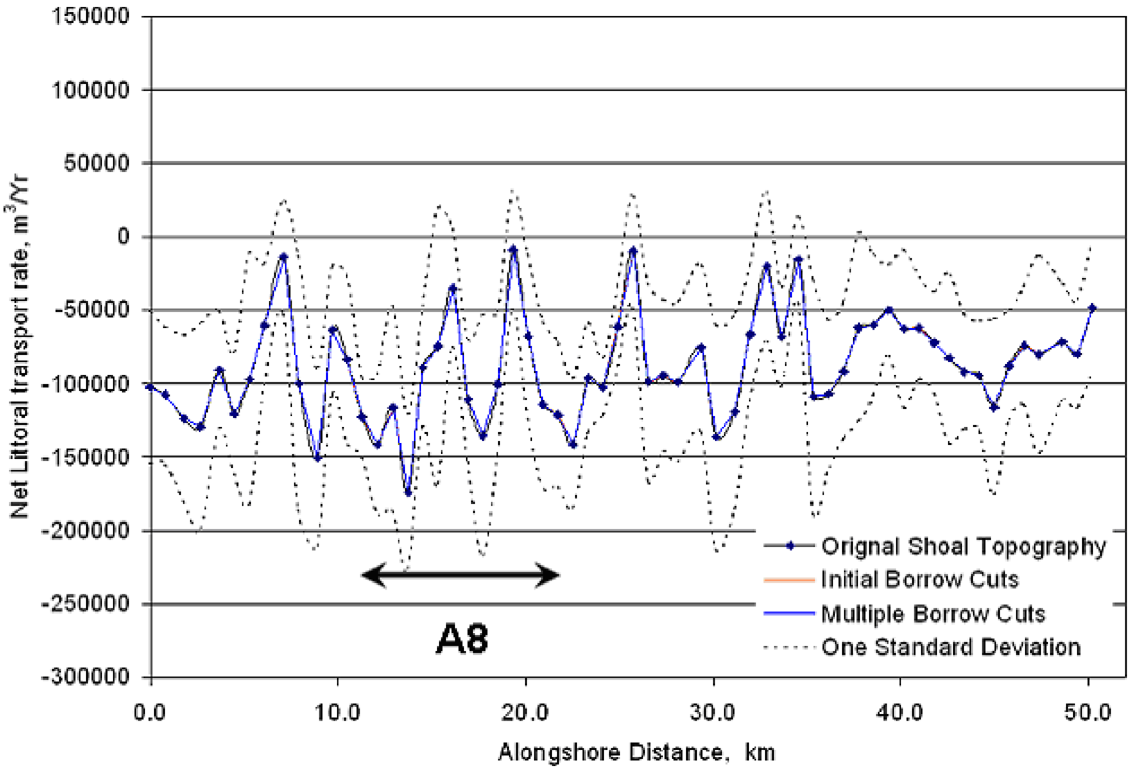


Figure 4-73. Net littoral transport rate annualized for the 1998–1999 period. Alongshore distance is from north to south. Relative position of the A8 shoal is indicated on the plot. Negative values indicate south-directed transport and positive values indicate north-directed transport. Also shown is the temporal standard deviation of transport rates calculated through time at each monitoring station.

The predicted difference between the annualized littoral sand transport with and without multiple borrow cuts in A8 is shown in Figure 4-74. The difference varied between -200 to +200 m^3/yr. This range was less than 5% of the minimum annual rate and well below 1% of the temporal standard deviation of calculated rates. It is worth noting that in the littoral zone onshore of the A8 shoal, the difference in the annualized rates were more variable and larger compared to littoral zones more distal from the shoal. The influence of borrow pits in the shoal may be detectible but very small compared to the natural variability of sand transport. This was consistent with the minimum differences in calculated topographic change and wave energy in the littoral zone.

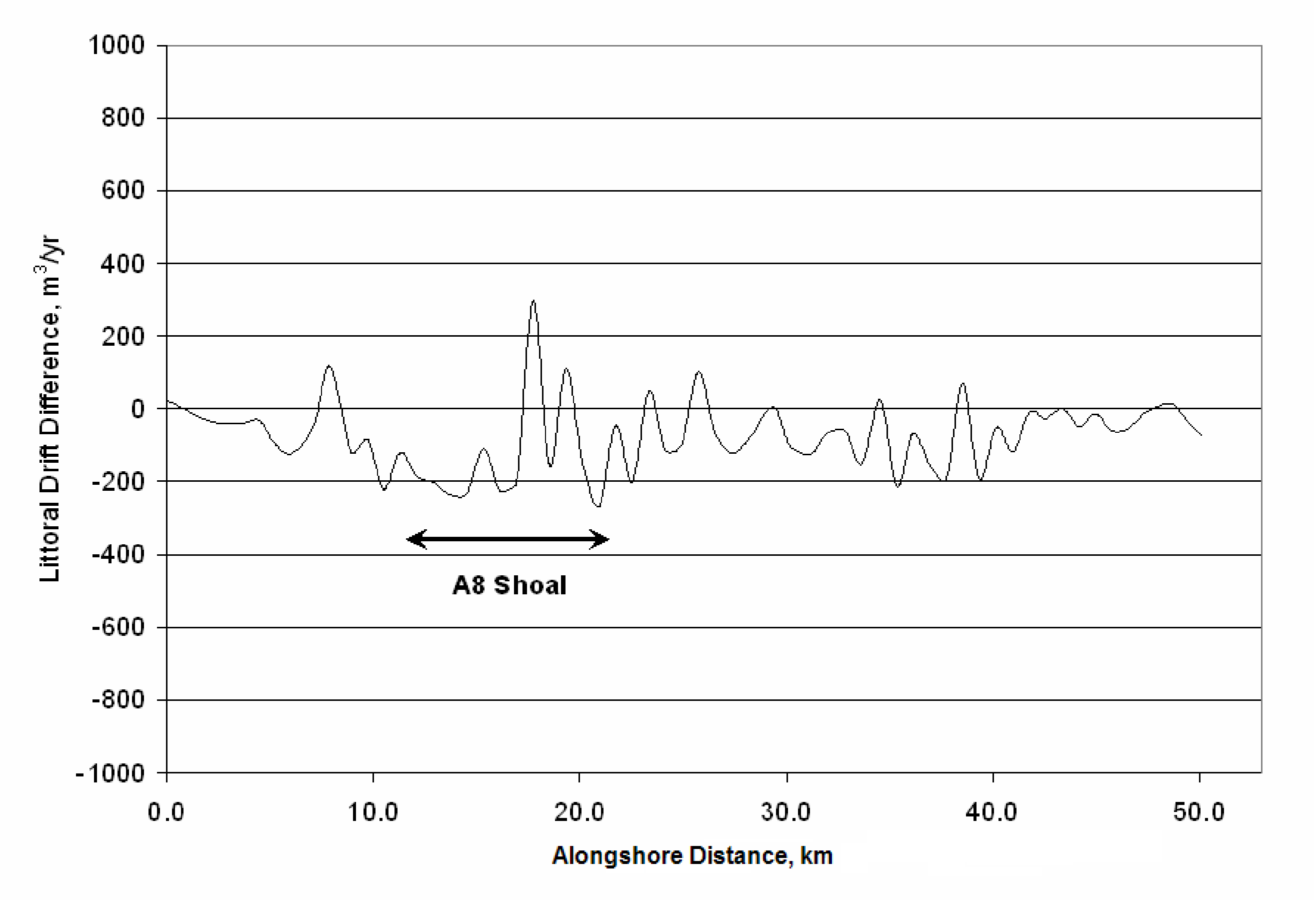


Figure 4-74. Net difference between the annualized littoral sand transport landward of A8 based on model simulations for Case 7 (existing topography) and Case 9 (multiple borrow excavations). The relative onshore location of shoal A8 is shown.

Model Results: A6, A5 and A4 Shoals

Location and overview

The crest of the A4 shoal is approximately 7.5 miles offshore of Duval County, whereas the center of the A6 shoal is 6 miles offshore of the north end of St. Johns County and 11 miles north of St. Augustine Inlet (Figure 4-75). The A5 shoal is located between the three-nautical-mile federal limit and A4 (Figure 4-75.). Water depths at the crest of these shoals were between 13.5 and 15 m (45–50 ft). Off the shoals, water depths ranged between 16.8 and 18.3 m (55 and 60 ft), depending on proximity to the lower shoreface where depths begin to decrease. As described under Section 2 of this report, the shoals and sand banks of the northeast Florida inner continental shelf are likely derived from littoral processes at lower stands of sea level and when tidal inlet ebb shoals become isolated from the shoreface (see Figure 2-19. All shoals in this area were described in some detail by Meisburger and Field (1975) as part of the ICONS study. Later, additional reconnaissance level surveys in the same area were completed by the FGS (Phelps et al. 2005).

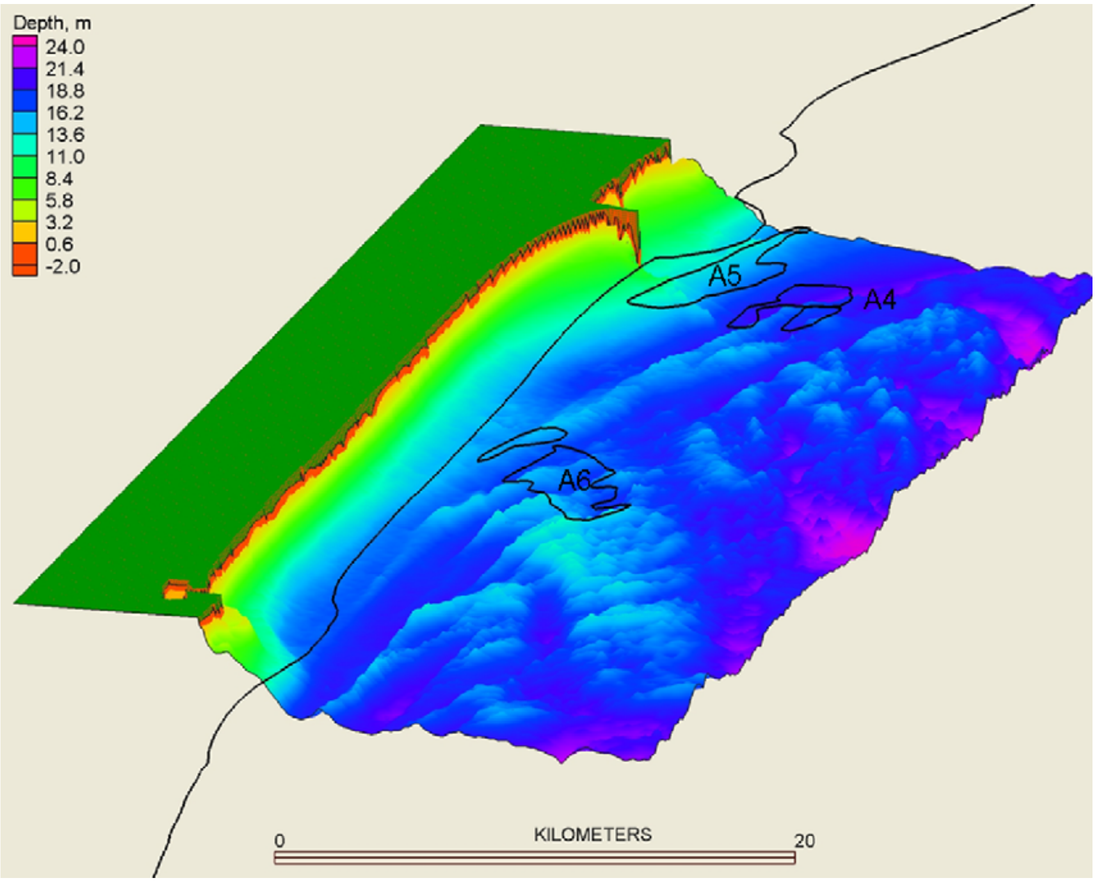


Figure 4-75. Location of the A6, A5, and A4 shoals offshore Duval and St. Johns counties, Florida.

Although the northeast Florida shelf was one of the primary focus area for the ICONS study and the later FGS study, only a limited amount of subsurface samples are available. A review of sub-bottom seismic reflection data collected by the FGS (Phelps et. al. 2005) indicates that these shoals contain substantial quantities of beach-quality sand (Zarillo 2008). Further, the few core borings that are available from the region indicate that the shoals under consideration are consistent with the stratigraphic model of shelf sand ridges presented in Section 2 of this report. Evaluation of these cores (see Appendix D) and sub-bottom seismic data indicates that beach-quality sand is likely below the crest and flanks of the shoal, as indicated by the conceptual model shown in Section 2. For instance, the stratigraphy of CERC 176 core recovered from the north end of A6 near the crest (see Appendix D) consists of 13 ft of medium to fine, quartz sand with some shell material over a base of compacted gray clay. Likewise, the sediment in CERC 174 core from the crest of the A7 shoal located to the south of A6 in federal waters contained about 9 ft of clean sand over a base of compacted gray clay.

Predicted Changes in Wave Pattern: A6–A4

Consistent with the other shoals considered in this study, refraction of wave energy over the shoal crest was only marginally detectible even during extreme conditions. In Figure 4-76, a 14-sec wave approximately 8 m high is seen to pass over the crest of the A6 shoal without significant change in direction. The orientation of the long axis of the inner shelf sand ridge topography was nearly perpendicular to the direction of wave movement across the shelf and limited the opportunity for altering the wave path.

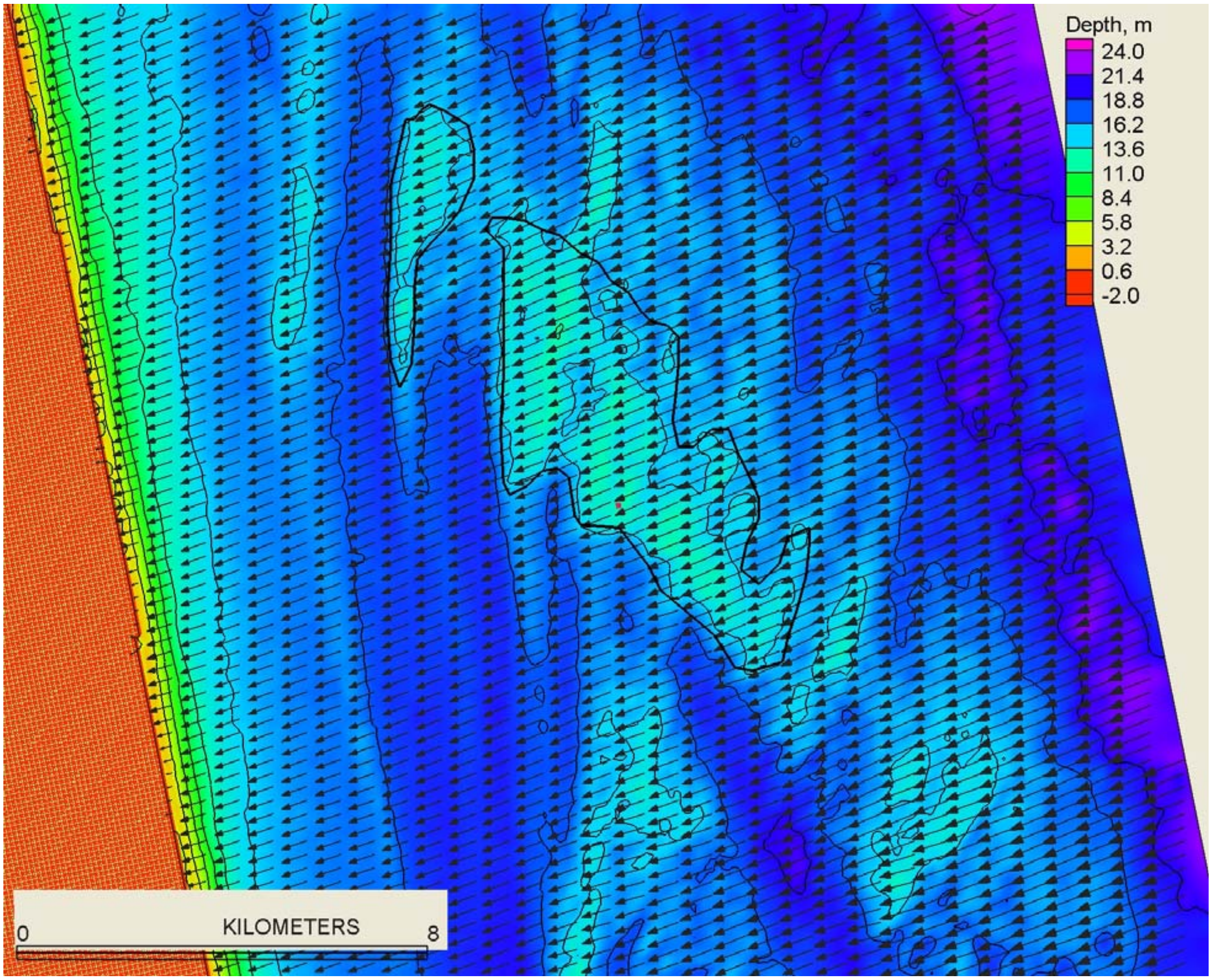


Figure 4-76. Predicted wave propagation over the A6 shoal and adjacent sand ridges. Conditions for a 14-sec wave period and an 8-m high wave were generated by strong winds from Hurricane Floyd in mid-September 1999.

Yet, at depths of only 13–15 m, the longest wave period allowed strong interaction with the topography at the crest of the shoals. The configuration of borrow excavations placed in the topography of A5 and A4 is shown in Figure 4-77A. Case 11 in Table 4.3 is consistent with areas of the A5 and A4 shoal that have already been designated as borrow sites. More extensive excavation of shoals A4 and A5 is shown in Figure 4-77B, which provides the hypothetical Case 12—the removal of about 52 million cubic meters of sand from shoals A5 and A4. The base case (Case 10) included topography for A5 and A4 without the existing borrow sites. Model tests showed that, under fair weather conditions, the topography of the shoal with or without borrow cuts positioned at the crest had little influence on the local wave regime. However, the model results for both Cases 11 and 12 were substantially different with respect to predicted wave height over the shoal.

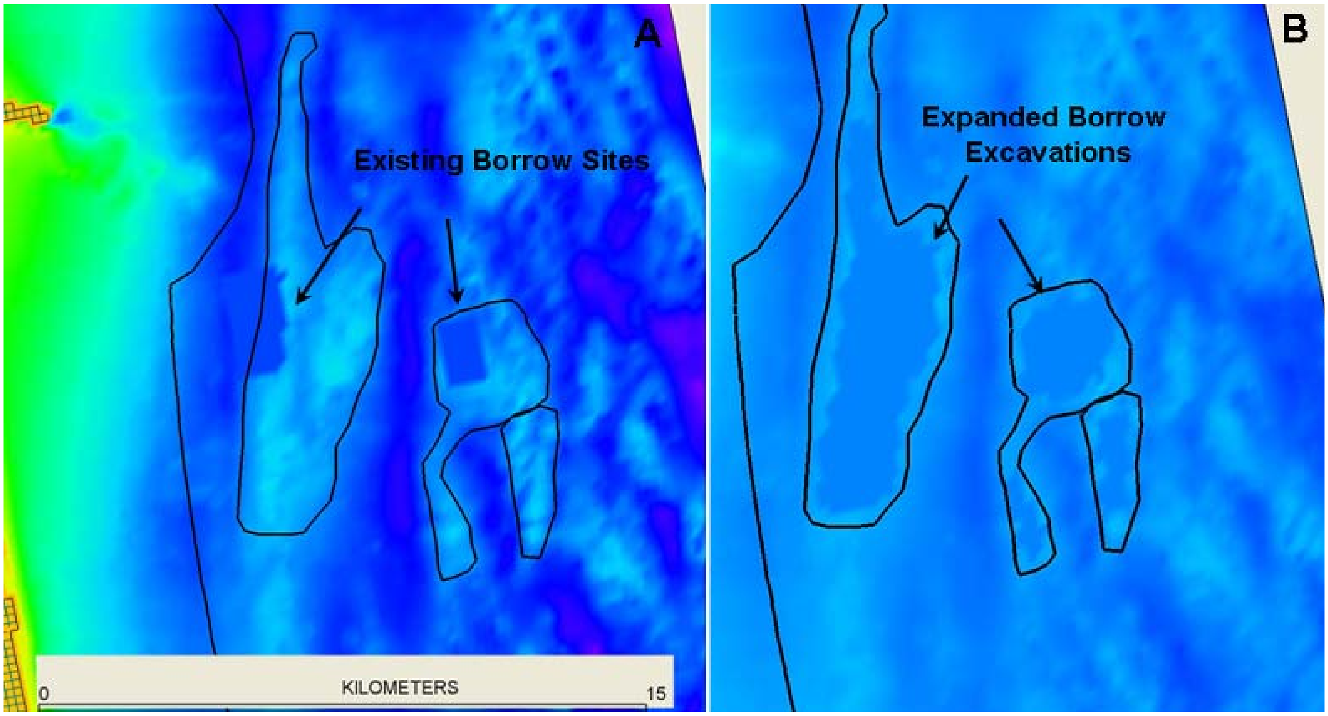


Figure 4-77. Existing and expanded borrow sites in the A5 and A4 shoals. Panel A shows the existing borrow areas of Case 11, and Panel B shows the expanded borrow excavations of Case 12.

Figure 4-78 shows the Case 11 and Case 12 model configuration of hypothetical borrow areas placed in the topography of the A6 shoal. The smaller cuts of Case 11 removed approximately 5 million cubic yards of sand, whereas the more extensive excavation of Case 12 removed the upper 2 m of sand from the crest of the shoal, totaling about 32 million cubic meters.

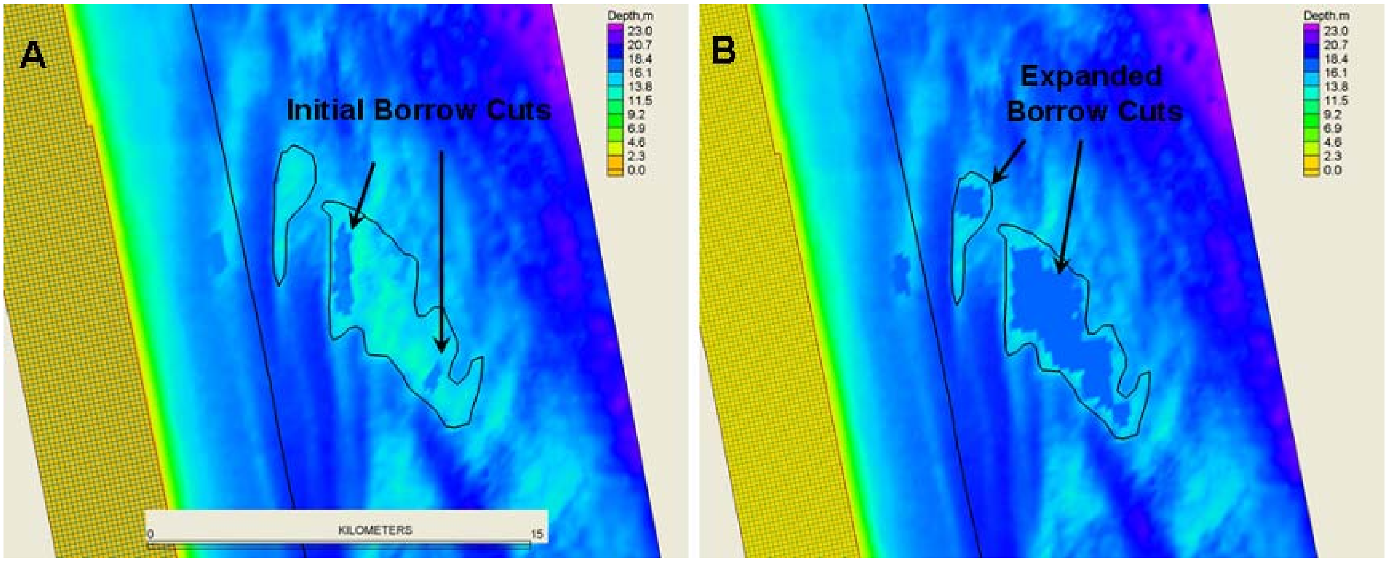


Figure 4-78. Initial (A) and expanded (B) borrow sites in the A6 shoal, Cases 11 and 12.

In Figure 4-79, the difference in wave height over the A5 and A4 shoals is shown with respect to the most extreme wave conditions that occurred within the model simulation. This condition was related to the passage of Hurricane Floyd and consisted of waves up to 8 m high over the shoal and wave periods as long as 14 sec. Panel A on the left in Figure 4-79 shows the difference that results from the borrow sites that currently exist (Case 11) and a shoal without borrow excavations (Case 10). Panel B in Figure 4-79 shows the predicted difference in wave height between Case 12 (expanded borrow excavation) and Case 10 having no borrow excavation on the shoals (see Table 4-3). In both examples, reductions in wave height up to 50 cm (1.6 ft) were positioned directly over the borrow excavations. Laterally between the borrow cuts, wave heights were predicted to increase up to 30 cm (1 ft). This pattern was consistent with predicted changes in the wave regime among the other shoal investigated in this study. The sharp topographic variation created by the dredged cuts is expected to increase diffraction effects over the shoal crest and result in abrupt variations in wave height. A similar result was found in model results over the A6 shoal as shown in Figure 4-80.

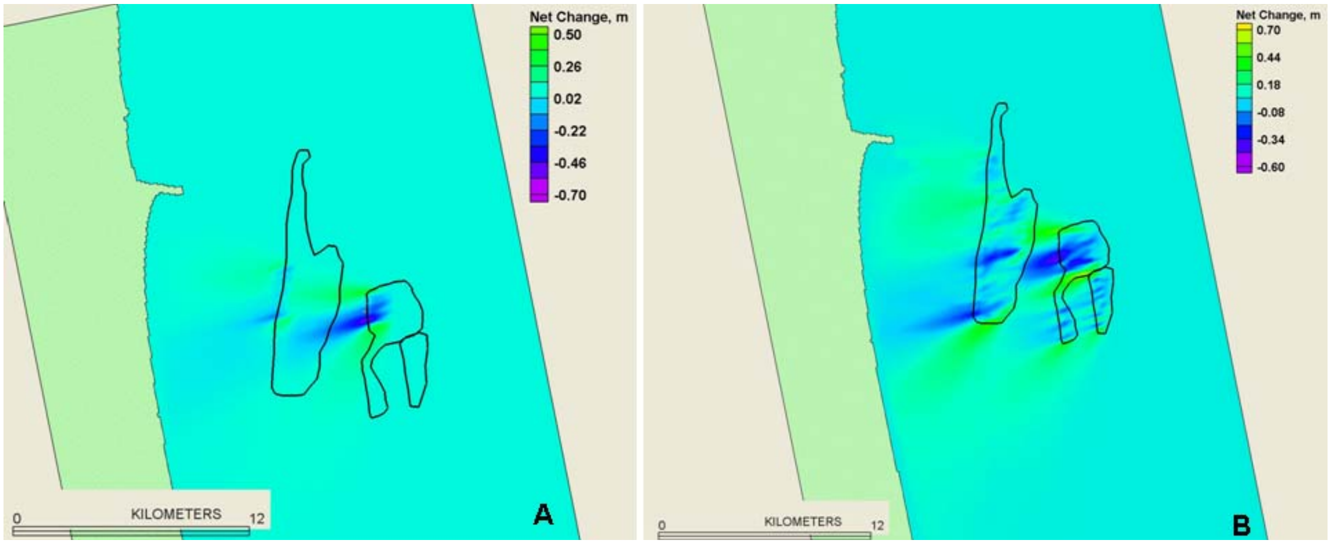


Figure 4-79. Difference in predicted wave height over the A5 and A4 shoal between Case 10 (no borrow cut) and Case 11 (A) and between Case 10 and Case 12 (B). Wave regime corresponds to the passage of Hurricane Floyd in September 1999.

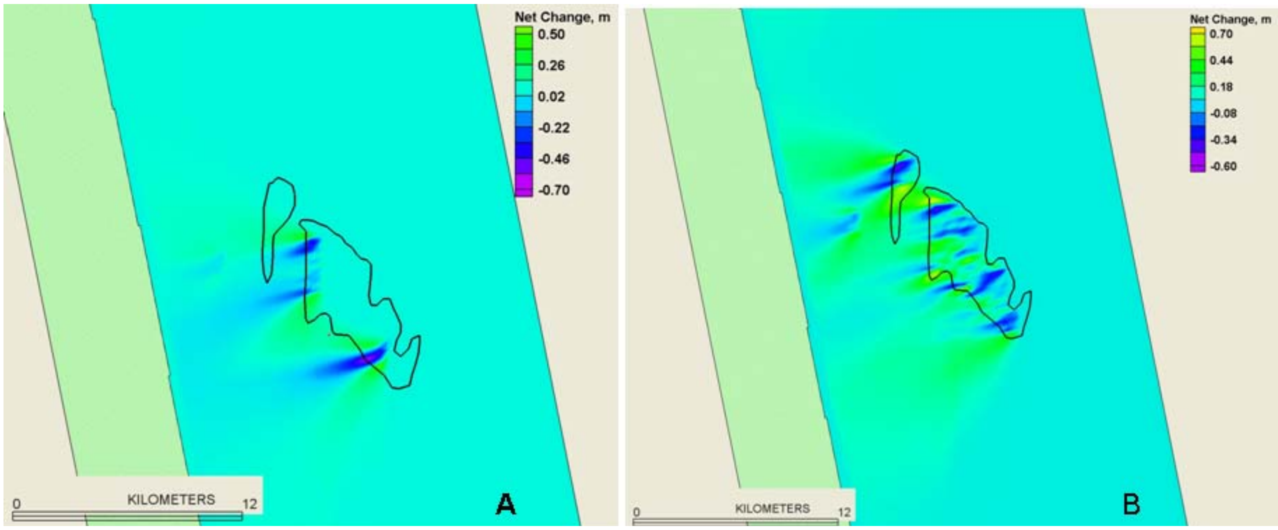


Figure 4-80. Difference between predicted wave height over the A6 shoal for Case 10 (existing topography) and Case 11 (A) and Case 12 (B). Wave regime corresponds to the passage of Hurricane Floyd in September 1999.

Predicted Sediment Transport and Topographic Change: A6–A4

The predicted velocity and sand transport field over the A6, A5, and A4 model grid was examined in two segments—one in the north, including the A5 and A4 shoals, and one in the south, including the A6 shoal. The most important influence at the shoreline of the existing and hypothetical borrow areas may be the modification of wave energy and related processes in the littoral zone. As in the other sites included in this study, sand transport circulation was strongest in the littoral zone under conditions of high wave energy. Here, breaking waves drove littoral currents that initiated sand movement. Figure 4-81 illustrates a high rate of sand transport within the littoral zone landward of the A5 and A4 shoals. Very strong transport was seen over the southside ebb shoal associated with the mouth of the St. Johns River at Mayport, Florida. The ebb shoal served as a sand bypass bar, moving sand around the inlet entrance. Offshore, lower rates of sand transport are predicted over a portion of the A5 and over the A4 shoal, as well as the surrounding flanks of the sand banks.

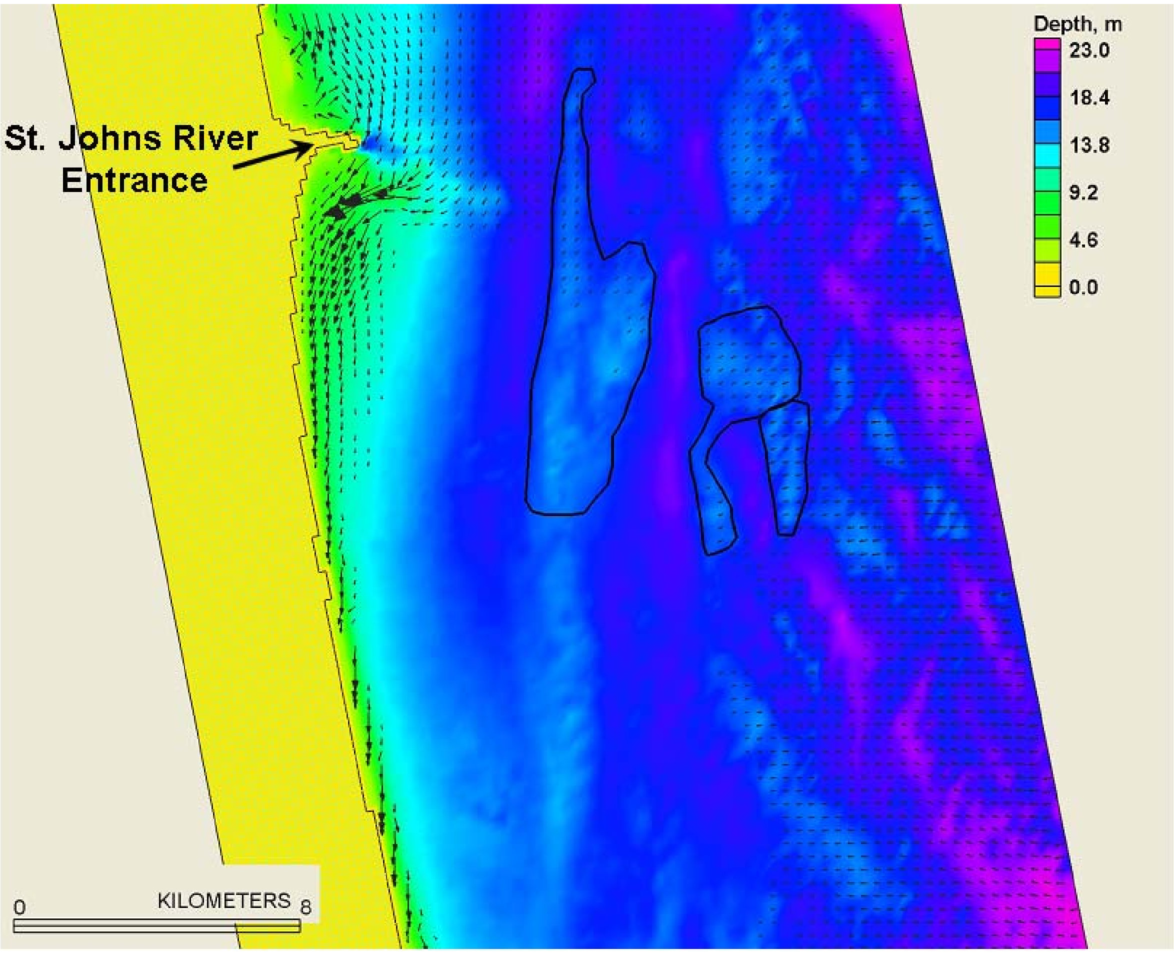


Figure 4-81. Patterns of sand transport in the vicinity of the A5 and A4 shoals. The model topography is according to Case 10, without borrow sites set in shoal. Wave conditions applied to the model boundary include the effects of Hurricane Floyd in 1999.

The vector patterns shown in Figure 4-82 indicate that the most intense sand transport is confined to the littoral zone under conditions of high wave energy. Just to the north of the entrance of St. Augustine Inlet, wave refraction over the ebb shoal resulted in converging littoral currents and a rip-like circulation cell. Offshore waves may stir sand over the crest of the A6 shoal and surrounding shoals. However, little net transport is predicted to occur over time. Sand transport was partitioned to the north and to the south in the littoral zone and could be seen at the outer edge of the St. Augustine tidal inlet, where breaking waves can produce strong currents.

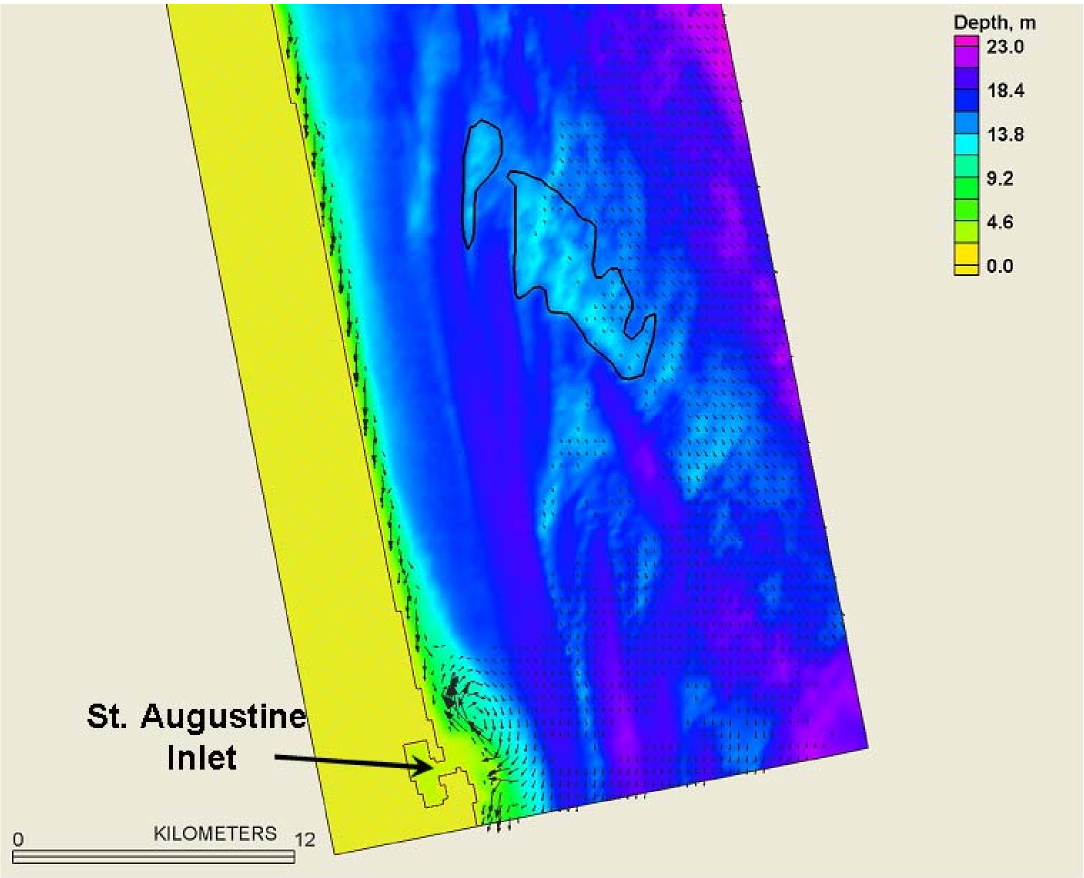


Figure 4-82. Sand transport in the vicinity of the A6 shoal. The model topography is according to Case 10, without borrow cuts set in the shoal. Wave conditions applied to the model boundary include the effects of Hurricane Floyd in 1999.

Predicted topographic changes over the two-year simulation period (Figure 4-83) were largely produced by the sum of repeated high energy wave conditions caused by local and distal storms. These storms generated large waves in the North Atlantic Ocean that eventually dispersed to the northeast Florida shelf. The overall pattern observed in the A6–A4 model area was similar to predictions in the study areas situated to the south. Net erosion on the upper shoreface at depths of 3 m (10 ft) or less was matched by a zone of deposition on the lower shoreface. Maximum topographic changes in all model runs included a range of +/- 2.5 m (8.3 ft). Significant topographic changes occurred over the ebb shoals at the mouth of the St. Johns River and at the entrance of St. Augustine Inlet at the south end of the model. A portion of the back bay area was included inside St. Augustine Inlet, and therefore, some tidal scour occurred through the inlet throat. Over the crest and flanks of the shoals, some topographic change was predicted but at approximately one order of magnitude less than topographic change predicted in the littoral zone and at the inlet. These changes are discussed separately by geographical location.

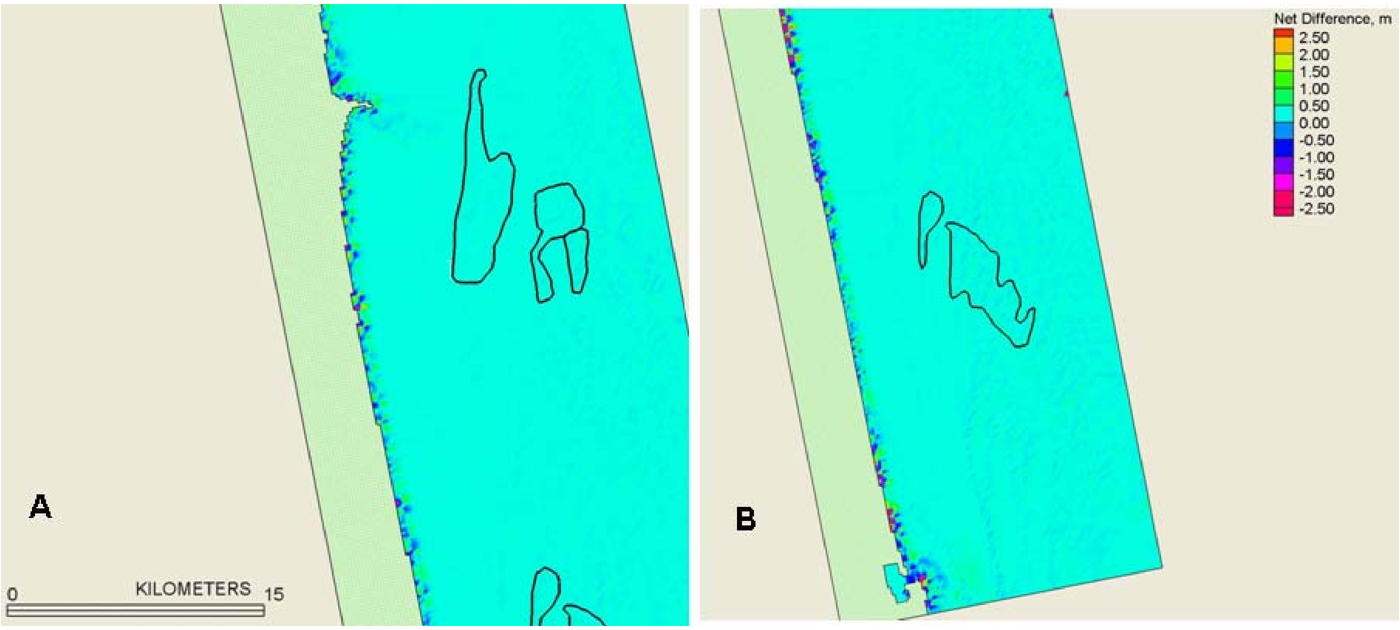


Figure 4-83. Predicted net topographic change over the two-year simulation period (1998–1999). Topography corresponds to Case 12, (extended borrow excavations in all shoals). Left panel (A) shows the north section of the model, and the right panel (B) shows the south section of the model.

Topographic changes over the crests of shoals A6, A5, and A4 reflected the impact of modification by dredging. In Figure 4-84, the crest of shoal A6 shows alternating zones of slight erosion and deposition after two years of simulation. This pattern probably indicates reworking by occasional storm-generated waves and is consistent with the bedforms seen in the video transects of the shoals included in this study (see Figures 3-22 to 3-31). Figure 4-85 shows the crest of A6 after two years of simulation under model Case 12, which included an extended borrow cut covering most of the crest areas of this shoal. Deposition up to 50 cm (1.6 ft) of sand along sections of the excavation perimeter reflected avalanching down the relatively steep side walls of the cuts. Although the morphologic time step in the CMS-FLOW model was set to one hour, the sand transport time step was much shorter and the total sand transport accumulating over one hour captured the influence of avalanching. The zones of sharp topography defined by erosion and deposition up to 30 cm (1 ft) may result from wave shoaling and refraction over the sharp topography created by the dredge cuts. Figure 4-86 shows a predicted time series of elevation change at four locations on the rim of the A6 cumulative borrow excavation (Case 12). The reality of the predicted topographic changes along the rim of the borrow cut is uncertain, since detailed field data over long periods of time are not available. However, the model results may indicate that topographic smoothing of the borrow excavation may occur. It is noteworthy that virtually no deposition occurred in the lower elevations of the A6 cut over the two-year simulation. To further investigate the morphologic evolution of the shoals before and after excavation, three-dimensional model simulations may be required to fully define the flow boundary layers over the topographic relief of the shoals. Furthermore, model runs representing time scales of a decade and longer are likely to be necessary.

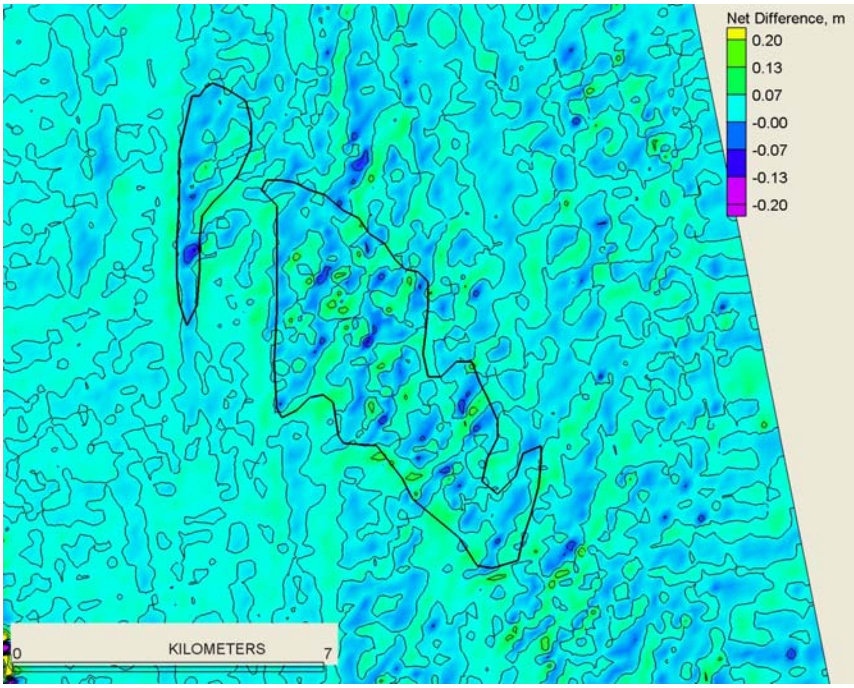


Figure 4-84. Net predicted topographic change over the crest of shoal A6 after two years of model simulation. Topography is from Case 10, no borrow cuts.

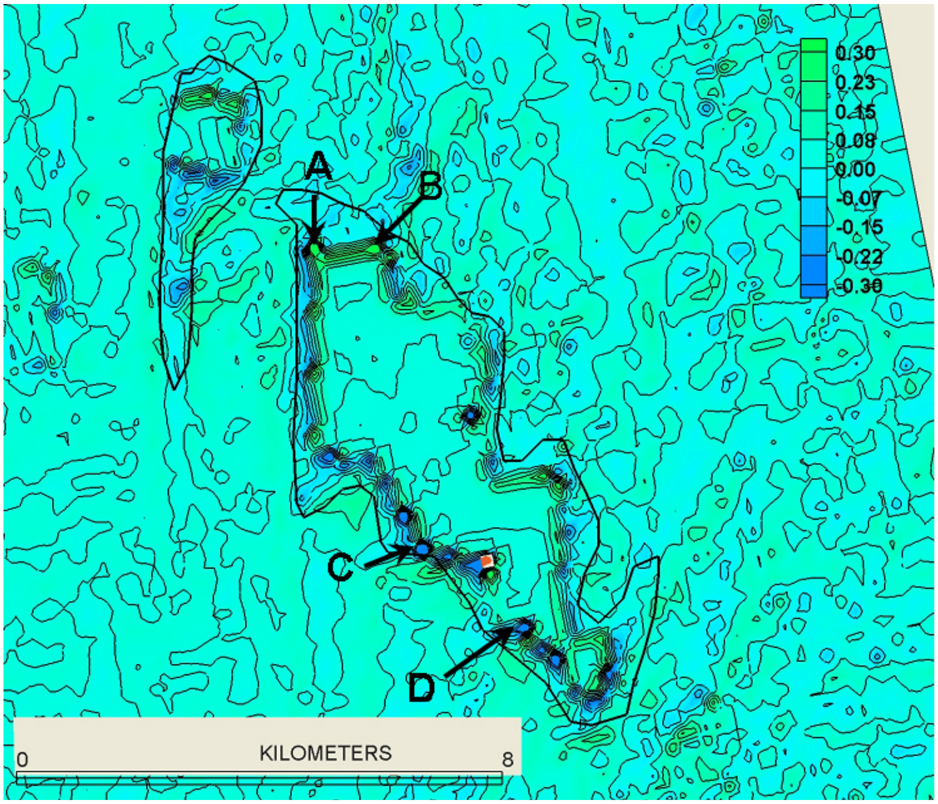


Figure 4-85. Net topographic change over the crest of shoal A6 after two years of model simulation. Topography is from Case 12, an extended borrow cut, as shown in Figure 4-83. Elevation changes at observation stations A, B, C and D are shown in Figure 4-86.

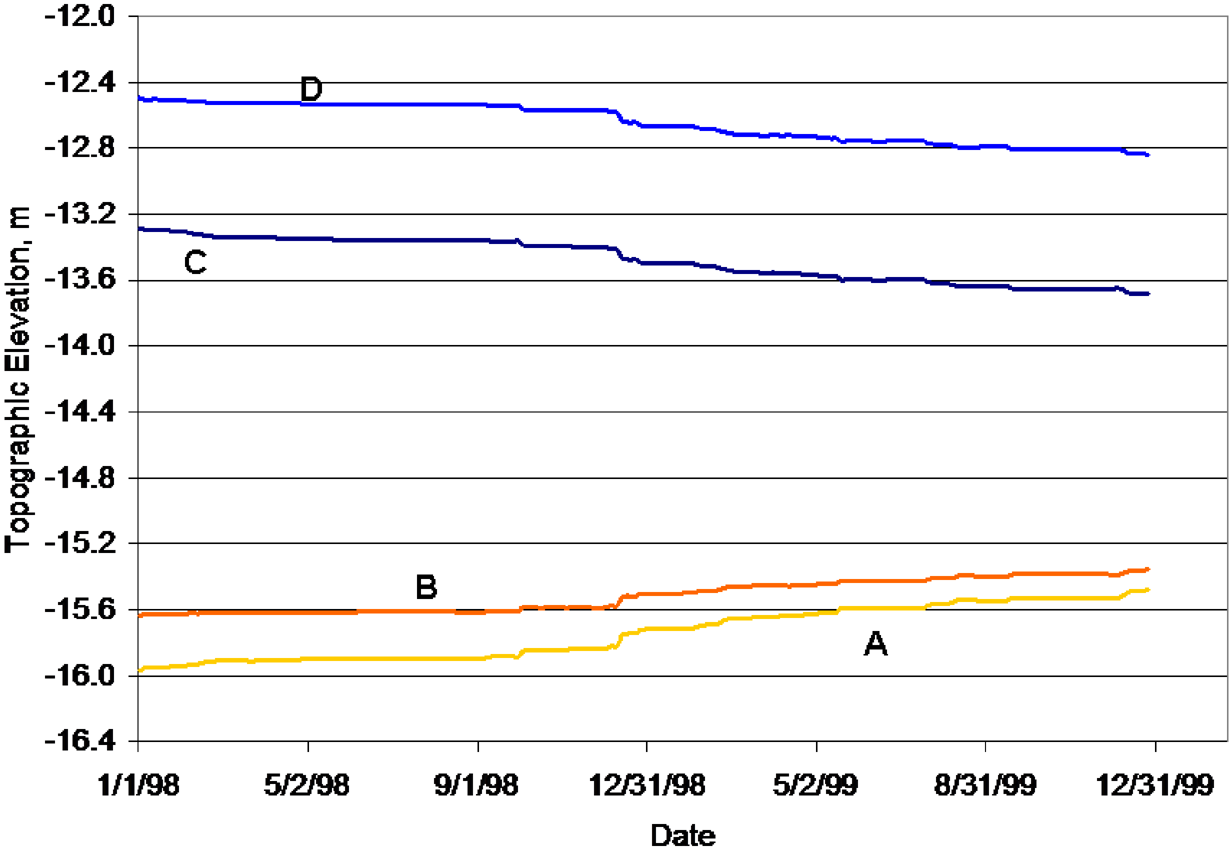


Figure 4-86. Elevation change at four numerical observation stations on the rim of the A6 cumulative borrow cut. Locations are shown in Figure 4-85

Topographic difference among the model test cases on the shoreface landward of the borrow sites were similar to those predicted at the other study sites along the northeast Florida shoreline. The net topographic differences among the cases listed in Table 4.3 were generally less than 1 cm over the two-year simulation period. In the A6 to A4 model domain, several time series of topographic change were selected among a total of 50 numerical monitoring stations to illustrate this point, as shown in Figure 4-87. Elevation change at upper shoreface Stations 8 and 14 is shown in Figure 4-88. At Station 8, sand deposition of 50 cm (1.6 ft) was predicted for 1998. At Station 14, net erosion of about 18 cm (0.6 ft) occurred. Differences among the three cases, with and without borrow cuts, was 1 cm or less over the two-year simulation period.

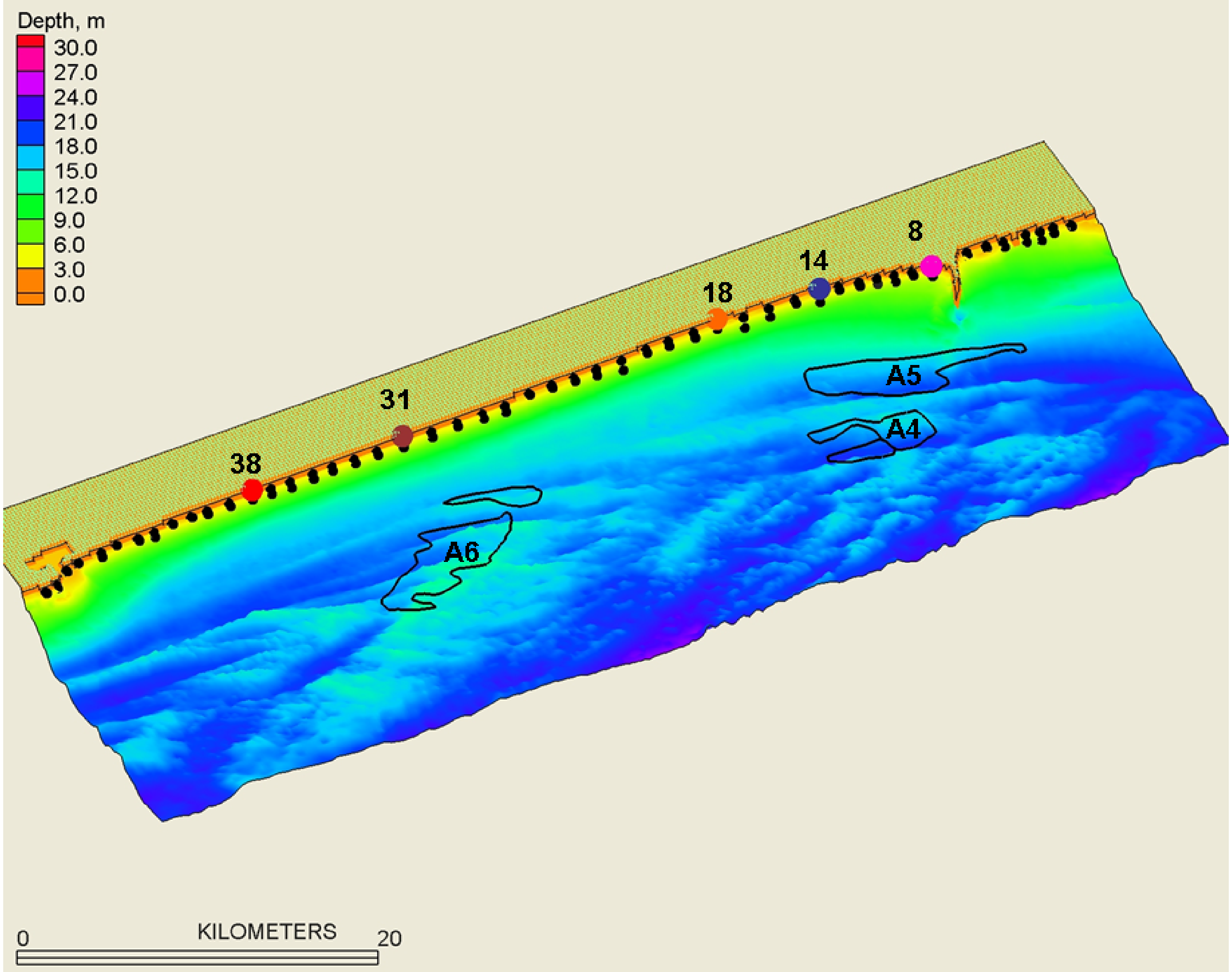


Figure 4-87. Location of numerical monitoring stations positioned along the shoreface in the littoral zone to capture individual time series of topographic change. Time series Stations 8, 14, 18, 31, and 38, as discussed in this report, are identified.

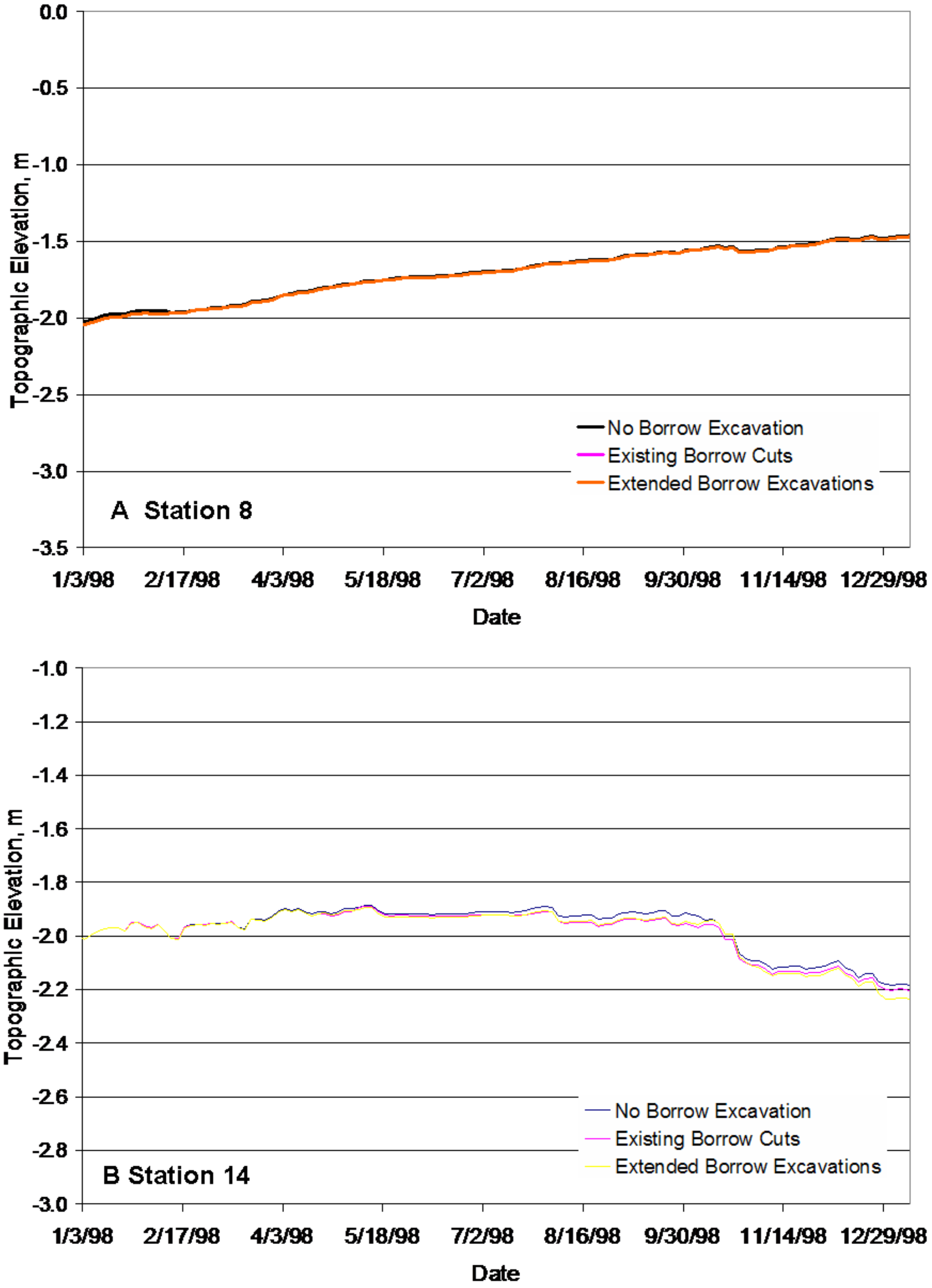


Figure 4-88. Time series of elevation change at numerical monitoring Stations 8 (A) and 14 (B). Locations are shown in Figure 4-87.

At monitoring Station 18, deposition of about 30 cm (1 ft) occurred just to the south of the A4 shoal (Figure 4-89). The predicted data for all three model test cases was nearly identical and consistent with the trend of deposition at lower shoreface monitoring stations through the duration of the model run.

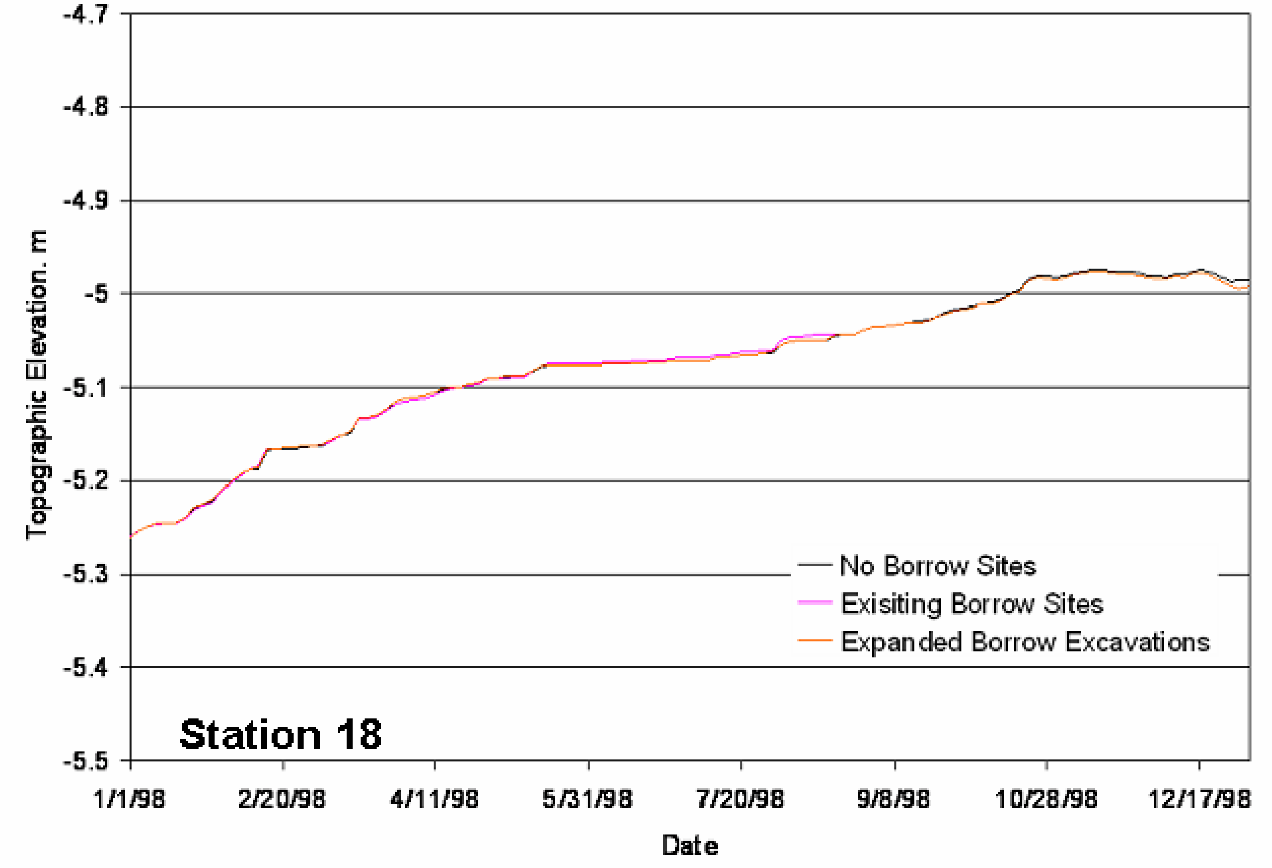


Figure 4-89. Predicted elevation change at lower shoreface Station 18 during 1998. Location is shown in Figure 4-87.

On the shoreface in the vicinity of A6, differences among the three test cases (Cases 10, 11, and 12) were predicted to be small. Figure 4-90 shows the predicted time series of elevation at these locations for 1998. The decrease in elevation at both locations (Stations 31 and 38) indicated erosion, which is consistent with the trend for most of the upper shoreface in the study area.

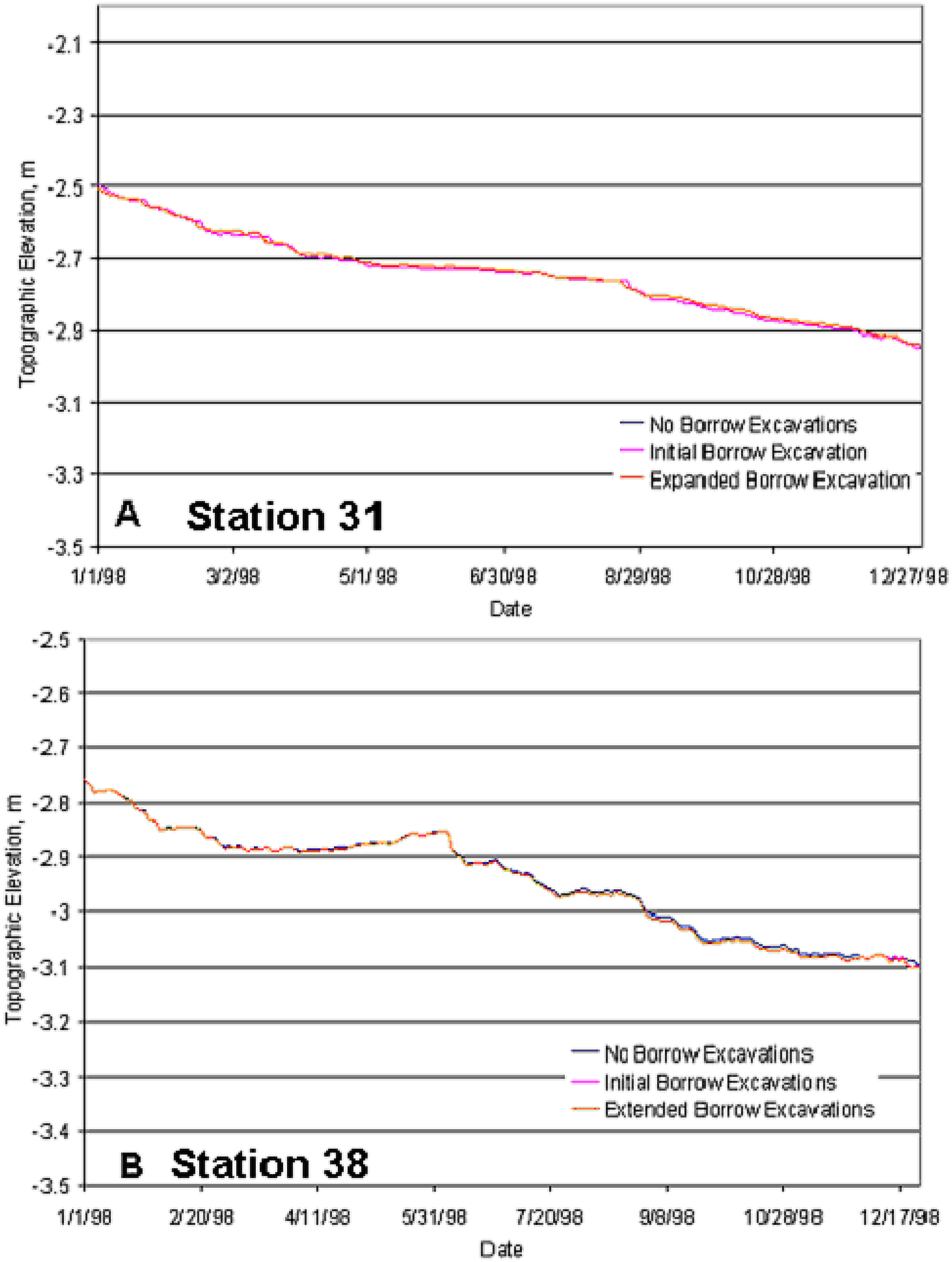


Figure 4-90. Predicted elevation change on upper shoreface Stations 31 (A) and 38 (B), landward of shoal A6.

Predicted Littoral Sand Transport Rate: A6–A4

The results of modeled sand transport in the littoral zone can best be summarized by examining the net transport rate over the two-year simulation period. The net rate can be compared for the three model test cases (Cases 10, 11, and 12) that include the original and modeled topography. The annualized rate of littoral sand drift, landward of the A6–A4 shoals, is plotted in Figure 4-91. Rates varied alongshore between -150,000 m^3/yr and +25,000 m^3/yr. Negative rates indicated south-directed transport, whereas a positive rate indicated that littoral sand transport in the littoral zone was directed north. Thus, as seen in Figure 4-91, the predominant net drift direction was south. In addition to the annualized rate, the temporal standard deviation calculated at each numerical recording station was also shown and can be compared to the net difference between model Case 10 and Case 12 (Figure 4-85). In Figure 4-91, the difference in the sand transport among these cases (see Table 4.3) were too small to be visually resolved.

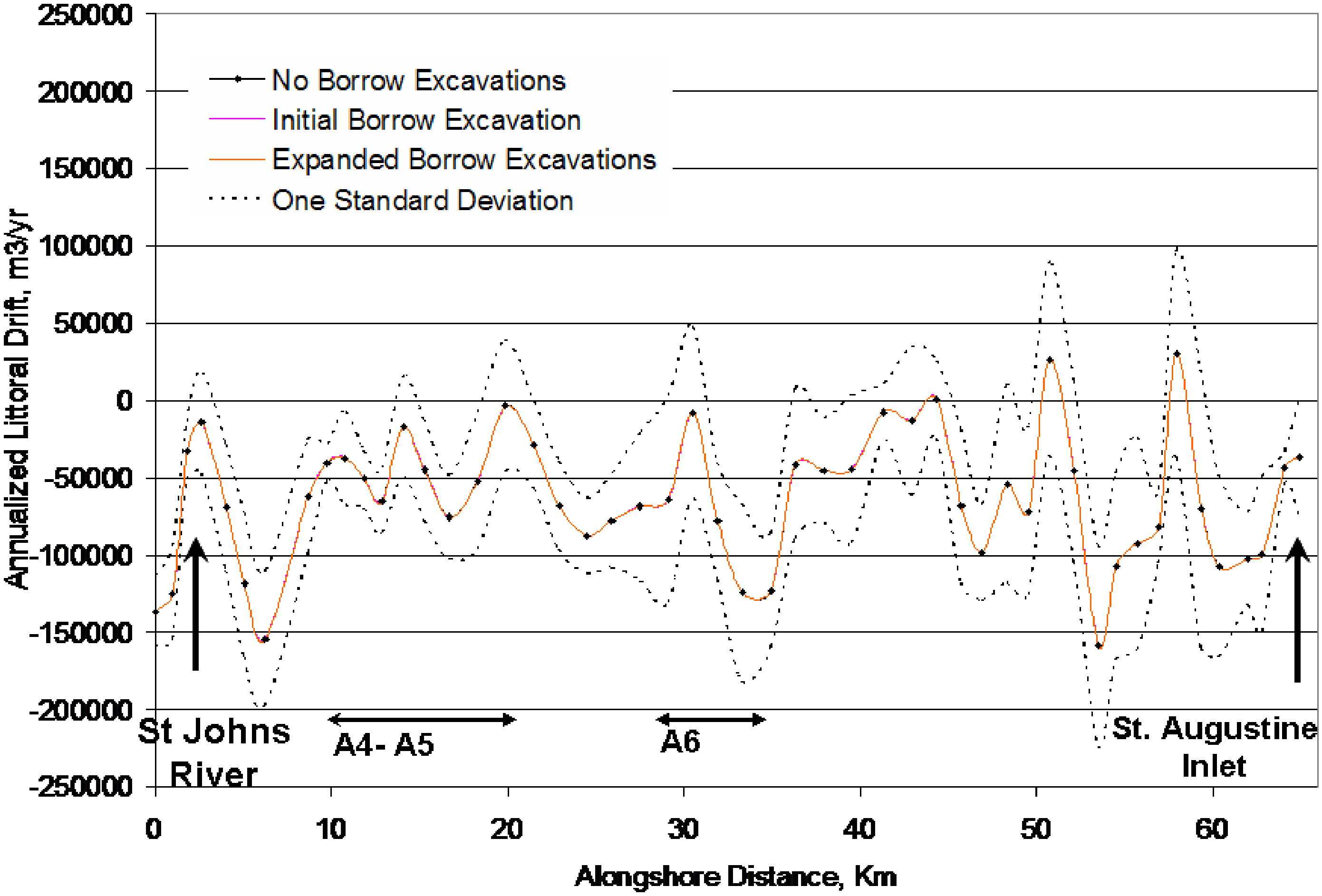


Figure 4-91. Net littoral transport rate, landward of the A6–A4 shoals. Rate is annualized for the 1998–1999 period. Alongshore distance is from north to south. Relative positions of the shoals are indicated on the plot. Negative values indicate south-directed transport, and positive values indicate north-directed transport. Also shown is the standard deviation of transport rates calculated through time at each monitoring station.

Figure 4-92 illustrates the difference in littoral sand transport with respect to model prediction over unaltered shoal topography and predictions in which the fully expanded borrow excavation were in place. This difference varies from near 0 to 500 m^3/yr. The difference and variability was higher in the littoral zone onshore of the shoals. However, the difference was less than 5% and mostly less than 1% of the temporal standard deviation in transport rate at any location in the littoral zone. This is consistent with the near-zero differences in predicted wave height and topographic change near the shoreline among the cases tested with respect to offshore borrow excavation.

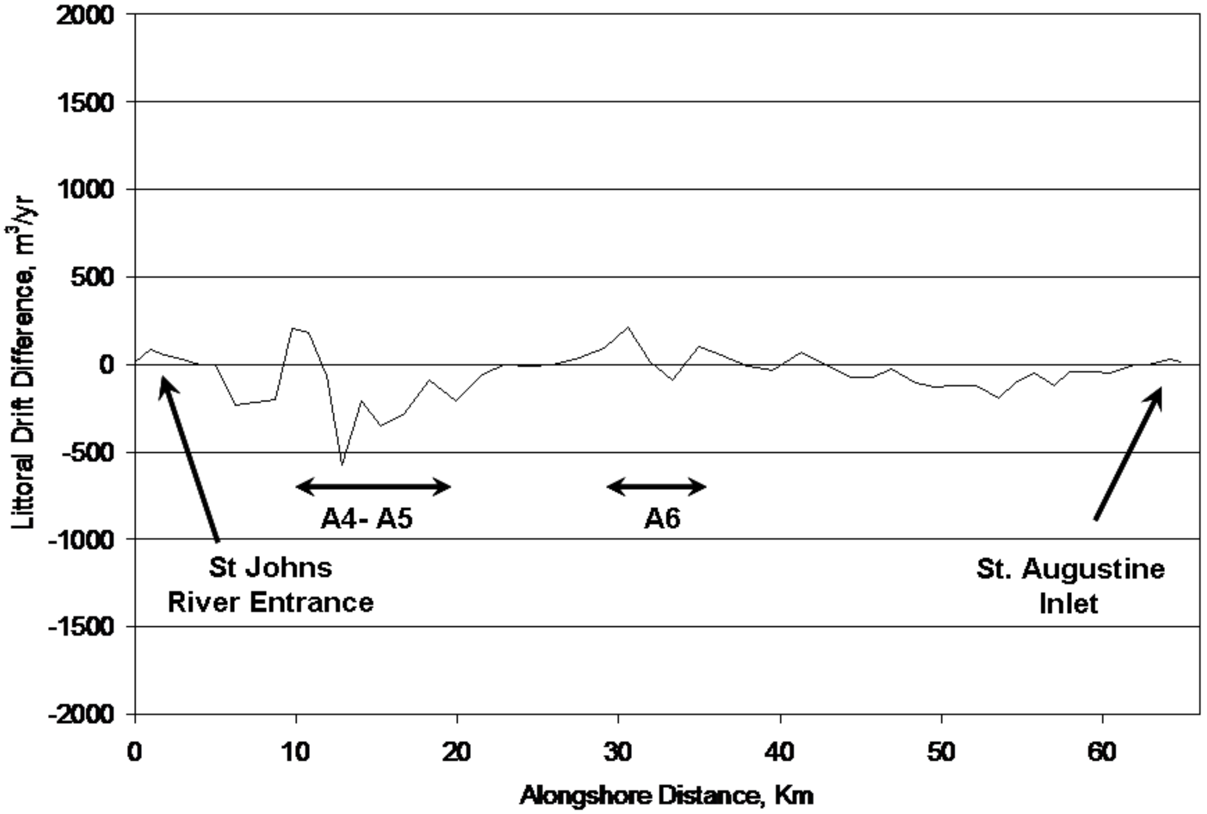


Figure 4-92. Difference between annualized littoral drift predicted for A6–A4 shoal topography, without borrow excavation topography and with multiple borrow excavations (Cases 10 and 12).

4.4 Short-Term and Long-Term Impacts from Dredging to Biological Resources

The benthic assemblages—fish, sea turtles, seabirds, and marine mammals—in the study area were characterized from results of two field surveys and data from literature research. Dredging offshore borrow areas can result in negative impacts to the biological communities, especially the resident benthic infauna, which have limited mobility. Impacts to the benthos may, in turn, affect commercially and ecologically important finfish that utilize the benthos as a food resource. In general, potential long-term impacts to sea turtles, seabirds, and marine mammals are expected to be limited to the active dredging phase of the project, with no impacts anticipated after dredging operations and placement of sand on the beach have been completed.

4.4.1 Benthos

To assess the potential impacts of dredging on offshore benthic populations, it is important to consider the effects in the context of other manmade and natural disturbances that may impact the population, as well as the spatial and temporal scales of the impact. For example, offshore benthic communities of Northeast Florida are exposed to large-scale disturbances such as periodic storms and harmful algal blooms (HABS) as well as small-scale disturbances due to biotic interactions such as organism feeding pits and epifaunal trails.

This section discusses the potential impacts to benthic organisms residing in the offshore areas that may be dredged for beach nourishment projects. Our study essentially characterized the pre-dredge conditions of the sand shoals. There was no post-dredging monitoring. As described in Section 3.2, we were able to collect a number of samples within the portion of the A4 shoal that was dredged from June through August 2005. To assess potential dredging impacts to the benthic communities in the study area, we present an overview of existing literature examining the effects of disturbances on the benthos including recolonization and recovery rates, a discussion of the direct and indirect impacts of offshore dredging, and predictions of the dredging impacts and recovery for the study areas.

4.4.1.1 Overview of Disturbance Effects

The field portion of this study characterized the existing baseline (i.e., pre-dredging) benthic communities within the study areas. As described in Section 3.2, we collected grab samples within the post-dredged portion of A4. There is a relatively substantial body of work examining potential offshore sand borrow areas from previous studies conducted by MMS in Alabama (Byrnes et al. 1999), New Jersey (Byrnes et al. 2000), Virginia (Hobbs 2000), North Carolina (Byrnes et al. 2003), Maryland and Delaware (Diaz et al. 2004), and East Central Florida (Hammer et al. 2005).

Similar to the current study, these projects characterized the existing or pre-dredge benthic communities and did not include post-dredging surveys. In these previous MMS studies, predictions of dredging impacts and post-dredging recovery were based on existing studies.

Numerous studies have investigated benthic recovery after manmade and natural disturbances (see reviews Rhoads 1974, Thistle 1981, Hall 1994, Thrush and Dayton 2002). These include studies examining the effects of dredging and other manmade disturbances in estuarine settings (Kaplan et al. 1975, Van Dolah et al. 1984, Bemvenuti et al. 2005). Offshore studies include investigations of the effects of offshore aggregate mining on macrobenthic communities, especially in the United Kingdom (Kenny and Rees 1994, 1996; Newell et al. 1998, 2004; Hitchcock et al. 2002). Other studies have examined the effects of trawling on offshore benthic communities (Watling and Norse 1998, Thrush and Dayton 2002, Løkkeborg, 2005). There is also a relatively robust body of literature that has examined the effects of natural disturbances (storms, feeding pits/trails, etc.) on benthic communities and their recovery (Thistle 1981, VanBlaricom 1982, Oliver and Slattery 1985, Hall 1994, Zajac et al. 1998). These natural disturbances range in spatial scales from centimeters to meters (e.g., feeding pits) to kilometers (e.g., storms and HABS).

There is limited information on the recovery of post-dredging biological communities on the OCS. The Virginia Institute of Marine Science field-tested a physical and biological methodology for offshore dredging operations at Sandbridge Shoal located offshore of Virginia (Hobbs 2006). There have also been studies examining the effects and recovery of dredged material placement on the OCS (e.g., reports prepared for the USEPA examining ocean dredged material disposal sites). These studies provide useful information in terms of potential benthic recruitment patterns on the OCS.

Spatial and Temporal Scales

Benthic communities vary over several spatial and temporal scales (Thrush 1991, Zajac et al. 1998, Gray 2002). Spatial heterogeneity in benthic communities is related to spatial variations in physical conditions such as sediment characteristics, water depth, and hydrodynamics as well as biological factors such as larval recruitment and post-settlement mortality. In addition, benthic community structure is impacted by the spatial extent and/or frequency of disturbance events. Over temporal scales, benthic assemblages demonstrate seasonal and year-to-year differences due to variations in individual species life histories and variability in larval recruitment, post-settlement mortality, and species turnover.

Softbottom organisms create much of their habitat's structure, ranging from micro-scale changes around individual animal burrows and tubes to larger scale changes such as sediment reworking by mobile epifauna (Thrush and Dayton 2002). As a result, they influence sediment stability, water column turbidity, nutrient and carbon processing, and the geochemistry of deeper sediment layers. At small scales, biogenic features such as tubes, feeding mounds, and burrows can play key roles in influencing benthic diversity and resilience (Brenchley 1981). They also have important roles in the sequestering and recycling processes on the seafloor.

Benthic communities in the Atlantic off of Northeast Florida are also impacted by large-scale events, both in terms of duration and spatial coverage, which affect community patterns. For example, HABs are large-scale (km) disturbance events that impact benthic communities off of Northeast Florida and usually occur from late August through November (FFWCC, FWRI website www.floridamarine.org). While no HABs occurred during the surveys, a large area off Northeast Florida experienced a HAB in the fall 2007 (Figure 4-93) that was caused by the red tide dinoflagellate, *Karenia brevis*. The dinoflagellate was trapped in cooler waters under warm, less dense surface water. *K. brevis* decreased oxygen concentrations, which resulted in benthic mortality. Mortality of Florida manatee and sea turtles can also be caused by red tide.

In addition to HABs, offshore benthic communities within the relatively shallow water depths (approximately 9–14 m) in the study area typically experience disturbance from periodic storms. Frequency of storms in the region were experienced during our field operations; prior to the 2005 sampling period, Hurricane Wilma traveled through the Gulf of Mexico and crossed South Florida to the Atlantic October 15–25, 2005, with maximum wind gusts of 185 mph. The presence of distinct and sharply formed sand waves in the epibenthic camera sled video is evidence of the storm's effect of the sediment.

The extent of dredging operations in the OCS are established over a fixed geographic area and conducted over a specific time period, as specified in the lease agreement. The disturbance generated by a dredging operation will be superimposed on a benthic community that has been exposed and will be exposed to a variety of natural disturbances, such as HABs and tropical storms that occur at various temporal and spatial scales. In addition, there are seasonal and annual variations in recruitment patterns based on the life history of individual species, which will affect recolonization and recovery of the dredged area. Together, these factors make it difficult to predict the precise timing and sequence of benthic community recovery.

As a result, predictions of potential impacts and recovery rates from dredging need to consider the spatial and temporal scales of the dredging operations. In addition, the composition of the existing benthic community and its life history traits, both at the dredge site and in adjacent areas containing potential colonists, and the life histories of the individual benthic species need to be considered. For example, Diaz et al. (2004) presented life history information for the benthos at proposed dredging sites offshore of Maryland and Delaware in order to predict potential recruitment and recovery patterns.

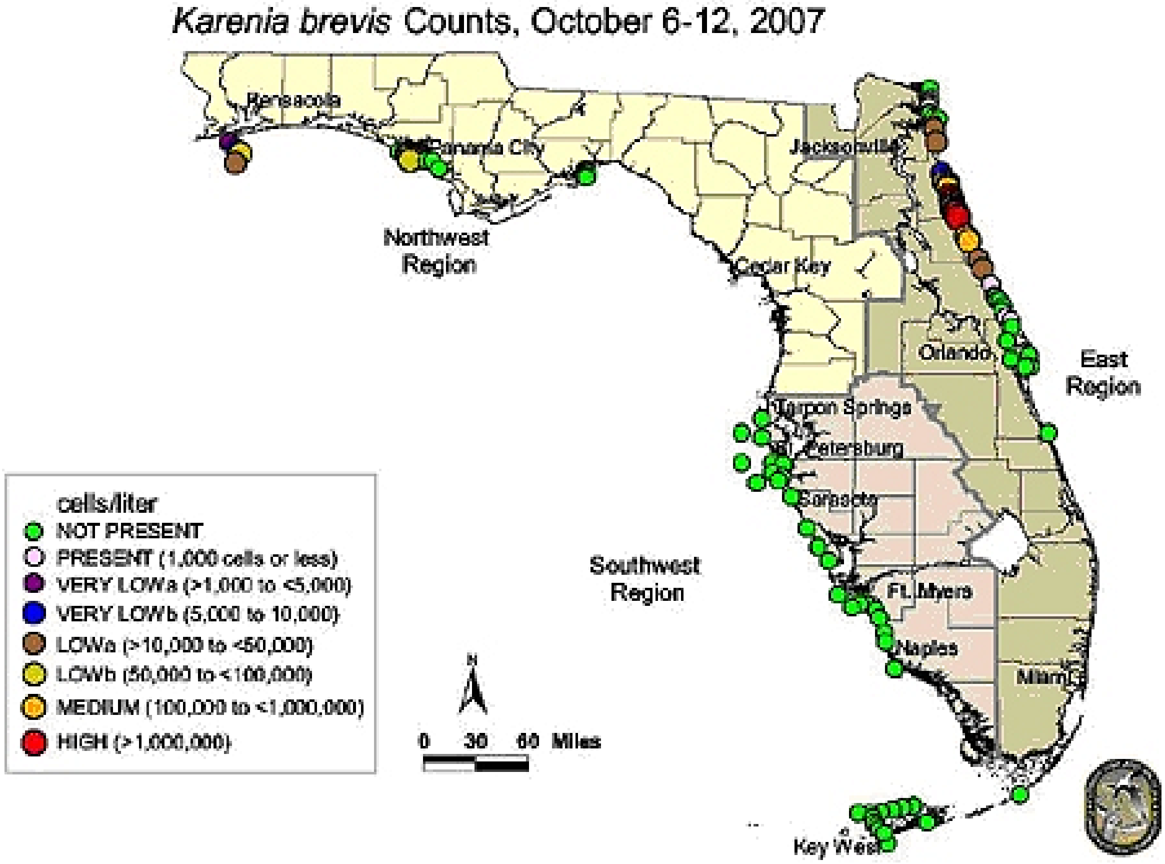


Figure 4-93. *Karenia brevis* counts, October 6–12, 2007 (FFWCC and FWRI).

Recolonization and Recovery Rates

Benthic recolonization rates of a disturbed area is dependent on several physical and biological factors at a dredge site. Physical factors include time of year the dredging occurs, duration of dredging, spatial extent of dredged area, depth that sediment is extracted, local currents/hydrodynamics, and sediment characteristics (e.g., grain size, organic content, chemistry) of the exposed sediment remaining after dredging, the degree of sedimentation that occurs after dredging, and the type of dredging equipment used. Biological factors include the availability of adult colonists from adjacent undisturbed habitats, availability of larval and juvenile colonists from the water column, and reproductive and recruitment cycles of species. Table 4.4 summarizes macrobenthic recovery times for several offshore dredged sites that are in areas having physical similarities to sites considered in this study.

Recovery is defined as the return of the community to pre-dredging diversity, abundance, and species composition. Various studies have concluded that benthic communities of comparable pre-dredging abundance and diversity can be expected to return to the dredge sites within several years (Van Dolah et al. 1992, Blake et al. 1996, Newell et al. 1998, Byrnes et al. 2004). However, investigators have pointed out that although the recolonized post-dredge communities may be similar in abundance and diversity to pre-dredge communities, their taxonomic composition may differ greatly (Kenny and Rees 1996, Nairn et al. 2004). Byrnes et al. (2004) note that although levels of abundance and diversity of benthos may recover within one to two years, it may take many years to recover in terms of sediment characteristics and species composition. Wilber and Stern (1992, as cited in Byrnes et al. 2004) concluded that infaunal communities recolonizing borrow sites may remain in an early successional stage for two to three years or longer, Jutte and Van Dolah (1999) report the infaunal community offshore of Myrtle Beach, South Carolina, recovered in approximately two years after dredging was completed. Newell et al. (2004) report that, for areas dredged for aggregate material in the U.K., species diversity generally recovered to within 70%–80% of adjacent areas within 100 days and species abundance within 175 days. Newell et al. (1998) present that recovery times for estuarine muds were approximately 6–8 months, sand and gravel approximately two to three years, and for coarser deposits, five to ten years.

In determining potential benthic recovery rates from disturbances, there is a need to understand the scales of mobility and the processes affecting the successful establishment and growth of potential colonists. In softbottom habitats, a range of life stages are typically involved in the recovery processes within a disturbed patch (Whitlatch et al. 1998, Zajac et al. 1998, Thrush and Dayton 2002). Colonizing organisms are comprised of larvae transported via the water column as well as post-settlement juveniles and adults actively moving into the area or passively transported via bedload transport (Whitlatch et al. 1998). Small disturbed areas with a larger edge-to-surface-area ratio should be predominately influenced by adult or post-settlement colonists compared with larger areas having smaller edge-to-surface-area ratios. Reproductive and larval development modes are critical to species responses to disturbances across all spatial scales (Zajac et al. 1998). Diaz et al. (2004) note that it is possible to predict the potential nature of recolonizing communities based primarily on the occurrence of other community groups in the vicinity.

Most subtidal benthic assemblages are highly patchy, which may be related to patchy settlement of certain larval year classes due to large-scale subtidal disturbances (Levinton 1982). A subtidal bottom can represent a mosaic of patches in various development stages following a major disturbance. At small scales, distributions are influenced by the presence of individual structures such as tubes and burrows.

By removing sediment, dredging with a THSD changes the seafloor topography by creating furrows on the bottom. Within the furrows, sedimentary structures such as burrows and tubes are destroyed or buried. As a result, the spatial heterogeneity provided by these structures is removed. In addition, dredging exposes sediments that may, or may not, have similar characteristics (e.g., grain size, organic content) as the overlying dredged sediment. Additionally, the geochemical characteristics of the exposed sediment will likely differ from the pre-dredge conditions. Reworking of exposed sediments by organisms is an important process in benthic recovery after dredging because it promotes diffusion of dissolved oxygen into soft substrate exposed during dredging (Byrnes et al. 2004). If sediments are vertically uniform, sediments exposed by mining/dredging would be similar to those removed, allowing a similar suite of taxa to colonize the dredged sites (Byrnes et al. 2004).

Diaz et al. (2004) note that the prediction of short-term responses of benthos is more difficult than predicting long-term response because of the asynchronous and naturally variable short-term population fluctuations. They also report that, overall, it is probable that larval and juvenile recruitment would be better after a spring/summer dredging than after a fall/winter dredging. Recruitment by adults during any season would likely be regulated by factors, such as storms, that affect passive transport.

Posey and Alphin (2002) sampled the benthic fauna of a borrow site offshore of southeastern North Carolina at water depths of approximately 12–15 m. The borrow area was part of an old channel. The benthic community in the project area exhibited strong resilience to dredging, with little detectable difference between the control and borrow sites one year after dredging. Their results suggest relatively quick recovery from dredging with inter-annual variability explaining more of the observed differences than dredging effects. Dredging was conducted using a TSHD with 1–2.5 m of sediment removed. In addition, there was no detectable change after the passage of several hurricanes, though they reported that the possibility existed for undetected long-term effects. The community exhibited strong temporal variability, both among years and seasons, which may have overshadowed any potential long-term dredging impacts.

Barry A. Vittor & Associates, Inc. (BVA) (1999a) reported that the infaunal assemblage in a dredged borrow pit located 3.6 km offshore of Coney Island, New York, still differed from adjacent reference areas for approximately a decade after dredging ended. They reported that the silt/clay content of the borrow pit was greater than sediment in the reference area. The infauna were dominated by two deposit-feeding spionid polychaetes and deposit-feeding mollusks, which were not recorded at the reference area. They concluded that the persistence of the borrow pit as a feature on the seafloor and the accumulation of fine sediment maintained the differences between the borrow area and reference infaunal communities.

Lotspeich and Associates, Inc. (1997) conducted a pre- and post-mining benthic study of a borrow area in Duval County, Florida, for the Jacksonville District USACE. They reported that troughs, ridges, and depressions observed by divers during the first post-dredging sampling event (less than six months after dredging) were no longer visible approximately one year after dredging, due to a series of severe storms. They speculated that the storms reworked the sediment in the area to such a degree that the dredging features were eliminated. They reported that differences in the benthic communities between dredged and control areas were “difficult to detect” during the post-dredging monitoring due to area-wide declines in species richness and abundance, suggesting other impacts such as storms may have affected the area over the length of the study. They also reported that strong temporal changes in benthic infaunal abundance and species richness greatly exceeded spatial variance.

Hobbs (2006) conducted pre- and post-mining benthic studies of a borrow area on Sandbridge Shoal, Virginia, and found little discernable difference between areas that were disturbed by sand mining and nearby areas that had not been mined. Although substantial quantities of sand were removed from the shoal, no negative environmental impacts were observed for benthos or demersal fishes. Differences in benthic abundance between years were observed both within and beyond the mined areas, indicating that inter-annual variability has a greater influence on benthic abundance than sand mining.

Table 4.4. Reported Macrobenthic Recovery Rates at Offshore Dredged Sites

Type of Impact/ Disturbance	Location	Recovery Time	Source
Dredged Borrow Pit	**Offshore Coney Island, NY**	**10+ yrs**	**BVA (1999a)**
Dredged Borrow Pits	**Offshore Panama City, FL**	**~1 yr**	**Saloman et al. (1982)**
Aggregate Mining	**North Norfolk, UK**	**>2 yrs**	**Kenny and Rees (1996)**
Aggregate Mining	**Offshore E. & S.E. coasts, UK**	**~8 yrs**	**Cooper et al. (2005)**
Aggregate Mining	**Isle of Wight, UK**	**100 – 175 days (pop'n density, spp diversity) >18 months (biomass)**	**Newell et al. (2004)**
Hydraulic Clam Dredge	**Scotian Shelf (70-80m), Nova Scotia**	**>3 yrs**	**Gilkinson et al. (2003)**
Dredged Borrow Area	**Offshore Duval County, FL**	**< 1 yr**	**Lotspeich and Associates (1997)**
Dredged Borrow Area	**Offshore Belmar to Manasquan, NJ**	**1.5-2.5 yrs**	**USACE (2001)**
Dredged Borrow Area	**Offshore Great Egg Harbor Inlet, NJ**	**~2 yrs**	**Scott and Kelley (1998)**
Dredged Borrow Area	**Offshore n. coast NJ**	**~1 yr abundance ~1.5 – 2.5 yrs biomass**	**Burlas (2001)**
Dredged Borrow Area	**Offshore Myrtle Beach, SC**	**~ 2 yrs**	**Jutte and Van Dolah (1999)**
Dredged Borrow Area	**Offshore southeast NC**	**~ 1 yr**	**Posey and Alphin (2002)**
Dredged Borrow Area	**Offshore Virginia Beach, VA**	**< 1 yr**	**Hobbs (2006)**

Successional Patterns

Benthic succession has been relatively well-studied in estuarine subtidal and intertidal environments and not very well-studied in offshore environments (Pearson and Rosenberg 1978, Thistle 1981, Zajac and Whitlatch 1982, Whitlatch et al. 1998). Previous MMS studies (Byrnes et al. 2000) have described successional stages and patterns in softbottom habitats, which primarily have been studied in silt–clay-dominated systems. Very limited information is available on successional patterns for offshore shelf communities and whether or not these sand-dominated habitats follow the silt–clay successional model. Although not well-established in shelf communities, various studies indicate that benthic disturbances tend to favor opportunistic species, which have high reproductive rates and are small, mobile, and short-lived. Later successional stages tend to be longer-lived, larger, and slower growing. For disturbances such as dredging where habitat structure and heterogeneity are reduced and large areas of habitat are modified, slow-growing and slow-reproducing species will be disproportionately affected. Over time, repeated intense disturbance will select species with appropriate facultative responses, and communities are likely to be dominated by juvenile stages, mobile species, and rapid colonists (Thrush and Dayton 2002).

The response of opportunistic species to disturbance depends on the magnitude or scale of disturbance and on life history traits such as mobility, reproduction timing, mode of development, and dispersal methods (Levin 1984). The Pearson and Rosenberg model describes a gradual succession of benthic communities along gradients of decreasing disturbance from opportunists to a climax-community with deep-burrowing organisms (Pearson and Rosenberg 1978, Norkko et al. 2006). The Pearson and Rosenberg model was developed using study results from organic enrichment of muddy, subtidal sediments. Early colonists have life history traits such as small size, rapid growth, high reproductive capacity, and good dispersal capacity that facilitate rapid responses and large increases in abundance in disturbed areas. Similar patterns may hold for continental shelf benthos dominated by sand substrate. However, these systems have relatively low organic content and are exposed to frequent large-scale disturbances.

4.4.1.2 Dredging Impacts on Benthos

The primary, direct impacts on the benthic community from dredging result from the removal, suspension, dispersion, and deposition of sediment. During sediment removal, dredging entrains and removes infauna and epifauna living within and on the sediment. Dredging typically results in an immediate and significant decrease in the abundance, biomass, and number of benthic organisms. Additionally, dredging causes suspension of sediments, which increases turbidity over the bottom as a benthic plume. The plume is dispersed by currents in the area and can extend for kilometers (Dickinson and Ree 1998). Suspended sediments settle and are deposited nearby or some distance from dredged sites. Turbidity may be a minor issue with offshore shelf sediments, which consist primarily of sands with small amounts of fine-grained sediment such as silts, clays, and organic matter.

Hall (1994) described the possible direct effects of physical disturbance, such as dredging, at various levels of the benthic community organization. Table 4.5 summarizes the potential effects of dredging on offshore benthos as a result of sediment removal, suspension, dispersion, and depositional processes.

Most adult infaunal organisms have limited motility. Tube-dwelling species are generally sedentary but can relocate over short distances on the order of centimeters. Errant species move over small distances. In addition, some species may enter the water column and be passively transported by currents over relatively larger scales, such as meters. Storms can suspend adult infauna in the water column and transport them over relatively large distances (Dobbs and Vozarik 1983, Committo et al. 1995).

Table 4.5. Possible Effects of Dredging on Offshore Benthos

Level of Organization	Possible Effects
Individual	**Increased probability of death or injury**
	Energetic cost of re-establishing
	Effect on reproductive output
	Effect on food availability
	Exposure to predation or displacement
	Provision of colonizable space
	Competitive release
Population	**Changes in density**
	Changes in recruitment intensity and/or variability
	Changes in dispersion patterns
Community	**Changes in species diversity**
	Changes in overall abundance
	Changes in productivity
	Changes in the patterns of energy flow or nutrient recycling

Source: Hall (1994)

4.4.1.3 Sediment Removal

Dredging physically removes sediment, or benthic habitat, and along with it any infauna and epifauna that cannot avoid the dredge. The majority of benthic infauna resides in the upper 15 cm of sediment. Most dredge cuts by a TSHD draghead are 0.25–0.5 m deep. As a result, the majority of benthic organisms will be permanently removed or displaced from the footprint of the dredge.
Dredging results in

- creation of furrows and depressions from the TSHD that alter sediment topography and lower topographic high features,

- changes in local hydrodynamics due to altered bottom topography,

- removal of substrate and exposure of underlying sediments with potentially different characteristics (e.g., grain size distribution, compaction, cohesion, total organic content, and DO levels) than the pre-dredged surface,

- removal of sedimentary structures such as burrows and tubes, and

- removal of potential benthic prey organisms for fish.

Dredging alters the local topography by creating furrows or trenches on these shoals. With alteration in local seabed topography, local hydrodynamics change, this may affect the distribution of benthic organisms. Larvae and adults may be passively carried by currents. Hydrodynamics can affect larval settlement and transport at several scales (Eckman 1983, Butman 1987). In addition, hydrodynamics may affect the distribution of food resources, which will impact benthic distribution.

In addition to physically removing surficial layers of sediment as well as the benthic community, dredging exposes sediment that has different physical and geochemical properties than the pre-dredge sediment. It exposes anaerobic sediment that likely affect recolonization by the benthos (Diaz et al. 2004). In addition, disruption of the sediment enhances the upward flux of nutrients by releasing pore-water nutrients as a pulse rather than a steady release controlled by bioturbation (Pilskaln et al. 1998, Thrush and Dayton 2002). The change in the surficial sediment characteristics may change its suitability for burrowing, feeding, or larval settlement for the benthos.

4.4.1.4 Sediment Suspension, Dispersion, and Deposition

In addition to removing sediment, dredging also suspends and disperses sediment at two primary points in the operation—at the draghead and the discharge of overflow. As described in Section 4.2.1, a TSHD is the typical dredge type used for offshore sand dredging. A TSHD is designed to maximize the concentration of sediments in the pump. The disruption to the seafloor caused by the draghead can result in suspension and plume development (W.F. Baird & Associates, Ltd. 2004). In addition, some of the sediments, typically the fine sands and silts, pumped into the dredge hopper do not settle out of suspension and are discharged through one or more spillways.

Water, displaced from the hopper and discharged, can have significant initial momentum, resulting in a body of water denser than the surrounding water and descending toward the seafloor (Baird and Associates 2004). The initial rapid descent of the plume is referred to as the dynamic phase and dynamic plume. The zone of influence of the dynamic plume can vary considerably, depending on the magnitude and direction of the current flow, dredge speed, initial density of the sediment–water mixture, and initial momentum of the mixture.

Sediment that is stripped from the plume into the water column during the descent of material or as the dynamic plume impinges on the seafloor or during the flow of material along the seafloor will form a passive plume of material that will slowly disperse with the mixing effects of currents and waves. The concentration of the passive plume will decrease over time with the settling of sediment particles from turbulent diffusion and shear dispersion. The zone of influence for the passive plume can be several kilometers or more and is dependent on the magnitude of tidal currents and the magnitude of sediment releases from the dredging operation (Baird 2004). Suspended sediment concentrations within the plume can be hundreds of milligrams per liter above background near the dredger, decreasing to tens of milligrams per liter above background as the distance from the dredger increases (Baird 2004).

Dredge plume sediments that have been deposited on the seabed may become resuspended if the local currents exceed thresholds for sediment erosion. As a result, these sediments may become even further dispersed (Baird 2004). Sediment suspension and redeposition may impact the immediate benthic community and adjacent areas due to burial of adults and/or recruits and/or impacts to suspension feeding (Miller et al. 2002). Dredging also uncovers and displaces benthic organisms into the water column, exposing the benthos to predators.

Dredging produces turbidity in the surrounding waters. Turbidity decreases light penetration and alters the wavelength of light capable of reaching the seafloor, which may decrease the productivity of benthic alga and other primary producers in an area. Light also affects the dispersal and settlement of larvae (Thorson 1964). Turbidity may also adversely impact available food for the benthos. Turbidity reduces visibility for predators that utilize sight to feed.

Turbidity may adversely impact filter feeders by clogging feeding appendages and apparatus with inorganic particles that have little or no nutritional value. Increased sediment concentrations in the water column may also negatively impact benthic organisms through tissue abrasion, slowed growth, and reduction in optimal feeding or foraging conditions. Through its physical disturbance of the sediment, dredging may release nutrients and other organic matter such as carbohydrates, fats, and lipids into the water column from damaged organism tissue, as a result of entrainment and fragmentation from dredging (Coastline Surveys Limited 1998). The suspended matter may result in localized hypoxia or anoxia due to increased oxygen consumption (LaSalle et al. 1991).

Depending on hydrodynamic conditions at the site, the sediment suspended by the dredging operation, both at the seafloor and from barge or hopper overflow, will generally settle in close proximity to the dredged site or at some distance from the site. Depending upon the magnitude, sediment deposition may suffocate and bury the benthic community present. Mobile softbottom organisms have the ability to migrate vertically to the surface through newly deposited sediment (Maurer et al. 1986). Sessile hardbottom organisms can be particularly sensitive to heavy sedimentation loads because they cannot relocate. As described in Section 3, some sessile organisms, such as sponges and gorgonians, were observed in the areas off the shoals and were captured in some of the trawls conducted in the adjacent areas. However, this study area is exposed to storms and, as such, the benthic organisms experience sediment resuspension and deposition on a frequent basis.

As noted in previous MMS reports, dredging effects are not limited to the borrow site (Diaz et al. 2003). Impacts from sediment suspension, dispersion, and deposition may be evident hundreds of meters from the dredged site. Studies have shown decreases in infaunal abundances adjacent to a dredged area as well as enhanced benthic diversity and abundance due to the release of organic nutrients from the dredge plume (Newell et al. 1998).

If sedimentation is similar to natural events, community responses are expected to follow natural seasonal and successional trends (Miller et al. 2002). If sedimentation exceeds natural thresholds, impacts may involve total loss of the community and subsequent colonization by pioneer or opportunistic species and be driven by an entirely different suite of ecological processes that may lead to dramatically altered benthic communities (Miller et al. 2002). Horizontal sediment movement is relatively unimportant to benthic infauna. The vertical movement of the bed, through erosion and deposition, is critical (Miller and Sternberg 1988, Miller et al. 2002).

4.4.1.5 Predicted Dredging Impacts to Benthos within the Northeast Florida Study Area

As noted in previous MMS studies (Byrnes et al. 1999, Diaz et al. 2003, Hammer et al. 2005, Zarillo et. al. 2008), determining the impacts of offshore dredging and the subsequent recolonization and recovery are difficult because most benthic communities are complex associations of organisms that demonstrate a large amount of spatial and temporal variability over a variety of scales. Additionally, because of the dynamic nature of the benthic communities and their variation over time, recovery of the dredged area does not mean that the benthic community will return to pre-dredging conditions such as species abundances and composition. Recovery means that the dredged area would return to similar species composition as similar non-dredged areas in the vicinity at a point in time in the future. Benthic communities off Northeast Florida are exposed to a variety of large-scale disturbances such as storms and HABs that affect community structure. Abundances, species numbers, and diversity in dredged areas may reach background levels relatively rapidly. However, species composition may require a longer period of time.

Dredging the sand shoals in this study area will result in an immediate decrease in the abundance, diversity, and biomass of benthic organisms within the dredged footprint. Because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the broad area of the northeast Florida shelf, it is expected that there would be a negligible impact on the ecosystem. In addition to larval recruits from the water column, the surrounding areas (that are not targeted for dredging) would supply the potential adult colonists with the area disturbed by the dredging operation. Similar to conclusions reached in previous MMS studies, the high densities and fecundity of the benthic populations in the area, together with the relatively small area of impact, would preclude significant long-term effects on the benthic populations (Byrnes et al. 2003, Hammer et al. 2005).

Slow-moving and burrowing epibiota inhabiting the study area include echinoderms such as sand dollars and brittle stars and decapod taxa, and local populations of these types of benthic organisms would most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge. Motile epifauna generally are migratory and are not restricted to the borrow areas.

The timing of dredging will be important because many benthic species have distinct reproductive and recruitment periods (Diaz et al. 2004, Hammer et al. 2005). Recovery will be primarily from larval recruitment and adult immigration from adjacent undisturbed areas. Therefore, recovery should be most rapid if dredging is completed before seasonal increases in larval abundance and adult activity (Herbich 1992, Hammer et al. 2005).

As described in Section 3.3.3, the benthic assemblages within the study area immediately following the passage of Hurricane Wilma in the fall of 2005 were generally dominated by motile organisms capable of avoiding shifting sands, including the hemichordate *Branchiostoma floridae* and the amphipods *Metharpinia floridana* and *Protohaustorius wiglei,* as well as active burrowing Tellinid bivalves that can burrow through sand once they are buried. While these disturbance-tolerant species were also common in the study areas in the spring survey, the small bodied, deposit-feeding spionid polychaetes *Prionospio* spp. were numerically dominant in the spring.

The dominance of this community type throughout the study area may be a function of the frequent and periodic large-scale disturbances that occur off Northeast Florida. These species live at the sediment surface. Byrnes et al. (2004) posit that the pioneering species, which colonize the dredged area first, share several ecological traits such as a tendency to confine their activities to the sediment–water interface, possibly because subsurface conditions cannot support a significant number of organisms. They also note that the subsurface conditions will change over time after dredging, possibly by the bioturbation activities (burrowing, tube building, feeding etc.) of early colonizers, and become suitable for deposit feeders and mid-depth burrowers. The absence of mid-depth burrowers and deposit-feeders is interpreted to mean that an area is still in a state of recovery (Byrnes et al. 2004).

Based on results of other studies, it is expected that recolonization of the dredged area should begin soon after dredging activities end from larval settlement from the water column and adult and post-settlement juveniles not entrained by the dredge as well as from adjacent areas. In addition, as previously noted, studies have indicated that although the abundance, species, and biomass of benthic infauna may approach pre-dredging levels in a relatively short time after dredging (less than one year in some cases) community composition may take much longer.

An additional consideration in predicting the potential benthic impact and recovery rate is the length of time that the dredging operation takes place. For example, the dredging operation at the northern portion of area A4 began June 10, 2005, and ended August 7, 2005, lasting approximately six weeks (Coastwise Consulting, Inc. 2006). As dredging occurred over a large area, some portions of the dredged area may be undergoing recovery while other portions are being impacted. As such, dredging is not like a storm or HAB event that affects a large area simultaneously. Therefore, meaningful future post-dredging monitoring programs should be aware of when a specific area was dredged, what specific areas were dredged, and the duration of the dredging operation.

Within days after dredging has ended, it is expected that the dredged area should be initially colonized by opportunistic species through both larval settlement and adult migration. It is also expected that these colonists will be comprised of certain species of polychaetes, crustaceans, and bivalves. Initial larval recruits likely will be dominated by deposit-feeding, opportunistic taxa, such as the *Prionospio* spp. and *Apoprionospio pygmaea* that were dominant in the samples collected during the June 2006 survey. These species are well-adapted to environmental stress and can exploit suitable habitat when it becomes available. Immigration of motile annelids, crustaceans, and echinoderms into impacted areas also will begin soon after dredging. In particular, motile species including *Branchiostoma floridae*, the amphipods *Metharpinia floridana* and *Protohaustorius wiglei*, and Tellinids, which were common to both surveys, will likely be among the first colonists. Later stages of the benthic recolonization will be more gradual and involve taxa that generally are less opportunistic and longer-lived. As noted by Newell et al. (1998) and Diaz et al. (2004), dredging portions of each shoal and leaving areas undredged will ensure that a supply of non-transitional, motile taxa will be available for rapid migration into dredged areas.

Hammer et al. (2005) noted that seasonal variability should be considered when considering potential impacts due to dredging. The timing of dredging would be less critical for minimizing the impact on infauna than for other faunal categories of concern (e.g., key pelagic species such as marine mammals or sea turtles) due to the great abundance and reproductive potential of infaunal populations. Many numerically dominant infaunal taxa inhabiting the study area are known to exhibit either year-round or late-winter–early-spring periods of recruitment. Because of these patterns of recruitment and lower winter densities, removal of sand between late fall and early spring would result in less stress on benthic populations.

4.4.2 Fishes and Macroepifauna

Fish catches in otter trawls were numerically dominated either by small-bodied pelagic taxa (e.g., striped anchovies) or demersal teleost taxa (e.g., searobins, lizardfish, flatfish) with a known affinity for open sand and mud substrates. Trawls contained few fish species of direct commercial or recreational value. Most notably, only eight species managed under the South Atlantic Fishery Management Council snapper–grouper reef fish complex were collected (<4% of total fish catch), and with the exception of the rock sea bass (*Centropristis philadelphica*), none were common. No fishes listed as endangered or threatened under the Endangered Species Act (i.e., smalltooth sawfish or shortnose sturgeon), nor those prohibited from harvest by the state of Florida or NMFS were collected. Macroinvertebrate trawl catches included a diverse assortment of decapod crustaceans and echinoderms and lesser numbers of stomatopod crustaceans, cephalopod, and gastropod molluscs. Commercially important penaeid shrimp were common (65% of invertebrate catch), and small numbers of rock shrimp (*Sicyonia* spp.) and *Callinectes* spp. (blue) crabs were also taken.

The species composition of trawl catches very likely was influenced by the physical features of the sample locations. Exposed limestone hardbottom substrate necessary to support a high diversity of reef-associated fish taxa is unavailable in the sandy areas dominated by shoals. Nonetheless, it is likely that hardbottom is present in Northeast Florida, so species richness may be much higher locally than indicated by trawling alone. Additional sampling at other times and in other portions of the study area with other gears (e.g., gill nets, longlines) may result in a slightly different species list and yield reef-associated and pelagic teleost and elasmobranch fishes of regional economic value.

Results of the MDS community analysis indicate that greater differences in the fish and macrocrustacean species assemblage occurred between seasons (i.e., cruises) than between or within individual sites. This is expected because, while most regionally common fish and macroinvertebrates are tolerant of varying water temperature, salinity, and depth (and thus range widely over the Florida continental shelf), many have distinct periods of spawning and recruitment with some undertaking temporally predictable estuarine-shelf migrations. Although life history strategies vary considerably among species, reproductive activity of many shelf fishes peaks during warmer months and wanes as temperatures drop in winter (Able and Fahay 1998). This phenomenon may partially explain why 62 taxa (often represented by recently recruited juveniles) were collected during Cruise 2 (June 2006) compared to only 44 on Cruise 1 (November 2005).

Dietary analyses of numerically dominant demersal fishes illustrate the importance of infaunal and epifaunal invertebrates to the food web of open-sand fish communities. Crustaceans, especially mysid and decapod shrimp, serve as dominant forage for the 11 fishes in which prey items were identified. Many other demersal fishes abundant on the northeast Florida shelf (e.g., drums, croakers, mojarras, porgies, and grunts) are known to exhibit a similar reliance on invertebrate prey.

Ichthyoplankton catches were dominated by larval gobies, herring, and anchovies, representing 60%, 11%, and 10% of the catch, respectively. Larvae of these families are among the most common in estuarine and shelf waters throughout Florida, and given their long pelagic stages, their distribution is likely independent of local substrate types. Because ichthyoplankton surveys typically demonstrate considerable variability in species composition and abundance even at a single location (Richards 2006), the limited collections in the present study are inadequate to fully describe fish spawning or recruitment in the vicinity of proposed sand borrow sites. Nonetheless, it is notable that, with the exception of ten unidentified larval sea bass, larvae of managed reef species were quite rare, which relates to the lack of hardbottom in the study area.

Coastal dredging operations affect marine organisms in a number of ways. Short-term impacts typically consist of ephemeral changes in water chemistry, habitat quality, or organism behavior derived from the mechanical disturbance of the seafloor during the act of dredging. While often harmful, these impacts are usually localized and dissipate rapidly once dredging activity ceases. Long-term impacts typically consist of more permanent alterations in benthic substrates and local hydrodynamics, or disruptions of vulnerable life-history stages of marine species. The following section summarizes the potential threats specific to fish and commercially important macroinvertebrate communities that may arise from dredging operations along the northeast Florida continental shelf including entrainment, behavioral alterations, turbidity and sedimentation, changes to soft-bottom bathymetry, and risks to hardbottom habitats. The magnitude of impacts and temporal windows (if any) when impacts can be minimized are also discussed. Much of this information is derived from other regions where dredging has been more thoroughly studied; however, even where dredging impacts to biota have received considerable scrutiny, long-term consequences to habitat suitability and population-level dynamics of marine organisms often remain poorly understood (National Research Council 1995). This review does not address impacts to nekton at the site of sand redeposition (e.g., shoreline). Renourishment of Florida beaches can have considerable negative biological consequences to shoreline habitats and associated fish fauna (Lindeman and Snyder 1999), but impacts are site specific, dependent on the size of renourishment area, dredging protocols, local wave and current characteristics, and proximity to nearshore reefs and inlets.

Entrainment: Entrainment refers to the physical uptake of organisms during dredge operation. Dredge entrainment of fish and invertebrates has been a concern for many years because in most instances, associated mortality rates are likely to be high. Entrainment rates are influenced by a number of factors including the type of dredge used, speed and volume of dredge operations, water depth, as well as animal size, mobility, and behavior. Benthic macroinvertebrates tend to be especially prone to entrainment. Dungeness crab (*Cancer magister*), off the coast of Washington state, for example, are susceptible to entrainment mortality because they congregate in deep navigation channels that necessitate repeated maintenance dredging (McGraw et al. 1988, Larson and Patterson 1989). Female blue crabs (*Callinectes sapidus*) are considered vulnerable because egg-bearing individuals overwinter within sediments and may be too lethargic to avoid uptake. Sand shrimp (*Crangon* spp.) and commercially valuable penaeid shrimp also are thought to be susceptible (although quantitative information regarding shrimp entrainment and mortality is lacking) as are sessile bivalves such as oysters, mussels, clams, and scallops (Reine and Clarke 1998).

Fishes are regularly entrained in dredges although generally in low numbers (Reine et al. 1998). Larval and juvenile fishes are often at greatest risk of entrainment due to their limited mobility and swimming strength; however, fishes as large as small sharks are known to be entrained. In one of the more complete studies, McGraw and Armstrong (1990) recorded entrainment of 28 fish species in Grays Harbor, Washington, at species-specific rates ranging from <0.001 to 0.594 individuals per cubic yard, with highest entrainment suffered by burrowing or otherwise demersal fishes. To date, however, the greatest concern is directed toward anadromous sturgeon, salmon, shad, and striped bass spawning and recruitment success that may be dependent on their ability to successfully bypass estuarine and riverine dredging operations and associated turbidity plumes. Entrainment-related mortality of fishes has not been adequately assessed in open coastal waters.

On the northeast Florida continental shelf, the distribution of individual fish and macroinvertebrate species is largely determined by water depth, temperature, and salinity, with most species ranging widely throughout the study area (ASMFC 2000, Rowe and Sedberry 2006). Therefore, entrainment during offshore sand dredging operations, even if associated mortality is high, is likely to have minimal population level impacts for most taxa. Fish entrainment should be a localized, short-term concern for only a few families such as burrowing eels and gobies, as well as slow-moving demersal taxa, including sea robins, flatfish, and batfish. Further, given the scarcity of economically valuable reef fishes in trawl samples, entrainment mortality is expected to have negligible negative economic impact on coastal fisheries. Entrainment of penaeid shrimp may be more of a concern, although density documented within borrow site boundaries (mean of 156 shrimp per ha averaged across sites and cruises) was not especially high. Some entrainment should be anticipated year round, but rates may be elevated during periods of high juvenile fish recruitment, likely during the spring and summer.

<u>Behavioral Alterations</u>: Fish use underwater sound-pressure waves to locate food and to detect the presence of predators. In addition, many coastal fishes are soniferous, using sound to communicate, especially during courtship and spawning. In fact, in the current study, 31 of the 77 taxa collected in trawls (41% of all individuals) are representatives of soniferous fish families including sea robins, cusk eels, and drum—some of the most prodigious sound producers in Florida coastal waters. Certain macroinvertebrates such as alpheid snapping shrimp and barnacles also produce sound. It has been demonstrated that biological sounds are often considerable at certain times and places and are known to attract settlement-stage fish larvae to reefs (Leis et al. 2003, Simpson et al. 2005).

While behavioral alterations of nekton resulting from anthropogenic sound pollution, including dredging, is poorly studied, it is possible that foraging, spawning, and recruitment success of fishes and macroinvertebrates will be impacted in the immediate vicinity of dredging operations, causing some organisms to relocate. It is also possible, however, that the physical presence of dredging infrastructure and light produced during nighttime operations may actually attract other species to the vicinity. Behavioral alterations from sound, light, and structure should be expected year-round but are localized and will cease once dredging has completed.

<u>Turbidity and Sedimentation</u>: Increased turbidity is often generated directly at the site of sediment excavation or as slurry overflow and dewatering from dredge barges. Wind, waves, and strong directional currents can also resuspend fine particles that accumulate in dredge areas for many years after excavation has ceased. Turbidity may alter the trophic dynamics of an area by reducing the feeding efficiency of planktivorous fish (Hecht and Van der Lingen 1992, Benfield and Minello 1996) and may clog feeding structures of infaunal taxa, leading to a reduction in benthic prey resources. In rivers and estuaries, turbidity plumes may hinder spawning migration of anadromous fishes, although some estuarine turbid zones are recognized as high value habitat for larval fishes due to high rates of survival and growth (North and Houde 2001). Turbidity can also directly influence fishes by irritating or clogging gill membranes, and sediment deposition can coat eggs of deposit spawners, hindering egg respiration and increasing mortality.

The direct impact of turbidity on mortality, growth, and spawning behavior for continental shelf fishes and macroinvertebrates is largely unstudied but is likely a minimal concern at the five proposed borrow sites since most fish are mobile enough to escape or avoid areas of highest turbidity. Further, many shelf fishes, especially those that also utilize estuaries, are likely adapted to relatively high ambient turbidity levels. Sedimentation also likely poses minimal threat to fish spawning success because most shelf taxa, including virtually all valuable fishery species, produce pelagic eggs. Possibly the largest turbidity-related threat to fish and macrocrustaceans are the consequences of sediment resuspension and redeposition on their benthic filter feeding prey, a process that may alter the forage base for several years.

Changes to Softbottom Bathymetry: Sand shoals may support an ichthyofauna somewhat dissimilar to the surrounding seafloor. Many shoals that possess differing sediment types and associated infaunal communities may also serve as shallow-depth refugia from predators (physical landmarks on which fish assemble or spawn) and may also be areas of high turbidity that enhance survival of small-bodied prey taxa. In U.S. Atlantic waters, the fisheries value of sand shoals has received some scrutiny as a result of MMS interest in mining offshore sand deposits (e.g., Byrnes et al. 1999, 2003; Hammer et al. 2005; Slacum et al. 2006). In addition certain shoals have previously been identified as valuable habitat for fishes (Vasslides and Able 2008) including cod (Fahay et al. 1999) and juvenile sharks (Rountree and Able 1996, McMillan and Morse 1999, Reyier et al. 2008).

As noted in Section 4.4.1.2, the physical removal of bottom sediments during dredging results in an immediate reduction in the biomass, density, and diversity of infauna and epifauna. These organisms serve as essential prey for many small-bodied benthic fishes, as demonstrated in gut content analyses conducted in the present study. Loss of this forage base during dredging will have an immediate negative consequence on the survival and growth rates of benthic fishes in the immediate vicinity of dredge operations, with the most severe impacts apportioned to those species with limited mobility. Further, borrow sites are often recolonized by differing benthic communities, a factor that may eliminate some selective benthic feeders and result in lower local diversity of demersal fish and macrocrustaceans. In certain cases, however, depressions left behind may serve as sites where fish aggregate or seek thermal refuge (Vose et al. 2005).

Whereas trawling is a sound method for characterizing shoal fish faunas, expense and logistical constraints often limit surveys to few, widely spaced collection efforts. Thus, in surveys with temporal components, only gross changes in community structure may be observable. Data collected from limited trawling in the present study provided no indication of a unique faunal assemblage inside the study shoals. The most common species collected were small-bodied, widely distributed demersal taxa of little commercial or recreational fishing value. Whereas impacts to the fish fauna from sediment alteration at dredge sites are largely unavoidable regardless of dredging method or season, these impacts should be largely limited to the dredge site itself.

Damage to Hardbottom Habitats: Dredging impacts to hardbottom substrates have been a concern for many decades. Damage to reefs is caused by the dredges themselves, barge anchors and mooring chains, and sand discharge pipelines. These dredging impacts typically destroy the coral and associated invertebrate communities and reduce reef rugosity. Such changes often reduce reef carrying capacity, alter fish spawning behavior, and shift the communities toward algal-dominated systems. In Florida, much dredging-related reef damage is related to sand deposition on nearshore reef structures. Lindeman and Snyder (1999) documented a dramatic decline in both fish species and individuals after the burial of a nearshore reef structure in Southeast Florida.

Although substantial hardbottom was not encountered during trawl collections, it is widespread in the general vicinity (Perkins et al. 1997). These substrates should be expected to harbor a diverse assemblage of reef fishes and macrocrustaceans, many of which are the target of recreational and commercial fishermen throughout the region. However, risk of damage to this habitat due to sand dredging is minimal, as hardbottom resources within the study area boundaries have been mapped and can easily be avoided.

4.4.3 Seabirds

Seabirds common in the study area include frigate birds and members of the family Laridae. Species federally listed as threatened that may feed near the study shoals during dredging are the Least Tern and Roseate Tern. The Least Tern is present in all but the winter months (November–February), with peak numbers occurring during nesting season from April to August. The Roseate Tern may occur in areas near the shoals, as they migrate throughout Florida in spring and fall.

Various types of gulls, family Laridae, were observed during the field surveys and are expected to be the most common visitors to the study area. Royal Terns *Sterna maxima* and Brown Pelicans *Pelecanus occidentalis* were also observed during field surveys. None are federally listed, although the Brown Pelican is listed as a Species of Special Concern by the state of Florida.

The greatest risk to birds from dredging operations in the study area is physical injury within the scow during beach fill. Consideration of disruption to nests and nesting behavior on beaches is excluded from this study. Terns and other birds will often fish in the scow as it is being filled. The influx of water and slurry may trap birds so that they are unable to fly out of the scow, which leads to drowning. It is possible that fishing birds, particularly plunge-diving terns, could drown in the dredge scow.

4.4.4 Sea Turtles

Of the five species of marine turtles known to occur in coastal and offshore waters of Florida, three are likely to occur in the vicinity of the study area: the loggerhead, green, and leatherback. Though Kemp’s Ridley turtles have been documented in one of the study area counties, nesting on the east coast of Florida is rare.

The potential impacts to sea turtles by offshore dredging activities include entrainment, disturbance to benthic foraging habitats, disruption of the prey base, interference with underwater resting habitats, noise disruption, and physical harm from contact with vessels and dredge equipment. Seasonal activity in the study area varies with species; yet all are present in greater numbers during nesting season from March to September. During this same period, juvenile and sub-adult loggerheads, greens, leatherbacks, and Kemp’s Ridley may be encountered.

Direct takes of individuals entrained by hopper dredges is well-documented (Mansfield and Musick 2003, Dickerson et al. 2004). As the suction tube of a hopper dredge is pulled on the ocean floor, turtles are pulled into the intake tube either while lying on the bottom or when startled as they dive in an attempt to move away from the dredge. Rarely do turtles survive the travel from the dredge pipe onto the catch screen without death or injury. A total of 360 confirmed loggerheads were taken by hopper dredges between 1980 and 2003. Hopper dredges in the U.S. have a record for the cause of 50 takes of greens and 37 takes of Kemp’s Ridley turtles between 1980 and 2003 (Dickerson et al. 2004). From 1980 to April 2008, 170 loggerheads, 40 greens, 15 Kemp’s Ridley, and 1 leatherback were taken by dredge hopper and trawls (4 by trawl) within the Jacksonville district. Most takes in the study area are associated with dredging in King's Bay entrance channel and Mayport Naval Station (USACE STDW 2008).

Disturbance to benthic foraging habitats and disruption of the prey base by dredging activities is less documented. Sea turtles feed on benthic invertebrates, fish, crabs, jellyfish, sponges, and sea grasses. Marine turtles, particularly loggerheads, show some foraging site fidelity. Therefore, turtles occupying or feeding at the shoals may be affected during and after dredging operations if benthic fauna are marginalized. The relief in the shoals is greater than the surrounding bottom, which is attractive to loggerheads who seek similar topographic features, thus increasing the likelihood of loggerhead presence during dredge operations. Dredging activity in and around floating Sargassum seaweed mats used by hatchling green turtles as nursery habitat (NMFS and USFWS 2008) may disturb or eliminate potential juvenile turtle habitat and/or harm hatchlings that may inhabit them.

Noise impacts to sea turtles have yet to be defined and may vary with species. As such, noise impacts cannot be assessed or mitigated. Early experiments indicated that loggerhead turtles responded to low-frequency sounds within the range of 250 to 1000 Hz and that they are able to filter ambient noise (Moein 1994). These experiments, once thought to support the development of acoustic deflectors for turtles during dredging and to aid in the diagnosis of disease, have had mixed results when replicated. Experiments conducted by Lenhart et al. (1994) found no proven change in directional swimming approach or avoidance in relation to frequency; turtles stayed on their original course. Controlled exposure experiments on captive turtles found an increase in swim speed and erratic behavior indicative of avoidance when exposed to seismic air-gun sound levels of 166–176 dB (O'Hara and Wilcox 1990, McCauley et al. 2000). Weir (2007) found it impossible to draw conclusions about the impact of certain sound frequencies on turtles during a study of seismic air-gun soundings in ocean waters in the presence of mixed turtle species.

Collisions with vessels are a concern for marine turtles because they mate, bask, and forage on the surface (NCR 1990). Between 1986 and 1993, about 9% of stranded sea turtles (living and dead) off the coast of Florida had propeller or other boat strike injuries. Vessel strikes were determined to be an important cause of sea turtle mortality (Lutcavage et al. 1996). Death from propeller damage is documented in standing data for counties onshore of the study area (STSSN 2006).

4.4.5 Marine Mammals

Although more than 30 species of marine mammals are listed as occurring in the western region of the North Atlantic Ocean, most inhabit waters greater than 100 m deep, are considered rare, or are extralimital in the range of the study area. Most species in the study area are from the family Delphinidae, typically dolphin and small whale species common off the southeast Atlantic Coast. All marine mammal species are protected under the Marine Mammal Protection Act, as regulated by the NMFS. Bottlenose dolphins (*Tursiops truncatus)* were documented during field surveys and are common in coastal Florida. In addition, at least three federally endangered marine mammal species may occur in the study area: the northern right whale, humpback whale, and Florida manatee.

Human-induced mortality via ship/boat strikes represents a significant percentage of injuries and death for whales and manatees. Secondarily, whale injuries and death are caused by entanglement in fishing gear and debris. Disturbance from ships and noise from industrial activities may also affect whales.

Northern right whale: At least 20 deaths of right whales were caused by ship strikes 30 years prior to 2004, and 7% of the right whale population have scars from encounters with ships (NMFS SAR 1998-2005). As a result, NMFS published regulations in 1997 prohibiting vessels from approaching within 500 yards of right whales. Additional restrictions include reduced speed of 4 knots to and from disposal sites when right whales are known to be in the area. Between the late 1980s and early 1990s, the Whale Early Warning System was established. The system is organized to monitor whale activity in the area with aerial surveys and to communicate via radio the coordinates of whale sightings to ship captains and dredge operation personnel. This system is limited by poor weather and extreme wave conditions. No injuries or mortalities to right whales from dredging activities have been documented as a result of the Whale Early Warning System, which operates fall through winter for hopper dredge projects in calving grounds.

Humpback whale: As with the right whales, ship strikes and entanglement in fishing gear are detrimental to humpback whales. Noise disturbance is also considered disturbing to marine mammals. Humpback whales are sighted during annual right whale surveys of winter migration although they are more likely found in deeper waters farther offshore.

Florida manatee: Boat or water craft collusions constituted 32.2% of the single largest cause of manatee deaths in Florida from 1995–2005 (FWC 2007c). Other major threats to manatees are loss of habitat and perinatal deaths from unknown causes both unrelated to this study area.

Potential impacts to marine mammals are unlikely or minimal in the study area. The speed of dredge operations does not pose a significant strike risk, and direct physical injury to marine mammals from the draghead (for hopper dredging) is unlikely.

Noise impacts to marine mammals are a concern in ocean and coastal construction operations. Under the MMPA, NMFS determined that continuous sound levels above 120dB constitutes harassment of marine mammal species and can temporarily impair normal behavior patterns. There is no known noise impact study conducted on dredge operations for marine mammals, and there is no indication that marine mammals would be injured or killed by the noise produced by dredging operations.

Tug, scow, and crew boat operations can pose a risk to marine mammals. The northern right whale, humpback whales, and the Florida manatee are species that require the most protection from vessel strikes. Slow movement of the scows (less than 4 knots) and the restricted maneuverability of scows decrease the chance of a possible strike. Right and humpback whales are expected to occur seasonally (December–March). All support operations working within one mile of shore and within intercoastal waters pose a significant strike risk for manatees. It is unlikely that humpback whales would enter the area, thus the likelihood of strike impacts to this species are considered to be very low. Dolphins, a common species in the study area, are unlikely to be impacted from dredging operations.

4.5 Cumulative Impacts

The Council on Environmental Quality's (CEQ) regulations (40 CFR 1500-1508) implementing the procedural provisions of the National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. 4321 et seq.) define cumulative effects as follows:

> *The impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonable foreseeable future actions regardless of what agency (federal or non- federal) undertakes such other actions (40 CFR 1508).*

To adequately address cumulative impacts, direct impacts from past and proposed dredging projects within a particular area should be identified. In addition to dredging projects, other projects and activities that may potentially affect the physical and biological environments should be identified.

Potential cumulative impacts may result from multiple dredging operations within a borrow area. The affect on the physical environment may be a deep dredge cut and substantial lowering of the shoal profile. Additionally, dredging from immediately adjacent areas may not cause direct impacts, such as entrainment, but may cause turbidity and sediment deposition in an area previously dredged.

Cumulative impact assessments must also consider other projects in the area or vicinity such as dredged material management sites, submarine infrastructure such as pipelines or cables, and fishing operations such as bottom trawlers or draggers.

4.5.1 Physical and Biological Resource Interactions

In this section, we examine the response of biological resources to simulations of the borrow cut cases applied to the five shoals to determine the potential impacts from the degree of dredging on each shoal and whether the outcomes of dredging negatively affect biological resources. Numerical modeling of dredge-cut cases varied from no borrow cut to multiple cuts with removal of large volumes of material from each shoal. Prevention and/or mitigation measures for protected species (seabirds, sea turtles, marine mammals, and fish) likely to be present in the study area and that may be impacted by dredging activity are provided in Section 5. In general, measures to protect listed species include modifications to dredge schedules, or setting environmental windows, and modifications to operational procedures. Also evaluated are interactions of potential impacts to the benthic community from single, small magnitude dredge cuts vs. multiple dredge events that are planned until the entire shoal is altered.

4.5.2 Potential Physical Cumulative Impacts: Borrow Sites and Nearshore

Model predictions of wave regime, sand transport, and resulting topographic changes for each of the seven shoals selected for analysis shows minimal potential for negative impacts in the nearshore and littoral zone of shoaling and breaking waves. When multiple and expanded borrow cuts are placed in the model, topographic changes near the shoreline are either zero or marginally detectable. When viewed at the shoreline, the signal from the offshore borrow cuts is about 1–3 cm difference in predicted topographic change over a two-year model simulation, or a difference of a few hundred cubic meters per year in an annualized littoral sand transport rate for a particular location in the littoral zone. This level of difference in an annual sand budget can be compared to net annual transport rates temporal variations, which are orders of magnitude larger.

On the other hand, the magnitude of difference in the distribution of wave energy over the borrow sites with and without limited or expanded borrow excavations in the model topography is large compared to the difference in the nearshore zone. These differences correspond to the portions of the model test case that involve severe storms and the resulting extreme wave conditions. Over the crest of the shoals, the difference in wave height for extreme waves can be as much as 30 cm (1 ft) in a pattern of wave height reduction directly over the borrow excavation and an increase of similar magnitude at the perimeter and between borrow cuts. This pattern may be caused by refraction over the irregular topography created by the excavation. Without alterations to the crest of the shoal, topographic differences from year to year are predicted to be on the order of 20 cm, or about 0.6 feet. This is consistent with bedforms observed in video transects across the crest of the shoals. After borrow cuts are placed in the shoals, topographic changes of a similar magnitude occur but appear in the model results as an organized pattern in the model test cases. Predicted topographic changes are organized around the boundaries of the borrow cuts in zones of accretion and erosion. In some areas, these patterns can be up to 60 cm or more (more than 2 ft) of erosion or accretion. Thus, the model results may indicate possible smoothing of the borrow cut morphology in the long term. Whereas, these patterns are interesting, high-resolution, time series data of the evolution of excavated borrow pits is not available to confirm the model results. To further elucidate the long-term influence of borrow cuts on shoal morphology it is recommended that model tests of much longer duration be applied, possibly representing time scales of a decade or longer. The relief and complexity of sand ridge morphology may also require calculations using a three-dimensional model. Since the beginning of this project, the CMS-FLOW model has been adapted to a 3-D solution scheme and may be applicable to the task of modeling long-term evolution of sand ridge morphology if the appropriate boundary conditions are applied.

In summary, the influence of dredging offshore sand ridges in federal waters off the northeast coast of Florida will have minimal influence at the shoreline. However, the potential for altering the wave regime and resulting topographic expression at the borrow sites is large. Historical analysis of shoal topography using available survey data over 8- to 50-year intervals indicates that the shoals may undergo some topographic changes up to 2 m (about 6.5 ft). Thus, the dynamic nature of the shoals, in combination with dredging activities, indicates a potential for extensive borrow excavations to alter both the hydrodynamic regime and topographic evolution of the crest of individual sand shoals. Therefore, it is recommended that this issue be further investigated by using long-term model runs at high spatial resolution.

4.5.3 Potential Cumulative Impacts to Biological Resources

Species accounts from literature research and data from field events document the presence of federally protected species in the study area and north of the Florida–Georgia state border, south to Brevard County. Considering the population counts of listed species together with the temporal nature of dredging operations, it is highly unlikely that cumulative impacts will occur. Especially if the MMS and/or lessee follow protection measures and appropriately schedule dredge events as recommended in this report. Potential cumulative impacts to benthos, fishes, sea turtles, seabirds and marine mammals are discussed in this section.

Benthos: The abundances, species numbers, and diversity of the benthic community in dredged areas may recover to background levels relatively rapidly; however, species composition may take a longer period of time (Section 3.3.3). In terms of cumulative impacts, if dredging occurs multiple times in the same area over a relatively short period, e.g., 2–3 years, recovery of the impacted area will be prolonged. Additionally, because the benthic community composition is closely tied to sediment composition, progressively deeper dredge cuts may expose sediments with different grain size and other physical characteristics than the pre-dredged conditions. Multiple dredge cuts in an area may also result in deeper trench or even pit-like features on the bottom, which would result in changes in hydrodynamic conditions at the bottom such that recovery rates may extend beyond the 1–2 years predicted, based on the literature. However, because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the overall area of east Florida shelf, it is expected that there would be a negligible impact on the ecosystem. Even though site-specific cumulative impacts may be detectable, the high densities and fecundity of the benthic populations in the area, together with the relatively small area of impact, would preclude significant long-term effects on the benthic populations even from a cumulative impact perspective.

Slow-moving and burrowing epibiota, such as sand dollars, brittle stars, and decapods, inhabiting the study area would most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge during each dredge event. However, it is anticipated that these motile populations would recover relatively rapidly and, if the topography of the dredged area is not dramatically different than the adjacent areas, i.e., not “pit-like,” there would be no significant cumulative impact. The motile epifauna generally are migratory and are not restricted to the borrow areas.

Fishes: Cumulative impacts to the local fish fauna are also expected to be minimal. Dredging operations will most adversely affect softbottom, demersal fishes through entrainment or removal of their invertebrate forage base. However, given the planktonic dispersal strategies of most OCS fishes and the relatively high adult mobility of even small fish taxa, recolonization will occur after each dredge cut. This recolonization should proceed rapidly because the species assemblage outside the borrow sites appears similar, offering a proximate source of both adults and young recruits. Nonetheless, community composition within a given dredge cut may not rapidly return to its pre-dredge state, especially if changes to sediment composition and the benthic invertebrate assemblage persist for several years. Any such delay would have negligible ecosystem-level consequences since most fish species expected at these proposed sites are common and widespread along the northeast Florida shelf. Cumulative impacts to reef fish taxa, which is a legitimate issue in many areas due to mechanical damage or siltation of exposed hardbottom, is of minor concern locally since no hardbottom is within the proposed sandy borrow areas. Impacts to pelagic fish species are also negligible given their high mobility and limited reliance on substrate type and benthic invertebrate prey.

Marine Mammals: North Atlantic right whale and dolphin species may be present in the northeast study. It is possible that humpback whales and Florida manatee may also be present. Routine activities associated with dredging the OCS material on the study shoals are not expected to have short or long-term adverse effects on the size and productivity of any marine mammal species or the population endemic to the area. Recommendations for avoidance of marine mammals during dredging are provided in Section 5.2.

Sea Turtles: Although sea turtles are most likely to incur potential lethal harm from dredging activities, take incidences have decreased with the implementation of combined protective actions. Harmful incidences that may occur are unlikely to have significant adverse effects on the size and recovery of any sea turtle species or population known to inhabit or frequent the North Atlantic region. Most routine OCS activities are expected to have sub-lethal effects. Lethal effects are more likely to occur from entrainment during dredging. Recommendations to prevent interactions between dredge operations and sea turtles are discussed in Section 5.2.

Seabirds: Impacts to seabirds and seabird habitat from dredging on the shoals in the study area are expected to be sublethal and short term in duration, or if lethal, extremely rare. Seabirds observed along the east Atlantic Coast are dominantly trans-migrants, shorebirds, wading birds, and waterfowl that may occupy the study area briefly, if ever, or use the dredgers and boats for temporary resting places. Seabirds may ingest discarded debris or drown from diving into the scow during dredge fill. Dredging on the shoals is not expected to have short- or long-term adverse effects on the size and productivity of any seabird species or the population endemic to the area. Shorebirds and beach nesting habitat were not discussed in this study. The best avoidance measure is to manage debris as recommended in Section 5.2.

5.0 DISCUSSION OF POLICIES, REGULATORY REQUIREMENTS, AND MEASURES TO OFFSET POTENTIAL ENVIRONMENTAL IMPACTS

5.1 Policies and Regulatory Requirements

This section distinguishes regulations and policies under federal or Florida jurisdiction and describes pertinent polices that were considered for potential environmental impacts from dredging activities to the physical resources and the biological communities in the vicinity of the shoals (B11, A9, A8, A6, and A4) within the study area and on the five shoals. The FDEP Joint Coastal Permit Application is the vehicle for implementation of state regulations governing the zone from the mean high-water level and seaward. Aside from potential shoreline erosion analysis, additional environmental impacts from dredge and fill activities that occur onshore and in state coastal waters are outside the scope of this study.

Although dredge and fill activities in the coastal zone are regulated by the state of Florida, several federal acts provide direction. Several federal acts provide direction and authorization to agencies and organizations to further the protection of natural and economic resources. References to these acts are mentioned throughout this report with regard to impacts on protected species and their habitats. If a potential impact was considered likely and under the purview of a federal policy, the recommendations for remedy were prioritized in order of avoidance, minimization, and/or mitigation. Acts relevant to future dredging projects in the study areas are the National Environmental Policy Act (NEPA), the Endangered Species Act (ESA), the Marine Mammal Protection Act (MMPA), the Magnuson–Stevens Fishery Conservation and Management Act (MSA), the Migratory Bird Treaty Act (MBTA), the Coastal Zone Management Act (CZMA), and the Outer Continental Shelf Lands Act (OCSLA).

5.1.1 National Environmental Policy Act

The National Environmental Policy Act (NEPA) United States Code Citation: 42 U.S.C. § 4321 et seq. is the national charter framework for protection of the environment. The act is a national policy to "encourage productive and enjoyable harmony between man and the environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; and to enrich the understanding of the ecological systems and natural resources important to the Nation" (42 U.S.C. §4321). The profound impacts of human activities on the interrelationships of the natural environment (e.g., urbanization, population growth, industrial expansion, resource exploitation) are recognized. The act calls for the federal government, in cooperation with state and local governments and other public and private organizations, to use all practicable means and measures to fulfill the policy.

Federal agencies are responsible for improving and coordinating program plans and actions to meet policy goals. Agencies must use a systematic, interdisciplinary approach to ensure the integrated use of science and environmental design to plan and conduct decision making. Unquantifiable environmental amenities and values may be considered in decision making along with economic and technical considerations (Section 102: 42 U.S.C. §4332 (2)(A) and (B)).

The method for implementing NEPA is a multi-step decision process that begins with an assessment of the regulated resource and the potential impacts attached to it, known as an environmental impact statement (EIS). This study provides the in-depth, area-wide, interdisciplinary scientific evaluation of the five shoals (B11, A9, A8, A6, and A4) and potential borrow areas as required for preparation of an EIS assessment and subsequent environmental assessments (EA). The MMS representatives, in consultation with other agencies, must decide if an EA is warranted for the extraction of offshore sand resources—in this case for a lease agreement(s) in the state of Florida for the purpose of beach re-nourishment. The MMS may use sections of this report or may adopt the report in its entirety to decide additional EIS and EA analysis.

In addition, the physical similarities of the B12, B11, A9, A8, A6, A5 and A4 shoals may be considered for future EIS and EA decisions. Shoals studied in this report are examples of geological features that share a common geological history and material composition and are a minimum distance from the coast. Potential impacts to the shoreline from dredging on other unstudied shoal features in federal waters are likely to produce results similar to those from the numerical model case simulations applied in this study.

Potential biological impacts from dredging shoals from Florida's state boundary to Volusia County, Florida, may be considered for certain protected species of the biological communities. For example, critical habitat for the federally endangered North Atlantic right whale is from Georgia to Volusia County, Florida. Loggerhead, green, and leatherback sea turtle species range from north of Florida's state boundary to the Florida Keys. The composition of documented offshore species listed as endangered and threatened begin to differ south of Brevard County.

5.1.2 Endangered Species Act

The MMS will participate in endangered species consultation in preparation of negotiated lease agreement for the shoals studied herein and possibly for other shoals (e.g., B14, A7, and A3) in the study area not specifically studied offshore of Florida's northeast coast. The Endangered Species Act (ESA) United States Code Citation: 16 U.S.C. §1531 et seq. provides a means to conserve the ecosystems upon which endangered species and threatened species depend and a program for the conservation of such endangered species and threatened species (16 U.S.C. §1531). It establishes a policy that all federal departments and agencies use their authorities to further the purposes of this Act (16 U.S.C. §1531 and §1536).

Section 7 (16 U.S.C. §1536) directs all federal departments and agencies to consult on any actions authorized, funded, or carried out by them to prevent jeopardy to the continued existence of any endangered or threatened species or to cause the destruction or adverse modification of designated critical habitat of such species unless an exception has been granted by the Endangered Species Committee (16 U.S.C. §1536 (a)(2)). In the study area, there is designated critical habitat for the endangered northern right whale (see Figure 2-38). Results of this study do not find dredging of any or all of the studied shoals to jeopardize the designated critical habitat for the northern right whale and/or endangered or threatened species in the study area.

Protected species are likely to be present in the study areas. This requires consultation between the MMS and USFWS/NMFS for a biological assessment and a biological opinion stipulating measures in the lease agreement for avoidance, minimization, and mitigation in accordance with Section 9 (16 U.S.C. §1531–§1544). Prohibited acts identified in Section 9 that relate to the "take" of endangered species by all persons includes all federal, state, and local governments, except as specified under the provisions for exemptions in 16 U.S.C. §1539. The term “take” is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct (16 U.S.C. §1532(19)). Provisions for civil penalties, criminal violations, enforcement, and citizen suits are found in (16 U.S.C. §1540).

5.1.3 Marine Mammal Protection Act

This Marine Mammal Protection Act United States Code Citations: 16 U.S.C. §1361 et seq, §1362, §1371, and §1538 establish a moratorium on the taking and importation of marine mammals and marine mammal products, with exceptions for scientific research, allowable incidental taking, exemptions for subsistence activities by Alaskan natives, and hardship exemptions. Marine mammals (dolphins) were observed in the study areas and are very likely to be present during dredging. It is possible that the northern right whale, humpback whale, and the Florida manatee may also transit in the study area. While it is highly improbable that the dredging activity will not cause a taking, avoidance actions and measures are recommended to prevent its occurrence. During the consultation process with USFWS and NMFS, the MMS will decide the merits of recommended deterrents to avoid harm to marine mammals that may transit through the offshore sites during dredging or that may encounter dredge vessels in the vicinity of the study shoals.

5.1.4 Migratory Bird Treaty Act

The Migratory Bird Treaty Act (MBTA) United States Code Citation: 16 U.S.C. §703–§708, §709a–§712 provides policy to protect migratory bird species native to North America and exemptions for permitted activities. It is unlawful at any time, by any means or in any manner to or attempt to pursue, hunt, take, capture, kill, or possess, offer for sale, sell, offer to barter, barter, offer to purchase, purchase, deliver for shipment, ship, export, import, cause to be shipped, exported, or imported, deliver for transportation, transport or cause to be transported, carry or cause to be carried, or receive for shipment, transportation, carriage, or export, any migratory bird, any part, nest, or eggs of any such bird, or any product, whether or not manufactured, which consists, or is composed in whole or part, of any such bird or any part, nest, or egg thereof, included in the terms of the conventions between the U.S. and Great Britain, the United Mexican States, and the Government of Japan. The list of birds protected under the MBTA was compared with seabirds observed during previous studies in Northeast Florida and seabirds observed during our field studies of 2005 and 2006. The species likely to be present in the vicinity of the study areas are discussed in Sections 2 and 3 of this report. Although, it is unlikely that the presence of birds during dredging operations in and near the study areas will lead to impacts, recommendations for actions to avoid potential impacts are provided in Sections 4 and 5.

5.1.5 Magnuson–Stevens Fishery Conservation and Management Act

The Magnuson–Stevens Fishery Conservation and Management Act (MSA), United States Code Citation 16 U.S.C. §1801 et seq. as amended by the Sustainable Fisheries Act of 1996 (Public Law 104-267) and reauthorized in 2006 (P.L. 109-479), provides for the conservation and management of fisheries and for other purposes. The 1996 amendment of the MSA requires description and identification of “essential fish habitat” (EFH) in each fishery management plan (FMP). EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.” Waters include aquatic areas and their associated physical, chemical, and biological properties. Substrate includes sediment underlying the waters. Necessary means the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem. Spawning, breeding, feeding, or growth to maturity covers all habitat types utilized by a species throughout its entire life cycle.

Only species managed under a federal fishery management plan are protected under EFH provisions. FMPs are established by one (or more) of the eight regional fishery management councils to manage species taken in or impacted by U.S. fisheries in federal waters. The MSA requires all federal agencies to consult with the NMFS prior to actions, or proposed actions that are permitted, funded, or undertaken by the agency that may adversely affect EFH. Adversely affect means any impact that reduces the quality and/or quantity of EFH. Adverse affects may include direct (e.g., contamination, physical disruption), indirect (e.g., loss of prey), site-specific, or habitat-wide impacts, including individual, cumulative, or synergistic consequences of actions.

The South Atlantic Fishery Management Council, whose jurisdiction includes the current study area, has developed FMPs for several species supporting economically valuable fisheries, with individual plans often covering multiple taxa sharing similar life history strategies. Current FMPs (many of which have been amended several times) include the snapper–grouper reef fish complex (73 species), coastal migratory pelagics (5 species), dolphin and wahoo (2 species), red drum (1 species), shrimp (6 species), spiny lobster (1 species), golden crab (1 species), and corals (numerous species). The coastal migratory pelagics and spiny lobster FMPs were developed jointly with the Gulf of Mexico Fishery Management Council because stocks overlap both regions; red drum fish are jointly managed with the Atlantic States Marine Fisheries Commission (ASMFC) because a large proportion of landings occur in state waters. In addition, 44 species of Atlantic sharks, tuna, swordfish, and billfish are managed under the highly migratory pelagics FMP developed by the NMFS Highly Migratory Species Management Unit, many of which are common along the Florida northeast coast. A list of 107 individual fish and invertebrate species in which EFH boundaries overlap or are in the vicinity of proposed sand borrow sites are provided in Table 5.1. Regional fishery management councils also have the authority to designate Habitat Areas of Particular Concern to focus conservation efforts on areas of EFH that play a particularly important role in the life history of federally managed fishery species, are especially vulnerable to degradation, are under stress, or are rare. Along the Florida east coast, Habitat Areas of Particular Concern are confined to hardbottom habitats (corals and snapper–grouper FMPs) and coastal inlets (red drum and shrimp FMPs).

An important consideration when extracting OCS sand resources is the mandate to conserve and manage both marine and diadromous fishery resources found in shelf waters of the U.S. Exclusive Economic Zones. Based on the small size of proposed borrow sites, the information obtained during the literature review, and results of field sampling events in 2005 and 2006, there is no indication of adverse impacts to protected fish species or their habitat. Nonetheless, some of the revisions and additions of the MSA 2006 reauthorization may change the MMS approach to lease agreements or consultation negotiations with NMFS. These MSA changes include (1) the addition of ecosystem research on a regional scale; (2) the implementation of measures to streamline the NEPA procedures; and (3) the designation of zones by FMPs to protect deep-sea corals and inclusion of conservation measures for non-target species (NMFS 2008a). The 2006 policy change includes improvements to the recreational statistical methods of catch data to improve scientific analysis of fish harvesting. These adaptations to improve research could improve data acquisition for the MMS planning and leasing of OCS sand and gravel. Directives to streamline NEPA procedures may also benefit the objectives of the MMS.

Table 5.1. Species managed under federal fishery management plans in which potential EFH overlaps or is in close proximity to study areas. * indicates FMP jointly managed by the South Atlantic Fishery Management Council and Gulf of Mexico Fishery Management Council.

Reef Fish FMP	
Balistes capriscus	Gray triggerfish
Caulolatilus chrysops	Goldface tilefish
Caulolatilus cyanops	Blackline tilefish
Caulolatilus intermedius	Anchor tilefish
Caulolatilus microps	Blueline tilefish
Diplectrum bivittatum	Dwarf sand perch
Diplectrum formosum	Sand perch
Epinephelus adscensionis	Rock hind
Epinephelus drummondhayi	Speckled hind
Epinephelus flavolimbatus	Yellowedge grouper
Epinephelus guttatus	Red hind
Epinephelus inermis	Marbled grouper
Epinephelus itajara	Goliath grouper
Epinephelus morio	Red grouper
Epinephelus mystacinus	Misty grouper
Epinephelus nigritus	Warsaw grouper
Epinephelus niveatus	Snowy grouper
Epinephelus striatus	Nassau grouper
Etelis oculatus	Queen snapper
Lachnolaimus maximus	Hogfish
Lopholatilus chamaeleonticeps	(Golden) Tilefish
Lutjanus analis	Mutton snapper
Lutjanus apodus	Schoolmaster
Lutjanus buccanella	Blackfin snapper
Lutjanus campechanus	Red snapper
Lutjanus cyanopterus	Cubera snapper
Lutjanus griseus	Gray snapper
Lutjanus jocu	Dog snapper
Lutjanus mahogoni	Mahogany snapper
Lutjanus synagris	Lane snapper
Lutjanus vivanus	Silk snapper
Mycteroperca bonaci	Black grouper
Mycteroperca interstitialis	Yellowmouth grouper
Mycteroperca microlepis	Gag
Mycteroperca phenax	Scamp
Mycteroperca venenosa	Yellowfin grouper
Ocyurus chrysurus	Yellowtail snapper
Pristipomoides aquilonaris	Wenchman
Rhomboplites aurorubens	Vermilion snapper
Seriola dumerili	Greater amberjack
Seriola fasciata	Lesser amberjack
Seriola rivoliana	Almaco jack
Seriola zonata	Banded rudderfish

Red Drum FMP	
Sciaenops ocellatus	Red drum

Coastal Migratory Pelagics FMP*	
Rachycentron canadum	Cobia
Scomberomorus cavalla	King mackerel
Scomberomorus maculatus	Spanish mackerel

Stone Crab FMP	
Menippe mercenaria	Stone Crab

Shrimp FMP	
Farfantepenaeus aztecus	Brown shrimp
Farfantepenaeus duorarum	Pink shrimp
Litopenaeus setiferus	White shrimp
Pleoticus robustus	Royal red shrimp

Spiny Lobster FMP*	
Panulirus argus	Spiny lobster
Scyllarides nodife	Slipper lobster

Highly Migratory Species FMP	
Carcharhinus acronotus	Blacknose shark
Carcharhinus brevipinna	Spinner shark
Carcharhinus leucas	Bull shark
Carcharhinus limbatus	Blacktip shark
Carcharhinus plumbeus	Sandbar shark
Galeocerdo cuvier	Tiger shark
Ginglymostoma cirratum	Nurse shark
Negaprion brevirostris	Lemon shark
Sphyrna mokarran	Great hammerhead
Sphyrna tiburo	Bonnethead
Thunnus thynnus	Bluefin tuna

5.1.6 Coastal Zone Management Act and Outer Continental Shelf Lands Act

The Coastal Zone Management Act (CZMA) United States Code Citation: 16 U.S.C. §1451-§1464 provides for state review of outer continental shelf lease sales, exploration, and development. The Act requires consistency of federal activities with federally approved coastal zone management plans. The outer continental shelf (OCS) is a jurisdictional term used to describe those submerged lands that lie seaward of state water boundaries (nine nautical miles off Florida's west coast and three nautical miles off the east coast). The MMS is the federal government managing agency of natural resources on the OCS, while states manage the resources directly off their coasts. The Outer Continental Shelf Lands Act (OCSLA) 1953 (67 Stat. 462), as amended (43 U.S.C. §1331 et seq. (1988)) is the principal federal law governing mineral activities in federal waters. It was written to guide decisions concerning the exploration for the development of oil, natural gas, and other mineral resources on the OCS. Under the OCSLA, the MMS manages the orderly development of OCS actions and coordinates with states to protect human, marine, and coastal resources. Sand and gravel resource extraction under the OCS is authorized on a noncompetitive and non-fee basis to government entities.

Florida's clearing house for federal and state interaction is supervised by the secretary of FDEP who serves as the governor's contact for OCSLA and CZMA activities. Florida has an approved coastal zone management plan, which is administered through the FDEP Coastal Management Program in the Offshore Projects Unit of the Office of Intergovernmental Programs (OIP). Under the direction of the Florida OIP administrator, staff of this unit review OCSLA and NEPA documents, CZMA-proposed laws/rules or other materials, and coordinate information requests associated with offshore activities. OIP staff members provide technical analyses, recommendations and expertise; communicate state policy, and develop state responses on OCS issues (FDEP 2008).

The MMS transmits any planning activity for the use of OCS resources to the OIP administrator, as is called for in Section 307 (16 U.S.C. §1456(c)(1)(A)) for federal agencies proposing activities or development projects, including civil works activities, whether within or outside of the coastal zone, that are reasonably likely to affect any land or water use or natural resource of the coastal zone, to assure that those activities or projects are consistent, to the maximum extent practicable, with the approved state programs. Non-federal projects requiring a federal permit for an activity in or outside of the coastal zone, affecting any land or water use or natural resource of the coastal zone of the state, must provide certification to the permitting agency that the proposed activities comply with the enforceable policies of the state's approved program. No license or permit shall be granted by a federal agency until the state has concurred with the applicant's certification or until the state has waived its right to do so (16 U.S.C. §1456 (c)(3)(A)).

5.2 Recommendations for Mitigating Potential Impacts

5.2.1 Setting Environmental Windows, Defining Operational Methods, and Protecting Physical Features

In 1998, in a technical note "Environmental Windows Associated with Dredging Operations," the USACE discussed some of the problems associated with restricting dredging to specific time periods from the onset of NEPA in 1969 (USACE 1998). The National Academy of Sciences produced "A Process for Setting, Managing, and Monitoring Environmental Windows for Dredging Projects: Special Report 262" for improving the process of establishing environmental windows. The workshop brought together experts with backgrounds in the dredging-related industry to better evaluate trade-offs between environmental benefits and operational costs, identify the strengths and weaknesses of the decision-making processes, assess the scientific and technical justifications used in establishing windows, and review dredging technologies designed to minimize environmental impact. The workshop committee found discrepancies in the technical information used to set windows varied greatly (TRB 2002).

The need to successfully protect endangered species from potential harm caused by human activities, such as dredging, brought attention to the complexity of measures necessary to reduce the risk for a myriad of species, each with specific reproductive cycles, habitats, and behaviors. Furthermore, concern that adequate information was lacking or information that was relied upon was outdated for some species could negatively influence the decision-making process for the biological community and the project costs, thus failing to efficiently and effectively protect species and maintain waterways and shores. Eight recommendations emerged from the workshop. Of those applicable to the proposed mitigation measures in this study, the use of environmental windows based on recent available scientific information and the principle of adaptive management proved to be the most relevant.

Recommendations provided below consider environmental windows as one tool among many to prevent potential adverse impacts to protected species and physical features. Measures for the protection of biological and physical resources consider planning dredge projects in terms of a life cycle. Many shore-protection projects require repeated renourishment every 5–10 years. Even locations not included in the category of repeated cycles but instead are emergency dredge and fill are project areas prone to natural hazards. Activities to protect endangered and threatened species from dredging can correspond to similar cycles. While we do not know all there is to know, scientific information on sea turtles and marine mammals has vastly improved since 1969 and so have methods to avoid them or reduce their exposure to harm. For example, operating when species are least likely to be present or in smaller numbers, implementing operational and personnel procedures to prevent interaction with species, and planning multiple dredging projects over longer time periods allow recovery of benthic organisms and habitat.

5.2.2 Seabird Mitigation Measures

Two potential impacts to protected seabird species—ingestion of discarded debris and drowning—may be mitigated by scheduling dredging operations and adjusting waste management procedures. An environmental window that protects marine turtles also helps protect Least Terns due to the overlap in nesting season for both species. In the study area, Least Terns are likely to be greater in number and feed offshore during the April–August nesting season, which is within the sea turtle nesting window of April–October. Observers for marine mammals and turtles should also monitor the scow for Least Terns or other diving birds present in the area. A shutdown protocol should be in place and implemented if birds are observed diving into the scow. Also, offloading food waste from the dredge during daylight should be eliminated to reduce attracting other birds, which can also attract terns to the area.

5.2.3 Sea Turtle Mitigation Measures

Sea turtle protection primarily centers on dredging outside of nesting season from April to October, thereby avoiding the peak number of sea turtles offshore and in the coastal zone. The environmental window for minimizing sea turtle takes is December 1 to March 31. Additional activities that have proven to reduce the number of sea turtle deaths are using a turtle deflector on the draghead and closely following the operational protocol for maximizing its effectiveness. Field tests of a hopper dredge modified with a turtle deflector to reduce turtle mortality have proved successful if the equipment is properly operated (USACE 2003). Instructions for proper operation and equipment specifications are documented in the

USACE Jacksonville District and WES (USACE 2003). Since 1993, NMFS has approved turtle deflectors throughout the southeastern U.S. (Dickerson et al. 2004). Use of these deflectors while dredging must be operated according to specifications and must be managed in concert with approved and trained endangered-species observers. Observers should monitor an exclusion zone surrounding dredge activities and be authorized to shut down operations as necessary to protect turtles.

Following a large number of sea turtle takes in Cape Canaveral in 1980 (Dickerson et al. 2004), USACE used a pre-dredge turtle survey and trawling and relocation to reduce the number of takes in channel dredging. These procedures are now used to reduce takes for beach-fill projects. In 2006, offshore of Collier County, Coastwise Consulting Inc. conducted pre-dredge turtle trawling and relocation effort from February to May 2006. The results were 87 turtles successfully relocated, with no reported turtle takes observed for 94 days of dredging (Coastwise Consulting Inc. 2006). Although the addition of pre-dredge trawl surveys and relocations are costly, it is an option to reduce turtle takes when dredging during nesting season or when takes are unusually high or approach take limits.

5.2.4 Marine Mammal Mitigation Measures

The likely presence of endangered northern right and possibly humpback whales during the environmental window timeframe recommended for sea turtles, together with the location of a designated right whale critical habitat in the study area, require a mitigation plan for the prevention of potential harm to either whale. There are slight differences among protective actions necessary for these whale species and the Florida manatee that may also be in the study area.

Recommended actions that would provide optimal protection for marine mammals include installation of an observer program similar to MMS NTL 2007-G02, Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program, and MMS NTL 2007-G4. Although, MMS NTL 2007-G02, Implementation of Seismic Survey Mitigation Measures, was designed for air-gun surveys in deep water, geophysical seismic investigations to determine vibracore sampling locations for future borrow area design should follow similar guidelines within the right whale critical habitat during winter season and when seismic equipment meets or exceeds the thresholds prescribed within this notice and documents referenced therein.

Following NMFS (2008) Vessel Strike Avoidance and Injured/Dead Protected Species Reporting is also recommended. During geophysical surveys and dredging NMFS vessel strike and avoidance procedures are recommended for marine mammals. Instructions are provided for obtaining up-to-date information and communication on right whale locations (NOAA weather radio, U.S. Coast Guard NAVTEX broadcasts) and for reporting sightings or incidents NMFS (2008).

Trained endangered species observers onboard all geophysical seismic investigations are recommended and are required for dredging operations. Education on protected species should be a required integral part of any mitigation program for crew and vessel operators. Crew members should be trained in basic observation and identification techniques and possess a thorough understanding of all federal and state laws and penalties concerning protected species. A right-whale training program is available in a training CD produced by NOAA/USCG, entitled *A Prudent Mariner's Guide to Right Whale Protection (*NMFS 2008). These measures would supersede standard dredge monitoring methods typically implemented by USACE and provide optimal protection from mechanical injury and noise impacts to all marine mammals likely to occur in the study area.

6.0 CONCLUSIONS

This study characterizes the physical and biological environments of five offshore sand sources and identifies the potential environmental impacts from dredging on the borrow sites and physical changes that may impact the nearshore beaches of Florida's northeast coast. Information from literature research and field studies was collected and analyzed to assist in developing criteria for future negotiated lease agreements, NEPA documents (Environmental Assessments and Environmental Impact Statements), and for other regulatory permits as required to use federal sand and gravel deposits off the Florida's northeast coast.

6.1 Characterization of Physical Environments Offshore and Nearshore

A review of the geology of the northeast coast continental shelf features was completed to characterize the dynamics of formation and morphological transformation that occur to linear shoals and sand ridges. The earliest surveys to characterize shoal features for their potential content of beach-quality sand were completed by the USACE ERDC in the 1960s and 1970s. This was followed by further reconnaissance studies by the Florida Geologic Survey in the mid-1990s, which were sponsored by the U.S. Minerals Management Service. Most recently, additional reconnaissance data were collected by the Florida Department of Environmental Protection Beaches and Shores Division as part of the ROSS database assembly. Results of these investigations show that the sand ridges and sand banks of the northeast Florida inner continental shelf may contain, in total, several hundred million cubic yards of clean sand. A limited number of cores and sub-bottom acoustic profiles indicate that the shoal features are probably constructed from the littoral sand supply at lower stands of sea level and may be related to the construction of ebb shoal deposits at migrating tidal inlets. The Florida shoals also can be shown to be similar to shoals known from the geologic record. Both the modern and ancient shoals are thought to be dynamic even when their crest elevations are at depths of 32 ft (10 m) or more. This is evidenced by large bedforms present on the modern shoal and sedimentary cross beds found in ancient shoals that indicate migrating bedforms. Analysis of the limited historical surveys available from the northeast Florida shelf are consistent with the dynamic nature of the shoals, since comparison of the surveys indicate up to 6.5 ft (2 m) of topographic changes at time scales of a decade or longer.

This qualitative understanding of shoal dynamics was further examined through numerical modeling of physical processes over the shoals and at the shoreline to determine if, over time, the local wave field and hence patterns of accretion/erosion at the shoreline may be affected by excavation of borrow areas. Predicted sand transport rates in the littoral zone were also compared with and without the borrow cuts placed in the model domains to determine if excavation of the shoals is likely to have influence at the shoreline. The results of these model experiments are described in the following section.

6.2 Numerical Model Predictions: Nearshore and Offshore Borrow Sites

Hind cast predictions using the coupled wave and circulation models of the CMS developed by the ERDC demonstrated the potential for impacts of dredging planned and hypothetical borrow sites in the B12, B11, A9, A8, A6, A5, and A4 shoals on the northeast Florida inner continental shelf. Predictions of the wave energy moving across the shoals with and without the borrow cuts in the model topography indicated that long-period swells generated by storms were influenced by shoaling effects over the crest of the shoals. When the borrow areas were placed in the model topography, reduction in wave height was predicted to occur as a result of the increased depth over the borrow sites. Some localized increases in wave height were predicted to occur at the perimeter of the borrow cuts.

The influence of the dredged cuts on wave heights was transmitted toward the shoreline as wave energy propagated to the west. Differences between pre- and post-borrow wave height on the upper shoreface and in the model surf zone diminished to 1 cm or less. Predictions of sand transport patterns associated with the wave and current fields compiled in the model hydrodynamics showed that the most intense transport occurred in the nearshore zone where breaking waves drive longshore currents. During the higher energy conditions of storms, sand transport also occurred over some portions of the inner continental shelf. This effect was strongest over the crest of shoal features. Topographic changes over the two-year simulations occurred over the shoreface from the shoreline to depths of approximately 16.4 ft (5 m), where predicted sand transport rates were greatest. Periods of detectible erosion and deposition were associated with storms and higher energy waves. Abrupt changes in offshore topography were often linked to severe storms in the model runs. The overall pattern of change across the shoreface included erosion of the upper shoreface at depths of about 10 ft (about 3 m) and less and deposition on the lower shoreface at depths greater than about 10 ft. Superimposed on this pattern were alternating zones of erosion and deposition in the alongshore direction.

Differences between pre- and post-borrow topographic changes were compared among three general cases. The base case included the existing topography of each shoal or the pre-dredge topography. The second case included existing, planned, or hypothetical borrow cuts of limited extent. The third case consisted of multiple borrow cuts or a single, large borrow excavation to represent repeated dredging for a long-term permit for beach restoration.

In the nearshore zone and upper shoreface over the 24-month simulation, the predicted topographic differences among the test cases were near zero and never exceeded about 1.6 in or 4 cm. The annual net longshore transport rates along the shoreline calculated from predicted, instantaneous transport rates were compared among the three types of test cases. The range of differences among the cases was about 500 m^3/yr or less. Inshore of some of the shoals that were investigated, the differences among the test cases were spatially organized in the alongshore direction, indicating a small but detectable zone of influence arising from the location of expanded excavations on the crest of the shoals. The range of differences in this zone of influence of +/- 500 m^3/yr compared with total annualized rates of littoral sand transport of about 10,000 m^3/yr to more than 150,000 m^3/yr. Analysis of the variability of predicted transport rates also indicated that the impact of offshore borrow cuts within the zone of influence was relatively small since the predicted difference in transport among the test cases was well below the temporal standard deviation of sand transport that can be predicted for any location on the shoreface.

The overall conclusion is that borrow cuts as currently designed will likely have a small but detectable impact on littoral sediment transport rates along the shoreline of Northeast Florida. However, compared to the annual sand budget and natural inter-annual variability, the impact is likely to be very small and almost indistinguishable from natural variability. On the other hand, it can be shown that predicted patterns of topographic change over the crest of all shoals examined in this study will be altered by the presence of borrow excavation. This is consistent with the expected changes in wave height that can occur as long-period and high waves generated by storms pass over the sand ridges.

6.3 Benthic

Based on the results of the field surveys and examination of the literature on benthic recovery rates from disturbances, it is anticipated that abundances, species numbers, and diversity in dredged areas may reach background levels relatively rapidly; however, species composition may take a longer period of time. Dredging the sand shoals examined for this study will result in an immediate decrease in the abundance, diversity, and biomass of benthic organisms within the dredged footprint. Because the benthic assemblages on the sand shoals examined were similar to the assemblages in the adjacent areas off the shoals and the spatial extent of the dredged area is small compared to the overall area of the east Florida shelf, a negligible impact to the ecosystem is expected. In addition to larval recruits from the water column, the surrounding areas (that are not targeted for dredging) would supply the potential adult colonists for the area disturbed by the dredging. Similar to conclusions reached in previous MMS studies, the high densities and fecundity of the benthic populations in the area, together with the relatively small area of impact, will preclude significant long-term effects on the benthic populations.

Slow-moving and burrowing epibiota inhabiting the study area include echinoderms such as sand dollars and brittle stars and decapod taxa, and local populations of these types of benthic organisms will most likely experience a reduction in density due to sediment removal and entrainment in the suction dredge. Motile epifauna generally are migratory and are not restricted to the borrow areas.

The timing of dredging is important because many benthic species have distinct reproductive and recruitment periods. Recovery primarily comes from larval recruitment and adult immigration. Therefore, recovery should be most rapid if dredging is completed before seasonal increases in larval abundance and adult activity. The benthic assemblages within the study area were dominated by small bodied, filter- and deposit-feeding species living at the sediment surface. However, there were differences in dominant species and overall abundances between spring and fall. Overall, infaunal abundances were nearly three times higher in the spring than the fall. The five most numerous benthic taxa in the fall were the amphipods *Metharpinia floridana* and *Protohaustorius wiglei*, the hemichordate *Branchiostoma*, and Tellinid bivalves. In the spring, spionid polychaetes *Prionospio* spp. were numerically dominant, and the spionids *Apoprionospio pygmaea* and *Spiophanes bombyx* were among the ten most numerous taxa, as were the fall dominants *Metharpinia floridana*, *Protohaustorius wiglei*, *Branchiostoma*, and Tellinid bivalves. This pattern agrees with Diaz's (2004) conclusion that mining activities ending before fall/winter would favor annelid recruitment. However, impacts to fish may be greater following mining in the spring/summer because recruitment of their crustacean prey would be affected (Diaz 2004).

Based on results of other studies, recolonization of dredged areas begins soon after dredging activities end. Repopulation comes from larvae settling out of the water column and adult and post-settlement juveniles not entrained by the dredge and/or those from adjacent areas. Recolonization rates will be dependent upon the size, edge-area, and proximity of undisturbed areas to the borrow site. As previously noted, studies have indicated that, although after dredging, the abundance, species, and biomass of benthic infauna may approach pre-dredging levels in a relatively short time (less than one year in some cases), community composition may take much longer.

6.4 Fishes and Macroinvertebrates

Fish trawl catches were dominated by pelagic or demersal softbottom species, most of which range widely over the Florida continental shelf (and throughout the western Atlantic Ocean) and are of little direct economic value to Northeast Florida. Only eight hardbottom-associated species protected under the South Atlantic Fishery Management Council's reef fish management plan were collected, of which only the rock sand bass (*Centropristis philadelphica*) was common. Further, no fishes listed as federally endangered or threatened under the Endangered Species Act (i.e., smalltooth sawfish or shortnose sturgeon) or those prohibited from harvest by the state of Florida or NMFS were collected or observed. Macroinvertebrate trawl catches did include economically valuable penaeid shrimp in moderate densities as well as rock shrimp (*Sicyonia* spp.) and *Callinectes* spp. (blue) crabs in lower densities. Ichthyoplankton catches were similarly dominated by fish taxa of little economic value (e.g., gobies, herring, and anchovies). Larvae of these families are among the most common in estuarine and shelf waters throughout Florida, and given their long pelagic stages, their distribution is likely independent of local habitat features.

Although the two sampling cruises cannot fully characterize the local ichthyofauna, the study areas were identified for their elevated deposits of beach-quality sand and thus do not offer the exposed hardbottom necessary to support a high diversity of reef-associated fishes. This was also demonstrated by the catch composition of the sampling cruises. Consequently, dredging will likely be of little detriment to economically valuable demersal fisheries such as snappers and groupers. Further, while migratory pelagic teleost and elasmobranch fishery species (including sawfish and sturgeon) may be encountered in the vicinity throughout the year, these groups are mobile and can easily avoid small-scale dredging disturbance. Consequently, establishing temporal dredging windows for the local protection of fishes appears unnecessary, especially if doing so alters the timing or duration of more critical windows established for protection of turtles or marine mammals.

6.5 Seabirds, Sea Turtles, and Marine Mammals

Literature reviews identified habitats and the likely presence of protected species (seabirds, sea turtles, and marine mammals) in study area of Northeast Florida and beyond. During sampling cruises, differences in abundance and species diversity were observed for protected species within the study area. Seasonal variability of protected species was evaluated to develop recommendations for mitigation.

The most potential harm to birds is when seabirds or shore birds dive into the scow during the beach fill. Seabirds observed in Northeast Florida are dominantly trans-migrants, shorebirds, wading birds, and waterfowl that may use the dredgers and boats for temporary resting places. Potential harm on dredgers is from ingesting discarded debris, which can be prevented by supervision of solid waste control that attracts seabirds to the dredge.

Sea turtles are most directly vulnerable to impact from dredging operations. In general, although sea turtle seasonal activity varies according to species, they are present in greater numbers during nesting season, which is from April to October. Loggerheads are the most abundant species in the study area, second are green sea turtles, and the least are leatherback sea turtles. Recommendations to avoid and/or minimize potential impacts to sea turtles include dredging from December to March, requiring onboard trained observers, requiring turtle deflectors on the draghead, turning off pumps when the draghead is lifted from the sea-floor bottom, using jet pumps to create a mobile water curtain, and conducting a pre-dredge survey and relocation program.

Endangered marine mammals likely to be present are the northern right whale (designated critical habitat), humpback whale, and the Florida manatee. Most likely, various dolphin species also will be present in the study area. Protection of endangered mammal species calls for measures of avoidance; personnel training; observers with authority to implement standard procedures MMS NTL 2007-G02, Implementation of Seismic Survey Mitigation Measures and Protected Species Observer Program; MMS NTL 2007-G4, and Vessel Strike Avoidance and Injured/Dead Protected Species Reporting for dredging operations (NMFS 2008b).

6.6 Recommendations for Future Studies

Recommendations for future studies to minimize potential impacts of dredging are to broaden the geographical boundaries of offshore resource studies, to add sampling surveys for pre- and post dredge scenarios to research initiatives, and to investigate physical shoal features and benthic-fish community dynamics on a finer scale. Pre- and post-dredge benthic monitoring studies of shoals with well-controlled time periods accounting for the duration of the dredging operation itself would help establish a better understanding of dredging effects over time and seasons. Studies of shoal systems over time, prior to and post-dredging, would help us more fully understand the spatial variability and dynamics with regard to shoal topography.

With respect to fishes, there are few intensive before-and-after comparisons of sand mining impacts to continental shelf benthic fish faunas of the U.S. South Atlantic and Gulf of Mexico. Funding and logistical limitations typically constrain such efforts to short-term pre-mining surveys, with little spatial and temporal replication. Similarly, there are few attempts to directly quantify dredge entrainment of continental shelf fishes or macroinvertebrates. These risks should be quantified to improve understanding of coastal sand mining to the shelf fish fauna.

Results of numerical modeling indicate that sand excavation in sand ridges and shoals within federal waters will likely have very small impacts at the shoreline, almost indistinguishable from natural variability. On the other hand, model results indicate that patterns of topographic change over the crest of all shoals examined in this study may be altered by the presence of borrow excavation. Thus, it is recommended that field and modeling studies be conducted at selected sites to determine the long-term potential impacts on the morphologic stability of the shoal. Such investigations should provide monitoring of physical processes, including wave, currents, and topographic change. Field surveys should then be used to calibrate high-resolution numerical simulations of sand transport and topographic change. A key element of such studies would be the ability to conduct simulations that represent a time scale of at least 10 years and longer.

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