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Final Report

THE DEVELOPMENT OF AN OFFSHORE ALABAMA SAND INFORMATION SYSTEM

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by
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ABSTRACT

A geographic information system (GIS) platform provides a powerful tool for managing and analyzing geospatial databases and for the visualization of geospatial themes and results. The application of GIS to sand resource investigations supports the identification and delineation of potential sand resources in the Federal Outer Continental Shelf, promotes the feasibility of sand mining, and facilitates the discovery of existing data to promote further sand investigations and minimize project cost. This assessment was tasked as part of Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery. The Offshore Alabama Sand Information System (OASIS) is an internet mapping service representing a compilation of shallow sediment, geophysical, and ancillary geospatial data from private, government, and academic entities. Source data implemented in this study mainly include digital legacy data as well as data recovered from an analog environment. The OASIS platform was developed to promote the discovery and management of offshore data related to sand resource investigations, provide a web-based avenue of information dissemination of past offshore sand source data, and provide a platform that is easily accessible and expandable. Through this interface, bottom geomorphology, sampling and lithofacies distribution, and supporting raster data promote the identification of data gaps and delineate areas of high sand source potential. Beach-quality sand in offshore Alabama is thought to be confined within the Graded Shelly Sand and Clean Sand lithofacies found within oblique sand ridges. Based on data obtained for this project and the OASIS GIS, Tier 1, and Tier 2, and alternative sand resource investigation delineations were determined.

INTRODUCTION

Alabama beaches fronting the Gulf of Mexico (GOM) are affected by both natural and anthropogenic modifications. Several areas are exposed to persistent erosion with much of the coastline subjected periodically to catastrophic or long-term sand loss due to hurricane strikes (Parker and others, 1993; Finkl and others, 2004; Morton and others, 2004; Jones and Patterson, 2006; Jones and Darby, 2009). Furthermore, the Alabama coastline along the GOM has undergone substantial topographic modification through ubiquitous beachfront development, existing hard shoreline defense structures, and beach nourishment. Loss of beach sand impacts areas of recreation, natural habitat, and soft shoreline protection. The recreational component or tourism base of Alabama's beaches and the need to maintain essential native habitat are the primary reasons high-quality sand sources are essential.

Through the Gulf Task Force, established in 1986 by the U.S. Department of the Interior, Minerals Management Service (MMS), the Geological Survey of Alabama (GSA) has worked cooperatively with the MMS to evaluate heavy minerals within the GOM Exclusive Economic Zone (EEZ) (Bearden and others, 1987; Parker, 1988, 1989, 1990). Due to the need to address chronic shoreline erosion, sand was determined to be the foremost mineral resource with leasing potential, resulting in cooperative sand source investigations (Parker and others, 1993; Hummell and Smith, 1995, 1996; Hummell, 1997, 1999; Kopaska-Merkel and Rindsberg, 2005; Rindsberg and Kopaska-Merkel, 2006). As documented in the essential sand management activities detailed by Michel (2004), it would be beneficial to Alabama to delineate additional offshore sand resource(s) through a detailed subsurface investigation, thus allowing for an inventory of known sand deposits to be determined and ultimately permitted. As part of Public Law 109-234, Emergency Supplemental Appropriations Act for Defense, the Global War on Terror, and Hurricane Recovery (MMS, 2009), the MMS established a cooperative agreement with the GSA to further assess offshore Alabama sand sources and develop a web-based interactive mapping system to assess damages caused by Hurricanes Katrina and Rita in 2005.

A fundamental concept of this project was to develop a web-based avenue of information distribution of past offshore sand source data. This tool facilitates periodic thematic updates, employs data used to delineate the potential areas of high-quality offshore sand deposits, guides future sand investigations using known, obtainable data, and promotes cost-effective planning. Web-based information exchange and transfer is vital to future offshore sand resource management and project planning. Thus, the basic objective of this study is to assemble geospatial data (such as offshore sand studies, environmental, and infrastructure) that support identification, delineation, and dredging feasibility assessment of beach-quality sand deposits on the Federal Outer Continental Shelf (OCS) or EEZ through geographic information system (GIS) analyses and visualization.

Achieving the fundamental purpose primarily included (1) the discovery, acquisition, and development of digital data and analog to digital conversion of offshore geological and ancillary data, (2) the development of a GIS project to promote further evaluation of potential borrow sites (fig. 1), and (3) the development of an interactive project web site with the functionality for on-line source dissemination for offshore data used in the sand-source investigation. Although initially called the “Interactive Alabama Sand Resource Mapper,” this web-based platform is now known as the “Offshore Alabama Sand Information System” or OASIS.

This report summarizes previous offshore Alabama sand deposit investigations and GIS development, provides a brief description of the study area geophysiography, documents geological and ancillary data resources that were incorporated into the project, and summarizes findings within and further evaluation needs of each MMS Study Area. The specific area of study includes five offshore target areas or MMS Study Areas (fig. 1) as previously delineated based on their potential. The potential for appropriate sand volumes and MMS Study Area delineations was determined from sand ridge, sand sheet, and ebb tidal delta characterization, bathymetry, and proximity to critically eroding shorelines (Parker, 1990; Parker and others, 1993, 1997).

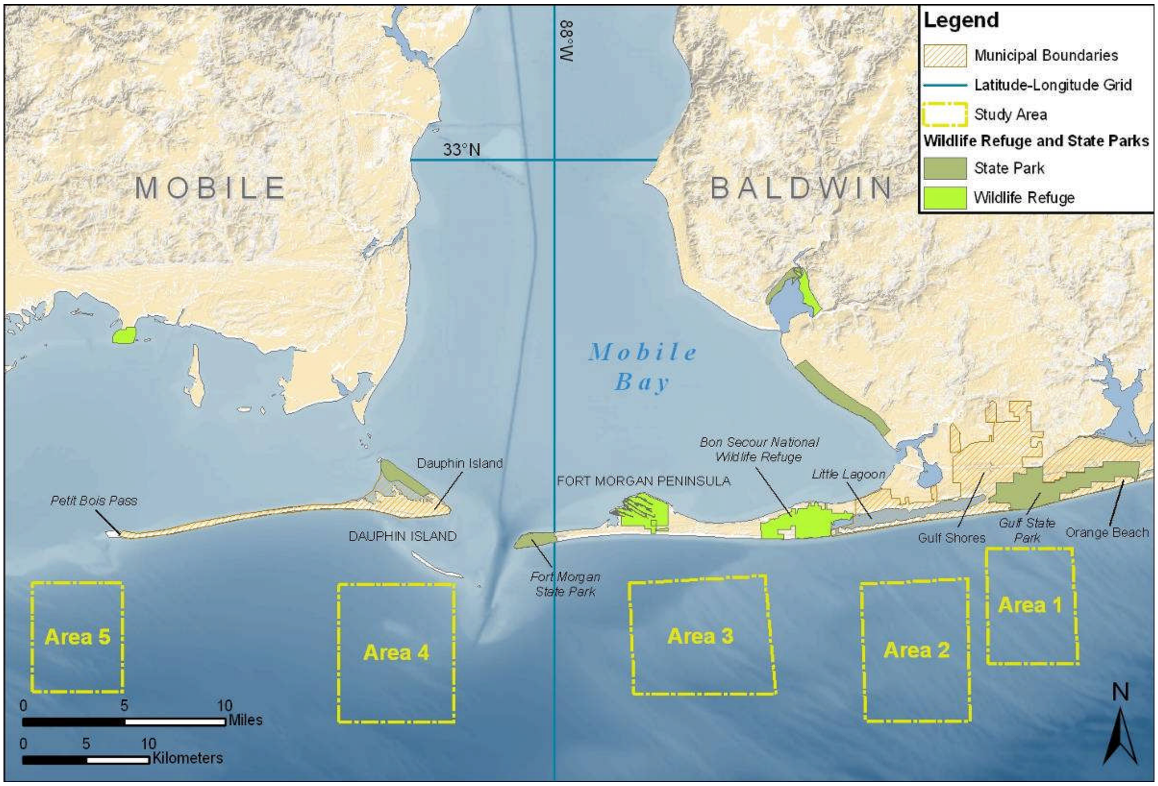

Figure 1.—Map of coastal and offshore Alabama illustrating the location of MMS study areas.

ACKNOWLEDGMENTS

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PREVIOUS WORK

INTERACTIVE GEOGRAPHIC INFORMATION SYSTEM MAPPING

Based on research during this study, no compilation of offshore sand search data (geotechnical and geophysical) and ancillary geospatial resources for offshore Alabama has been developed. The latest work to disseminate offshore oil and gas infrastructure and lease data, natural hazards, Alabama sand resource data, and historical reports was through an Environmental Systems Research Institute Inc. (ESRI®) ArcView© 3.2 project (Kopaska-Merkel and Rindsberg, 2002; Natharius, 2002). Limited to previous MMS and GSA cooperative agreements completed by Parker (1990, 1993), Hummell and Smith (1995, 1996), and Hummell (1999), the interactive GIS interface contained photography, foundation boring logs, beach profiles, and vibracore data "hotlinked" to the appropriate geospatial themes.

Although several web sites with interactive mapping interfaces relevant to offshore sand resources within the GOM exist, they vary in functionality and available data. The Louisiana Sand Resource Database (LASARD) developed by the Louisiana State University Coastal Studies Institute and the Louisiana Department of Natural Resources (LDNR) was designed to support further offshore sand search coordination and planning from a comprehensive database of geophysical, geotechnical, environmental, and ancillary data (Khalil and others, 2005). Upon completion, the LASARD will be accessible over the internet. The Louisiana Sedimentary and Environmental Database (LASED)(http://coastal.er.usgs.gov/lased/) was developed by the U.S. Geological Survey and academic entities. The LASED is an ESRI® Arc Interactive Map Server (ArcIMS©) interface that supports the dissemination of geospatial and supplemental data such as core logs, sediment analysis, supporting raster data, field books, and geophysical profiles archived in a geodatabase environment coupled with hyperlinks, highly functional visualization tools, and quantitative queries (Dadisman and others, 2005). Notable characteristics of LASED includes the visualization tool (SonarWeb software, Chesapeake Technology Inc.) which allows the cursor to provide geospatial coordinates and depths of locations on hyperlinked seismic profiles as well as the value gained from the conversion of numerous core logs from analog into a queriable digital format (Dadisman and others, 2005). Through an ArcIMS interface, the Florida Reconnaissance Offshore Sand Search Database (ROSS) (http://ross.urs-tally.com/) is a detailed relational database with geospatial themes and a comprehensive tabular sand characterization derived from offshore sediment samples. ROSS supports Atlantic- and

GOM-fronting offshore sand source investigations. The Texas Bureau of Economic Geology (BEG), Coastal Studies Group has developed the “Sabine and Heald Banks” and “Central Texas Continental Shelf” interactive mapping platforms and related publications (http://www.beg.utexas.edu/coastal/sand.htm) as a research archive. Data specific to the Sabine and Heald Banks database, compiled through a BEG and MMS Office of International Activities and Marine Minerals (INTERMAR) cooperative project, are downloadable through the BEG; the Rice University Coastal Research Group is working with the BEG on the east and central Texas continental shelf sand sources and interactive mapping.

SAND ASSESSMENTS, OFFSHORE ALABAMA

Although limited offshore sand research has been done within state waters, and to a lesser extent within federal waters, existing research and bottom sampling for beach quality sand is not sufficient to delineate a high-quality sand resource in federal waters. Offshore beach-compatible sands are those that match native beach grain characteristics, including color, shell content, and fines content (Olsen, 2003b). Traditional surveys to locate high-quality offshore sand deposits were based on geophysical and geotechnical bottom sampling coupled with corrected long-range navigation system (LORAN-C) positioning. Coordinates derived from LORAN, coupled with sparse geotechnical sampling, adds to the complexity of delineating potential sand deposits. Recent sub-bottom sampling and digital hydrographic surveys incorporate global positioning system (GPS) technology leading to accurate placement of geologic geospatial themes and better sand source interpretations.

Fundamental sediment characterization used in various studies, summarized below, as well as in log data, attributes, and lab analyses includes grain-size distribution, sorting, skewness, and to a lesser extent, kurtosis. Grain-size scales for sediment distribution, minimum sieve mesh, and classification scheme are listed in table 1. Sorting or phi (Φ) standard deviation (table 2) is defined as the grain-size distribution 34 percent from the mean; skewness (table 3) reflects the grain-size curve asymmetry relative to the mean where a positive skew represents an abundance of fine particles or positive Φ values. Kurtosis is the degree of the grain-size curve peak on a graph where a sharp peak is leptokurtic or a flat peak is platykurtic (Boggs, 1987). These analytical parameters are provided on most core logs and lithological descriptions.

In order to better understand Holocene geology and the inner continental shelf in offshore Alabama, the GSA, in cooperation with the U.S. Geological Survey, compiled existing sediment data and collected new beach and offshore vibracore data in 1990 and 1992 (Hummell, 1996). Offshore work was done onboard the *R/V Deborah-B* operated by the Dauphin Island Sea Lab.

Table 1.—Grain-size scale for sediment (modified from Boggs, 1987).

Phi Scale (Φ)	**Range (metric)**	**Range (inches)**	**U.S. Standard sieve mesh (minimum retained)**	**Wentworth size classification**
< -8	>256 mm	> 10.1		Boulder
-6 to -8	64-256 mm	2.5 – 10.1		Cobble
-5 to -6	32 – 64 mm	1.26 – 2.5		Very coarse gravel
-4 to -5	16 - 32 mm	0.63 – 1.26		Coarse gravel
-3 to -4	8 – 16 mm	0.31 – 0.63		Medium gravel
-2 to -3	4 – 8 mm	0.157 – 0.31	5	Fine gravel
-1 to -2	2 – 4 mm	0.079 – 0.157	10	Very fine gravel
0 to -1	1 – 2 mm	0.039 – 0.079	18	Very coarse sand
1 to 0	0.5 – 1 mm	0.020 – 0.039	35	Coarse sand
2 to 1	0.25 – 0.5 mm	0.010 – 0.020	60	Medium sand
3 to 2	125 – 250 µm	0.0049 – 0.010	120	Fine sand
4 to 3	62.5 – 125 µm	0.0025 – 0.0049	230	Very fine sand
8 to 4	3.9 – 62.5 µm	0.00015 – 0.0025		silt
> 8	< 3.9 µm	< 0.00015		clay

Since the Gulf Task Force was established, several investigations have been performed by the GSA ranging from the assessments of existing data to the collection and evaluation of new data (Bearden and others, 1987; Parker, 1988, 1989, 1990; Parker and others, 1993; Hummell and Smith, 1995, 1996; Hummell 1997; Kopaska-Merkel and Rindsberg, 2002, 2005; Rindsberg and Kopaska-Merkel 2006).

Table 2.—Terminology describing phi standard deviation or grain-size distribution (modified from Boggs, 1987).

Folk classification	Standard Deviation
very well sorted	<0.35 Φ
well sorted	0.35 to 0.50 Φ
moderately well sorted	0.50 to 0.71 Φ
moderately sorted	0.71 to 1.00 Φ
poorly sorted	1.00 to 2.00 Φ
very poorly sorted	2.00 to 4.00 Φ
extremely poorly sorted	>4.00 Φ

Table 3.—Terminology describing the skewness in the grain-size distribution curve (modified from Boggs, 1987).

Folk classifaction	Skewness
strongly fine skewed	> + 0.30
fine skewed	+ 0.30 to + 0.10
near symmetrical	+ 0.10 to - 0.10
coarse skewed	- 0.10 to - 0.30
strongly coarse skewed	< - 0.30

Other notable investigations specific to sand deposits for offshore Alabama include an environmental survey of potential dredge sites in federal waters funded through INTERMAR (Byrnes and others, 1999), state waters bottom investigations funded by the city of Gulf Shores (Olsen, 2001), and a state and federal waters investigation funded through the city of Orange Beach, the Alabama Department of Conservation and Natural Resources' Gulf State Park, and the city of Gulf Shores (Olsen, 2003b; 2006b). A primary source for offshore sand resource data is Olsen Associates, Inc. (Olsen). Olsen serves as the Engineer-of-Record responsible for the design, permitting, and engineering study for the engineered beach fronting Orange Beach, Gulf State Park, and Gulf Shores. Although Olsen has collected numerous vibracore and geophysical survey data mainly in state waters, some of their data does extend into federal waters and into MMS offshore study areas. Each sand investigation, in chronological order, is summarized below.

Bearden and others (1987) identified, evaluated, and interpreted existing geophysical data (high-resolution seismic and sidescan sonar) collected from offshore

Alabama and the OCS. Bearden and others (1987) identified three nonproprietary, high-resolution datasets: Fairfield Industries data for OCS Lease Sales 67 and 69 (1982); Intersea Research data for OCS Lease Sale 65 (1978); and Aquatronics data for OCS Lease Sale 32. The data collected by Fairfield Industries includes, in part, the current MMS Study Area extents.

Parker (1988, 1989, 1990) supplemented the geophysical data compiled by Bearden and others (1987) with existing bottom sediment samples and core data to provide a more comprehensive inventory of existing data. Although the focus of this study was nonhydrocarbon mineral resources, these data were used to develop generalized maps of potential sand deposits, ridge characterization, and a cross section of the Alabama shelf to estimate an offshore sand deposit (> 75 percent sand) volume of 31.8 billion metric tons of fine- to medium-grained sand (Parker, 1990). Further, many of the sediment samples were associated with the geotechnical investigations of the Mobile Bay navigational channel and hydrocarbon production on and adjoining the Mobile Bay ebb-tidal delta. Sediment data used to assess offshore Alabama sand were very sparse and were mainly characterized with qualitative descriptions.

Parker and others (1993) identified areas of erosion along the gulf-fronting shoreline; delineated five offshore sand resource target areas (MMS Study Areas); delineated six lithofacies; conducted preliminary shelf circulation, human marine activity, and local benthic biota environmental analysis; and sought to characterize the possibility of a high-quality sand deposit in offshore Alabama. Sample collection mainly included sand ridges oblique to the Alabama coastline. Parker and others (1993) defined six lithofacies: (1) Graded Shelly Sand (GSS), (2) Clean Sand, (3) Dirty Sand, (4) Biogenic Sediment, (5) Muddy Sediment, and (6) Pre-Holocene. Their study indicates that the Holocene deposits primarily represent Shelf Sand (reworked palimpsest sand deposits), Sand Ridge (crests and troughs embedded in the Shelf Sand), Bay/Lagoon, and Muddy Shelf depositional environments. It is important to note that Parker and others (1993) determined that high-quality beach-compatible sand exists within the most common GSS lithofacies (probable storm deposits with shelly, poorly sorted basal material) and the abundant Clean Sand lithofacies (median grain-size 2.07Φ (fine sand); mean standard deviation of 0.85Φ (moderately sorted)). The Clean Sand lithofacies was divided into the orthoquartzite, sand with mud burrows, echinoid sand, and shelly sand (SHS) microfacies. Based on limited sample locations and analysis, the authors were unable to determine a distribution pattern within the MMS Study Areas; although they suggested that in Shelf Sand and Sand Ridge environments, ridge crest and upper flanks are represented by GSS, Echinoid Sand, or SHS.

Between 1994 and 1997, GSA sand resource investigations involved MMS Study Area 4, which is located south of Dauphin Island and southwest of the Mobile Bay ebb-tidal delta. Hummell and Smith (1995) assessed MMS Study Area 4 due to the lease potential for use on Dauphin Island sand restoration projects. Dauphin Island shoreline erosion was assessed and sand volume needs were estimated. Using existing and new data including grain texture and size analyses, lithofacies patterns, and 3-dimensional distribution of sediment type, potential sand deposits areas were determined to be within the ebb-tidal delta, shelf sand sheet, and shelf sand ridges (Hummell and Smith, 1995). Although horizontal and vertical lithofacies transitions were documented within MMS Study Area 4, the authors determined a viable medium (1.39 Φ), moderately sorted (average standard deviation 0.89 Φ) sand source (GSS Lithofacies) located in a sand ridge in the east-central portion of MMS Study Area 4 having an estimated volume of 30 million cubic yards (yd^3). A limited, preliminary evaluation of the impact of dredging this resource on shelf circulation, ongoing human marine activity, and local benthic biota was completed.

Hummell and Smith (1996) further assessed the geometry and granulometric characteristics of a sand ridge in the east-central portion of MMS Study Area 4 by collecting 10 vibracores and 10 bottom sediment samples to supplement existing data. Lithofacies determined in this area were the GSS, Clean Sand (orthoquartzite microfacies), Dirty Sand (muddy shelly sand and muddy sand microfacies), Biogenic Sediment, Muddy Sediment, and Pre-Holocene. The GSS Lithofacies sand ridge deposit was further evaluated and the authors determined a viable medium (1.31 Φ), moderately sorted (average standard deviation 0.93 Φ) sand source with an estimated adjusted volume of 15.5 million yd^3 (Hummell and Smith, 1996). GSS always preceded the deposition of Dirty Sand lithofacies.

Hummell (1997) assessed the feasibility of hydrographic numerical modeling of MMS Study Area 4 and began the development of datasets that support hydrographic modeling. In general, this effort included research and documentation of historic tropical storms that affected the Alabama coastline and historic channel dredging practices and resulting offshore disposal, and development of bathymetric differencing maps between 1732 and 1997, mainly in association with MMS Study Area 4 and Dauphin Island. No new bottom sediment samples were collected.

Expanding on the work by Parker (1990) and Parker and others (1993, 1997) that focused on shelf ridges and oblique bars (transverse bars) offshore Baldwin County, Hummell (1999) focused additional offshore Alabama sand research on the east Alabama inner continental shelf, specifically the surficial sand sheet (SSS) locally present in MMS Study Areas 1 through 3.. In order to further characterize and delineate the SSS and better understand the distribution of coarse sand found on the crest of oblique sand ridges by Parker and others (1997), vibracore and bottom grab samples were collected south of Morgan Peninsula to Perdido Pass. Additional vibracores and bottom grab samples were collected in MMS Study Area 4 to examine the impact of tropical storms. Ten lithofacies were identified in the inner continental shelf sand sheet with emphasis placed on the characterization of the SSS. Although variations in the SSS were observed in cross sections and isopach maps developed for the project, the combined estimated sand volumes of the SSS lithofacies for MMS Study Areas 1 through 3 were calculated to be 564 million yd^3 and 1.18 billion yd^3 in state and federal waters, respectively (Hummell, 1999). This estimate assumes all SSS deposits are suitable for beach placement. Additional work during this study included an evaluation of the mud layer deposited by Hurricane Danny in MMS Study Area 4, as well as the collection of 29 beach profiles which followed Hurricanes Danny and Georges.

Under INTERMAR and driven by the OCSLA, Byrnes and others (1999) completed a comprehensive environmental survey of the five MMS Study Areas for offshore Alabama which included (1) the geologic, hydrodynamic, and biologic setting, (2) shoreline and bathymetric change analyses, (3) wave transformation modeling, circulation, and sediment transport (except MMS Study Area 5), (4) a biological field survey, and (5) a summary of likely sand borrow sites and assessment of the potential dredging impact to hydrodynamics, sediment transport, and the benthic and pelagic environments. Two field surveys that included Smith-McIntyre grab sampling occurred in May 1997 and December 1997. Through bathymetric differencing analysis, Byrnes and others (1999) found net sediment movement and ridge migration was to the west, seemingly a function of periodic storm impacts to shelf hydrodynamics. In addition to the sand resource area delineated by Hummell and Smith (1995, 1996) for MMS Study Area 4, Byrnes and others (1999) delineated a 1.94×10^6 square meter (m^2) potential borrow area within MMS Study Area 1, a 0.57×10^6 m^2 potential borrow area within MMS Study Area 2, and a 1.19×10^6 m^2 potential borrow area within MMS Study Area 3 based on shoal and geological characteristics.

Olsen (2001) reported on a sand search investigation that provided beach quality sand for the 2001 Gulf Shores, AL, Beach Restoration Project which involved the placement of about 1.6 million yd^3 of sand along a 3.1-mile segment of gulf-fronting beach within the city of Gulf Shores (Olsen, 2003a). Although the investigation was exclusive to state waters, the seismic and vibracore data collected provided valuable insight into transverse ridge sand deposits and complements all available data. Based on featureless returns, the seismic sub-bottom survey directed vibracore sampling of two transverse ridges (Olsen 2001). The analysis of native beach sand, collected from four transect locations extending from the back berm or toe of dune to gulfward of the longshore bar crest suggested offshore fining and sand with a median diameter range of 1.889Φ to 1.351Φ (coarse- to fine-grained sand), well sorted, and predominantly less than 1 percent of shell volume (Olsen, 2001).

In order to establish baseline beach sand characteristics, investigate spatiotemporal trends in sediment distribution, and evaluate abundance and condition of shells on natural and restored beaches, Kopaska-Merkel and Rindsberg (2002) performed quarterly and post-storm sampling following Tropical Storms Bertha, Hanna, and Isidore, which resulted in 240 sand samples, 66 shell samples, 255 field photographs, and 33 grain-size analyses. General observations from the impacts of the tropical systems mentioned above to the Alabama coastline were addressed; Tropical Storm Isidore was the most significant of these. Emphasis was placed on shell species and distribution in native and restored beach sand, and Kopaska-Merkel and Rindsberg (2002) reported that shell species found in native beach environment reflect species found on the restored beach and that sharp shell fragments were abundant in the sand used to restore the Gulf Shores Public Beach in 2001. Kopaska-Merkel and Rindsberg (2002) suggested separating shells from the sand prior to placement or to search further offshore (depths ≥ 30 feet) where seashell species contributing to sharp shell fraction are less abundant.

To investigate and identify offshore sand deposits needed to support the restoration of about 11.6 miles of shoreline with about 6.0 million yd^3 of beach-compatible sand on Orange Beach, Gulf State Park, and Gulf Shores, Olsen (2003b) directed the collection of offshore sediment data. Based upon beach sand characteristics (see Olsen, 2001), sand can generally be described as fine- to coarse-grained, well-sorted quartz sand with less than 1 percent seashell content (Olsen, 2003b). Using previous and new geotechnical analysis, Olsen (2003b) delineated four sand resource borrow sites in state waters (table 4). Ultimately, sand dredged from Borrow Sites 1, 2, and 3 were used to construct the “2005-2006 Orange Beach/Gulf State Park/Gulf Shores Beach Restoration Project” using about 7.94 million yd^3 of sand on 15.3 miles of shoreline (Olsen, 2006a).

Table 4. General summary of state water borrow sites (Olsen, 2003).

Borrow Area	Location	Area (acres)	Estimated Volume (yd^3)	Grain Size (average; mm)	Color (average in-situ)	Shell Content (percent)
1	Perdido Key	156	3,000,000	0.28	10YR 8.3/0.6	3.5
2	Gulf State Park	189	3,800,000	0.28	10YR 8.4/0.7	3.0
3	Gulf Shores	179	3,400,000	0.29	10YR 8.0/0.8	4.7
4	West Gulf Shores	131	2,000,000	0.24	10YR 7.5/0.5	5.4

Kopaska-Merkel and Rindsberg (2005) collected and sieved 73 sand samples taken from 18 beach locations to examine spatiotemporal trends mainly as a function of seasonal cycles, variation alongshore, urbanization, and storms and compared these data to grain-size data representing MMS Study Areas 1 and 2 from previous investigations. In addition, seashells were collected in the windrow and surf zone, a sediment density of living *Donax* surf clams was made, and general offshore bar and beach cusp observations were recorded. Notable findings include: (1) Alabama beach sand is well to very well sorted, medium- to coarse-grained (average diameter of 331 µm), and positively skewed (table 3), (2) variations in longshore bar morphology and urbanization cause Baldwin County beach sand to coarsen westward, (3) GSS and Clean Sand lithofacies were predominant in MMS Study Areas 1-3, and (4) offshore sand deposits suitable for beach nourishment include the GSS lithofacies and, to a lesser extent, the Shelly Sand (SHS) lithofacies (Kopaska-Merkel and Rindsberg, 2005). Kopaska-Merkel and Rindsberg (2005) constructed a new surface lithofacies distribution map characterizing MMS Study Area 1 and much of MMS Study Areas 2-4 (fig. 2).

Rindsberg and Kopaska-Merkel (2006) further examined MMS Study Areas 1 and 2, which are characterized by an oblique sand ridge field. Through a quantitative analysis of archived vibracore sediment collected in and around MMS Study Areas 1 and

2 (Hummell, 1990, 1999; Parker and others, 1997) and the application of a more recent bathymetric interpretation, the authors correlated bottom geomorphology (swales and oblique ridges) to the distribution of lithofacies, notably the GSS, SHS, and Sand with Mud Burrows. No new offshore or beach sediment samples were collected for this study, but through further analysis of existing sediment their work indicated that the oblique sand ridges are underlain by GSS and SHS lithofacies. Further, Rindsberg and Kopaska-Merkel (2006) divided the ridge field into the inner, outer, and middle geomorphic zones. Ridges within the state water inner zone are very similar to native beach sand and this resource has been used on engineered beaches (Olsen, 2003a, 2006a).

Olsen (2006b) conducted an exploratory geotechnical sand search to identify additional offshore sand reserves to support future maintenance of the engineered beaches along the Baldwin County coastline. Their findings included the expansion of Borrow Sites 1, 2, and 3 (Olsen, 2003b) for an estimated 3 million yd^3 of sand within state waters and the need for additional sampling in key areas. These areas include southeast of Borrow Site 2, the AL/FL State Line, and south of Perdido Pass in state waters and within federal waters south Baldwin Shoal and southwest North Perdido Shoals (fig. 2). As previously noted, (Olsen, 2003b), beach quality sand is generally found on nearshore ridges and shoals; featureless areas, troughs and swales tend to have increased fines and shells. The MMS Study Area 3 is located on the Baldwin Shoal but the North Perdido Shoals is located about 10 miles southeast of MMS Study Area 1. It should be noted that Olsen (2006b) reported that current dredging technology limits sand dredging to waters with a maximum depth of -100 ft North American Vertical Datum of 1988 (NAVD88). Olsen (2006b) noted that a small quantity of beach-compatible sand exists within MMS Study Area 1 at sample location BC06-23; the vibracore was collected on the southeastern end of an oblique sand ridge containing Borrow Site 3 within state waters. Within MMS Study Area 3, Olsen (2006b) verified beach-compatible sand within locations BC06-44 and BC06-46; a vibracore collected on the northeastern part of the Baldwin Shoal revealed beach quality sand but with an increase in shell content and grayness.

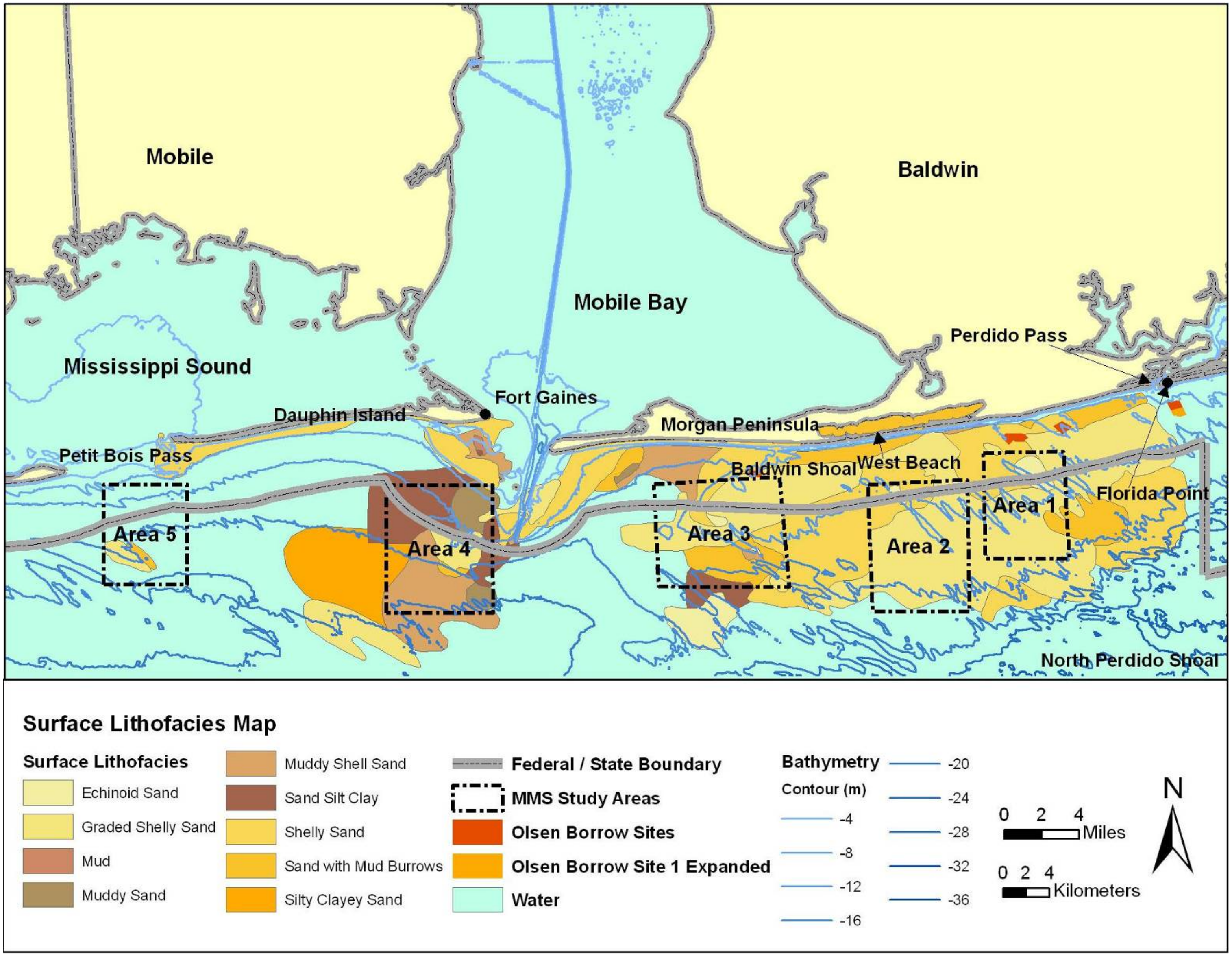

Figure 2.—Surface sediment texture of the inner Alabama shelf (modified from Parker and others, 1993; Kopaska-Merkel and Rindsberg, 2005).

SHORELINE EROSION STUDIES

Consideration and development of sand deposit target areas involves not only the location of previous beach restoration projects and the identification of borrow sites but also the location of areas of chronic beach erosion. Beach recession threatens developed areas as well as essential habitat. In an early study, Parker (1993) determined from 1985 and 1955 aerial photography that the east end of Dauphin Island was receding and that 1.85 million yd^3 of sand was needed to reestablish the beach to its 1955 location. Although Parker (1993) was unable to evaluate erosion of west Dauphin Island, slight erosion was identified westward of Perdido Pass and Little Lagoon Pass and sand placement volumes were determined.

Using the Digital Shoreline Analysis System (DSAS), an extension to the Environmental Systems Research Institute Inc. (ESRI®) ArcGIS® platform that models and determines shoreline change rates and statistics from various historical shoreline vectors, Morton and others (2004) concluded that (1) short-term recession occurred on the western half of Dauphin Island at a rate ≤ -4.7 m/yr, (2) accretion of 3 kilometers of Dauphin Island that adjoins Petit Bois Pass occurred due to island growth, and (3) Morgan Peninsula and Perdido Key were characterized as stable due to beach restoration and an active littoral system. Long-term periods modeled and validated through linear regression were 1849-1867, 1918-1957, 1978-1981, and 2001; short-term periods modeled were 1978-1981 and 2001 as derived from end-point rates (Morton and others, 2004).

Since 2006, the GSA has developed shoreline vectors from recent orthophotography and from the conversion of historic contact prints to orthophotography using the Earth Resources Data Analysis Systems (ERDAS) IMAGINE® V9.0 AutoSync™ module and has modeled shoreline change using DSAS (Jones and Patterson, 2006, 2007; Jones and Darby, 2008, 2009). Positive and negative changes to gulf-fronting beaches, as monitored through the "Alabama Beach Monitoring Program," mainly depict changes due to engineered beach restoration and tropical storm impacts and associated recovery as documented by Jones (2004, 2005), Jones and Patterson (2006, 2007) and Jones and Darby (2008, 2009). In contrast to the short- and long-term periods established by Morton and others (2004), short-term and long-term shoreline vectors used by the GSA for DSAS modeling range from 1997 – 2007 and 1978 – 2007, respectively (Jones and Darby, 2009). Long-term analysis does not reflect the same historical period found in Morton and others (2004).

Although much of the shoreline trend remains uncertain or statistically invalid, Jones and Darby (2009) quantified short-term recession of the western extremity of Morgan Peninsula (-5.3 to -53.7 ft/yr). Long-term results reflect less erosion as illustrated in figure 3. Long-term DSAS data quantified a mean shoreline change rate of -6.6 ± 3.5 ft/yr and a mean erosion rate of -10.9 ± 4.0 ft/yr for the western end of Morgan Peninsula (fig. 3); transects with the highest erosion values occurred in the western extremity of Morgan Peninsula, ranging between -37.5 and -6.3 ft/yr. Although the long-term DSAS mean suggests a degree of uncertainty (-1.9 ± 3.8 ft/yr), 65 percent of the transects for eastern Dauphin Island have strong regression values (fig. 4). Based on short-term data, recession was also documented on the eastern end of Dauphin Island with a mean erosion rate of -9.3 ± 5.7 ft/yr and a maximum rate of -19.2 ± 2.9 ft/yr, and erosion of the western extremity of the island between -10.8 and -70.8 ft/yr. The highest erosion was -18.1 ± 3.0 ft/yr at the southeastern tip of Dauphin Island. Although areas exist within western Dauphin Island for which long-term data support a recessional trend between -14.8 ± 3.7 and -5.2 ± 4.6 ft/yr, the overall long-term trend is uncertain along this undeveloped portion of the Dauphin Island sand spit. The long-term shoreline change trend for the western extremity of Dauphin Island adjoining Petit Bois Pass suggests growth in island length and width. In agreement with Morton and others (2004), accretion ranging between 20 to 75 ft/yr of the western extremity adjoining Petit Bois Pass suggests growth in island width and length. In summary and as determined through short- and long-term DSAS modeling, the greatest need for sand replenishment for chronically eroding shorelines is at west Morgan Peninsula, east Dauphin Island, and sections of the Dauphin Island sand spit.

RECENT BEACH RESTORATION PROJECTS

Parker and others (1993) prioritized gulf-fronting shoreline restoration areas as eastern Dauphin Island, the west side of Perdido Pass, and the west side of Little Lagoon Pass. Each of these areas has received sand placement whether by engineered design or best management practices of dredged maintenance material as documented in the Alabama Sand Placement Inventory (Jones and Darby, 2009). Historically, sand has been placed along the Alabama coastline at only select locations as part of beach nourishment projects, emergency berm construction, post-storm recovery of overwash deposits, and placement due to channel or canal maintenance activities.

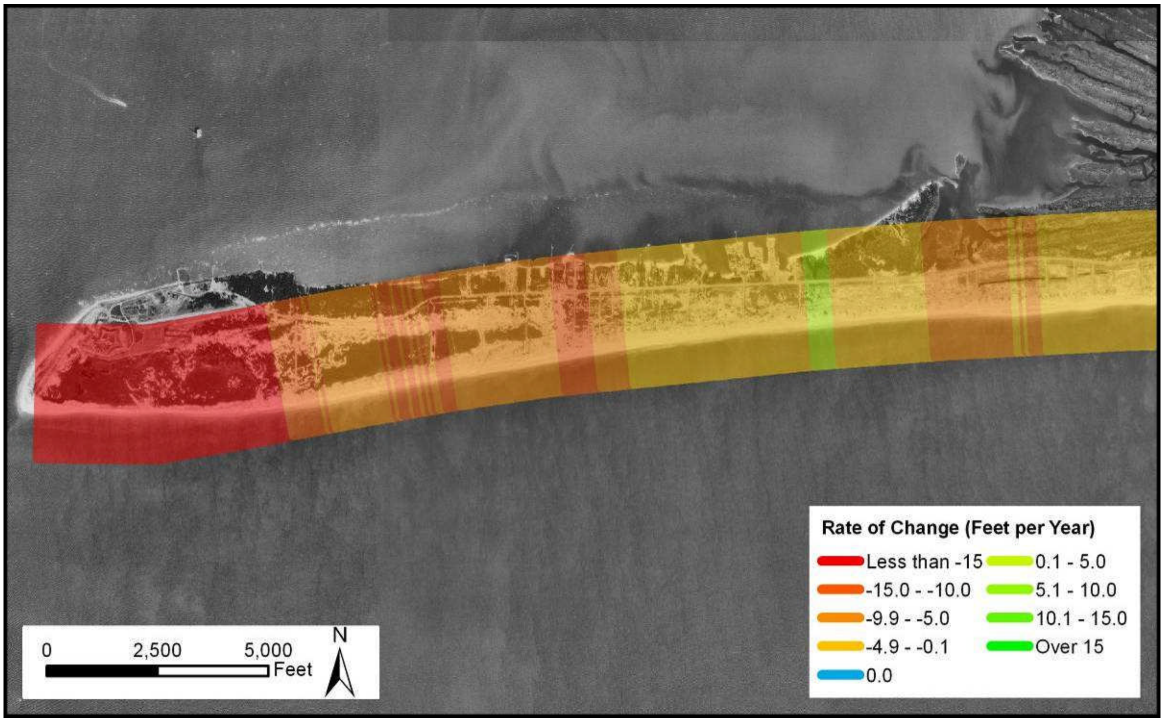

Figure 3.--Illustration of long-term DSAS results, Morgan Peninsula, Alabama (Jones and Darby, 2009).

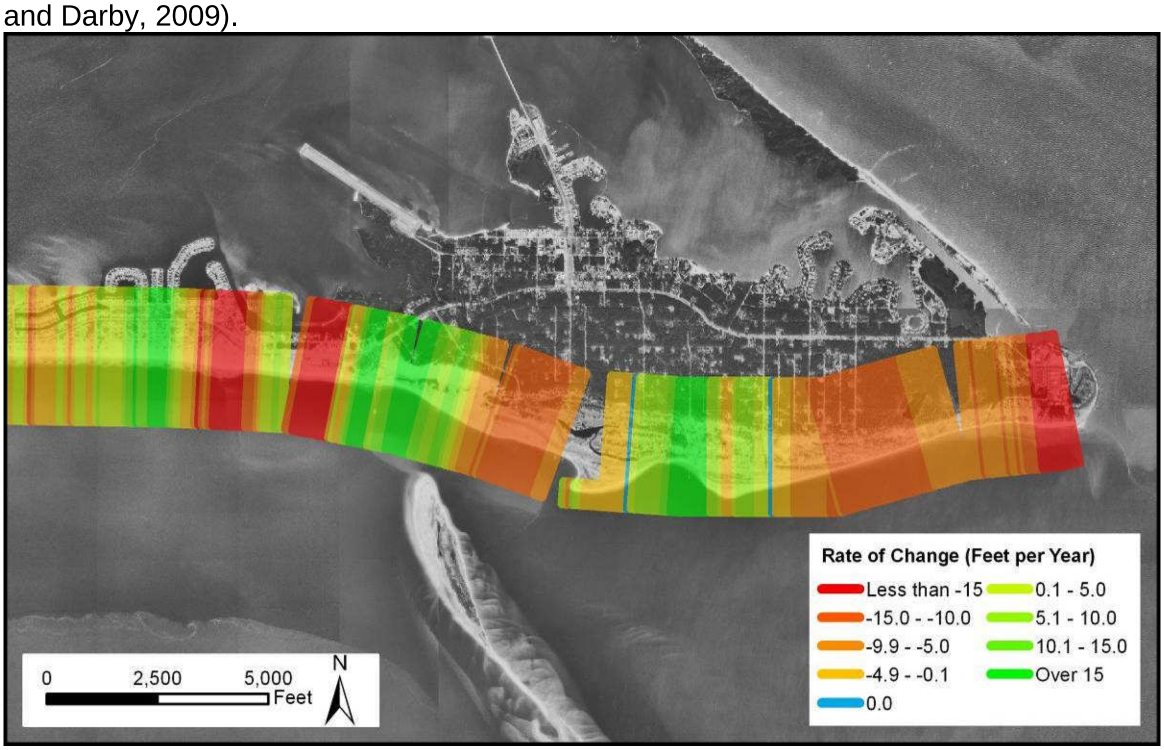

Figure 4.--Illustration of long-term DSAS results, eastern Dauphin Island, Alabama (Jones and Darby, 2009).

Much of the developed areas of Dauphin Island have directly or indirectly received sand placement through storm recovery, berm construction, and maintenance dredging. Sands used on engineered beach nourishment projects were mined from state waters, offshore Alabama. Figure 5 is a generalized map depicting the most recent sand placement activities along Alabama's gulf-fronting shoreline.

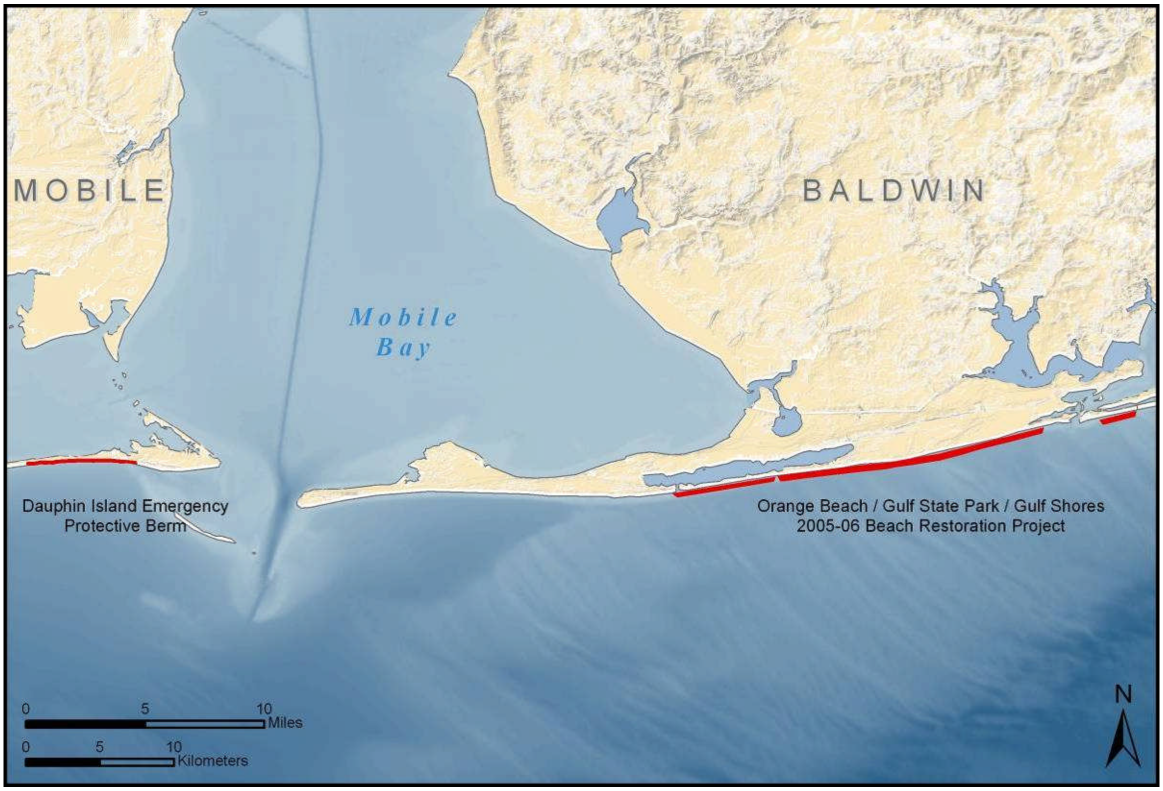

Figure 5.--Approximate location of recent sand placement, Baldwin and Mobile Counties, Alabama.

Large-scale beach nourishment projects have occurred mainly in Baldwin County for the purposes of widening beaches, recovering loss due to storms, making the beaches more aesthetically pleasing, and providing and protecting habitat areas. A number of projects have been completed in recent years. The most recent project was the Orange Beach/Gulf State Park/Gulf Shores 2005-2006 Beach Restoration Project where 7,940,000 yd^3 of offshore sand was dredged and placed on about 15.3 miles of shoreline (Olsen, 2006a). Jones and Patterson (2007) reported other notable projects and their estimated sand placement volumes as follows:

- Gulf Shores, AL, 2001 Beach Restoration Project (1,635,000 yd^3)
- West Beach Gulf Shores 2003 Emergency Beach Fill Project (850,000yd^3)
- Florida Point Habitat Restoration Project (561,000 yd^3)

According to Ms. Elizabeth Godsey (personal commun., U.S. Army Corps of Engineers (USACE), October 23, 2007), the Dauphin Island Emergency Protective Berm was completed on May 18, 2007, using a borrow site north of Dauphin Island in Mississippi Sound; the project was completed with an approximate length of 19,500 feet and volumes of 562,032 yd^3 (gross) and 432,866 yd^3 (net) (USACE, 2006a). Figure 6, an oblique aerial photograph provided by Dr. John Dindo (personal commun., Dauphin Island Sea Lab, March 4, 2008) illustrates the berm construction process. Prior to this project, the most notable engineered sand placement on Dauphin Island was the protective beach berm constructed in 2000 west of the public beach using about 300,000 yd^3 of sand (Jones and Patterson, 2007; USACE, 2000).

Figure 6.--Dauphin Island Emergency Berm construction.

METHODS

This resource assessment was primarily based on data mining; data development; the compilation of geotechnical, geophysical, and supplemental geographic information system (GIS) thematic layers and supporting raster data; and the construction of a web-based interactive mapping service. Although offshore geology is of primary importance, supplemental data such as oil and gas infrastructure, marine obstructions, and hazard areas are essential to compile with geological data to delineate and assess MMS Study Area sand resources potential. Because numerous geospatial data will decrease performance of web-based mapping applications, data not critical to this study were excluded from the web platform. Excluding proprietary geospatial data, all supplemental data are included in the accompanying DVD.

GEOSPATIAL DATA ACQUISITION

To promote GIS development, analysis, and visualization of data, a comprehensive geospatial database was developed. Largely represented by infrastructure, administrative, and biological geospatial data, supplemental thematic data are needed in the analysis of potential sand resource areas. This effort consisted of generating and retrieving external thematic layers as needed, compiling the data in a logical structure, and disseminating a comprehensive GIS database with Federal Geographic Data Committee (FGDC)-compliant metadata records. Sources for the various themes were found at several locations: (1) web-based downloads, (2) publications and databases found on CD-ROMs, (3) existing GIS data within the GSA agency, (4) networking with other state and local stakeholders, and (5) tabular and map “white-copy” publications.

As part of the networking effort, numerous government, academic, and private entities were contacted, directly or indirectly, for potential GIS thematic layers. Governing agencies with numerous references included the Minerals Management Service (MMS, 2006a, 2006b, 2008; Mr. Geoffrey Wikel, MMS, personal commun., November 6, 2008; Ms. Elizabeth Peuler, MMS, personal commun., November 6, 2008; Mr. Matt Frye, MMS, personal commun., February 9, 2009), the USACE (Davis and others, 1999; USACE, 1985, 2006a, 2008; Mr. Ronald I. Nettles, USACE Geotechnical & Dam Safety Section, personal commun., May 26, 2008; Ms. Rose Dopsovic, USACE contractor, personal commun., May 6, 2008; Mr. Gregory Dreaper and Mr. Larry Parson, USACE, personal commun., May 14, 2008; Mr. Donald K. Stauble, USACE Engineering, Research and Development Center, personal commun., September 24, 2008), the U.S. Geological Survey (USGS) (USGS Center for Coastal & Watershed Studies, 2004a, 2004b; Sanford and others, 2008a, 2008b; http://walrus.wr.usgs.gov/infobank/, http://woodshole.er.usgs.gov/operations/ia/), operating branches of the National Oceanic and Atmospheric Administration (NOAA) such as the National Ocean Service, National Geophysical Data Center (NGDC) (Ms. Robin Warnken, NOAA NGDC, personal commun., January 26, 2009; http://www.ngdc.noaa.gov/mgg/dat/), and the Coastal Services Center (CSC) (NOAA CSC, 2008), the Naval Surface Warfare Center (NSWC), Panama City Division (PCD) (NSWC PCD, 2008; Ms. Carmen Ferrer, NSWC PCD, personal commun., May 13, 2008), Louisiana Department of Natural Resources, Florida Department of Environmental Protection (FLDEP) (Dr. Jennifer Koch, FLDEP Bureau of Beaches & Dunes, personal commun., August 8, 2008), Mississippi Department of Environmental Quality (Ms. Barbara Yassin, personal commun., January 16, 2009), Alabama Department of Conservation and Natural Resources, Alabama Department of Transportation, and the Alabama State Oil and Gas Board. Academic sources included the University of New Orleans (Dr. Mark A. Kulp, personal commun., April 28, 2009), Louisiana State University (Dr. Harry Roberts, personal commun., December 14, 2007), University of Alabama at Birmingham (Dr. Scott Brande, personal commun., February 24, 2009), The University of Alabama (Dr. Andrew Goodliffe, personal commun., January 12, 2009), University of South Florida (Locker and others, 1999), University of North Carolina (Dr. Lou Bartek and Dr. Tony Rodriguez, personal commun., February 24, 2009), University of Southern Mississippi (Ms. Melissa Schneider, Mississippi-Alabama Sea Grant Consortium, personal commun., February 24, 2009), University of Texas at Austin (Dr. William "Bill" E. Galloway, Institute for Geophysics, personal commun., February 24, 2009), and University of South Alabama (Dr. Doug Haywick, personal commun., January 13, 2009). Private sources included Applied Coastal Research and Engineering, Inc. (Byrnes and others, 1999), Olsen Associates, Inc. (Olsen, 2001, 2003b, 2006b) and URS Corporation (Mr. Lyle Hatchett, personal commun., August 11, 2008). Entity contributions are reflected in this final summary report or metadata records.

In order to provide the most current bathymetric data for the MMS Study Areas, digital hydrographic survey data collected during 1982 through 1988, 1991, and 1992 were acquired from National Ocean Service Hydrographic Survey Data (NOAA NGDC, 2007b). The ASCII format data were converted to a triangulated irregular network for raster development and contours using Inverse Distance Weighted interpolation. The data were acquired with a horizontal datum of North American Datum 1983 (NAD83) and depth corrected to meters. Other bathymetric data incorporated into the project raster include the areas of Mobile Bay, Perdido Bay, and Mississippi Sound. These data were collected as part of the "Alabama Comprehensive GIS Inventory of Coastal Resources" project (Jones, 2006). Lower resolution bathymetric data (3 arc-second) was also processed (NOAA NGDC, 2007b) to provide coverage for the complete project extent.

DATA MANAGEMENT AND STANDARDS

Geographic Information System thematic development and modifications were performed using the Environmental Systems Research Institute, Inc (ESRI®) ArcGIS® ArcInfo® 9.3 platform; ArcCatalog™ and ArcToolbox™. These provided the necessary tools for data management and conversion. Other extensions used for project development or assessing data included ArcGIS Spatial Analyst™ and ArcGIS 3D Analyst™. The GSA maintained certain data format standards throughout this project to maximize compatibility and efficiency. Vector data, consisting of points, lines, or polygons, were created in or converted to the ESRI shapefile format. Raster data were stored in Tagged Image File Format (TIFF) or Earth Resource Data Analysis System (ERDAS™) IMAGINE's IMG format. Hyperlinked data were stored in Adobe™ Portable Document Format (PDF) due to both its widespread use and suitability to display single and multi-paged documents in a single file. The GSA used the freeware "Image capture and character recognition" (JOCR) Version 1.0 (EverRex Software, 2006) to capture and migrate analog tabular data into a digital format (for example, the conversion of grain-size data (Parker and others, 1993; McBride, 1997)). Adobe Photoshop™ CS3 was used for formatting hyperlinked raster data, such as tracklines and seismic scans. After digitization and file format conversion, the images were cleaned in Photoshop of stray pixels and color distortion and were optimized for both clarity and reduced file size. Throughout this process, the integrity of the original documents was maintained.

Geographic data from a wide variety of sources were used for both the GIS and the web map aspects of this project. As data were developed or collected, information about each dataset was entered into a database containing multiple categories and subdivisions. Also included in the database was additional information on each dataset, including scale, projection, originator, metadata status, etc. In this manner, the GSA was able to organize the data categorically, effectively identify redundant or unneeded datasets, and determine which datasets needed to be reviewed or updated. This database provided the basis for both file structure and design of the GIS project and the interactive web map.

The GSA worked to develop theme categories initially based on DataFinder Theme Categories, derived from the Minnesota Geospatial Data Categories and ISO 19115 topic category definitions (MetroGIS, 2003; FGDC, 2008). The objective was to create a layer scheme that can be all inclusive for geospatial diversity, yet retain a simple, logical, and manageable IMS platform. The category and subcategories are provided in table 5.

Table 5.--Project file structure and organization schema.

Human	Environmental	Geological/Geophysical	Baselayers
Administrative	Biological	Sediment	Study Area
Energy	Areas	Interpreted Geology	Physical
Cultural Resources	Hazards	Geophysical	Political
Infrastructure	Studies		Reference
			Raster

FGDC-compliant metadata (FGDC, 2008) was written for all datasets created by the GSA and, when absent, for those gathered from other sources. This process involved not only identifying the source of the data, but also documenting the process—if applicable—by which the GSA altered the data (additions, cropping, truncating of attribute table, etc.) for future reference. FGDC metadata standards ensure that users fully understand not only the origins of the data, but how the data has changed from its initial development to the final product.

All data in this project were created in or converted to the NAD83 horizontal coordinate system. This procedure was implemented to ensure all data had a common frame of reference and had the added benefit of allowing the software to operate more efficiently and quickly with no need to continuously convert between coordinate systems.

Within the ArcGIS project file (fig. 7), special consideration was given to the organization of the data layers. Data were organized according to the categories defined in our database. However, due to the nature of GIS, all datasets occupied the same area and, in many cases, directly overlapped. Datasets were organized so that the user would see only the base layers and a few selected datasets after opening the map. The user would then be able to select additional datasets to display as needed. The same method of organization and presentation was also used for the interactive map portion of the web site.

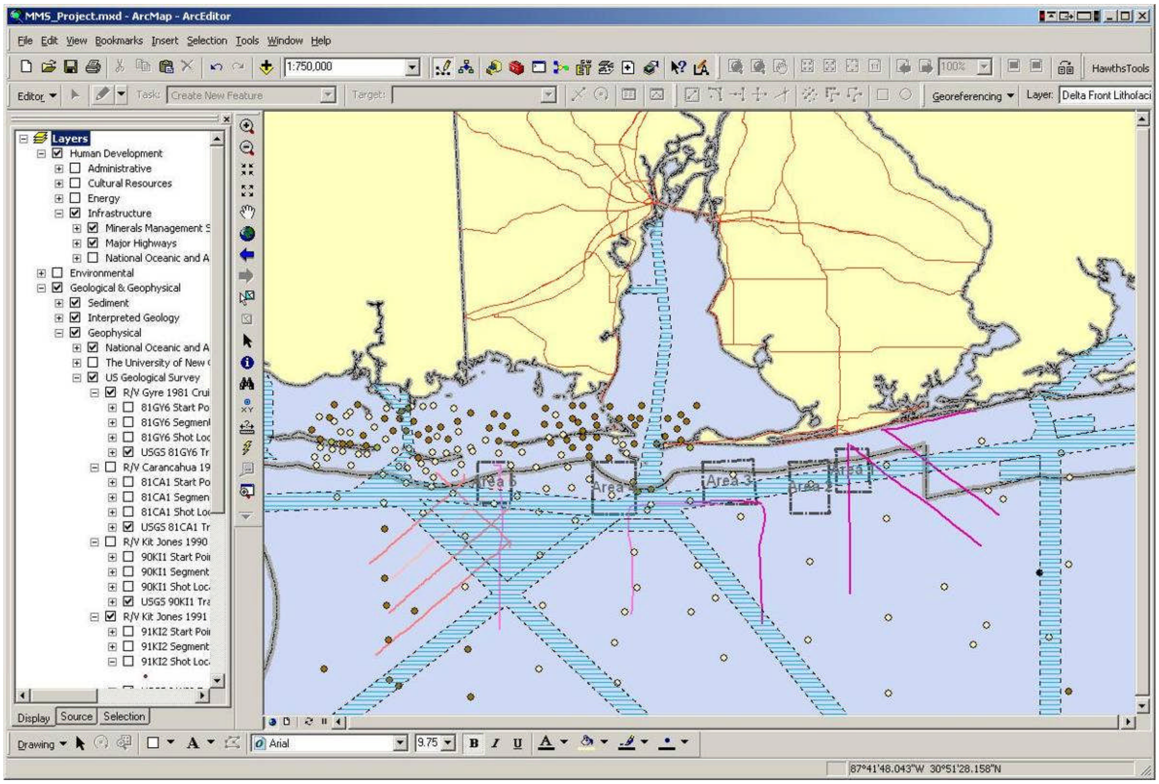

Figure 7.—Display of OASIS GIS.

WEB SITE APPLICATION

To facilitate project development and implementation, data storage, formatting and management, and software/hardware requirements, the GSA conferred with two governing agencies with existing web-based internet mapping services (IMS). The LASARD (Khalil and others, 2005) was reviewed in Baton Rouge, Louisiana, at the Louisiana State University Coastal Studies Institute (Mr. DeWitt Braud, personal commun., July 8, 2008) and at the LDNR (Mr. Syed Khalil, personal commun., July 8, 2008). Regarding LASED, project personnel met with Mr. James G. Flocks and Ms. Shawn Dadisman with the USGS, Center for Coastal Geology and Regional Marine Studies, located in St. Petersburg, Florida, on July 12, 2007. LASED is a very robust interface tool based upon Oracle databases maintained by the ESRI ArcSDE and stored on a Sun Enterprise E250 server (Dadisman and others, 2005).

The web site for the Offshore Alabama Sand Information System (OASIS) was created to contain historical sand resource reports published by the GSA and an interactive web map or IMS containing data the GSA has gathered for this project (fig. 8). The interactive map service is powered by ArcGIS Server™. This software communicates seamlessly with ArcGIS Desktop and provides convenient and efficient transfer of data between these applications. Currently, the project data are stored on a Dell PowerEdge server using Microsoft Windows Server 2003 web platform.

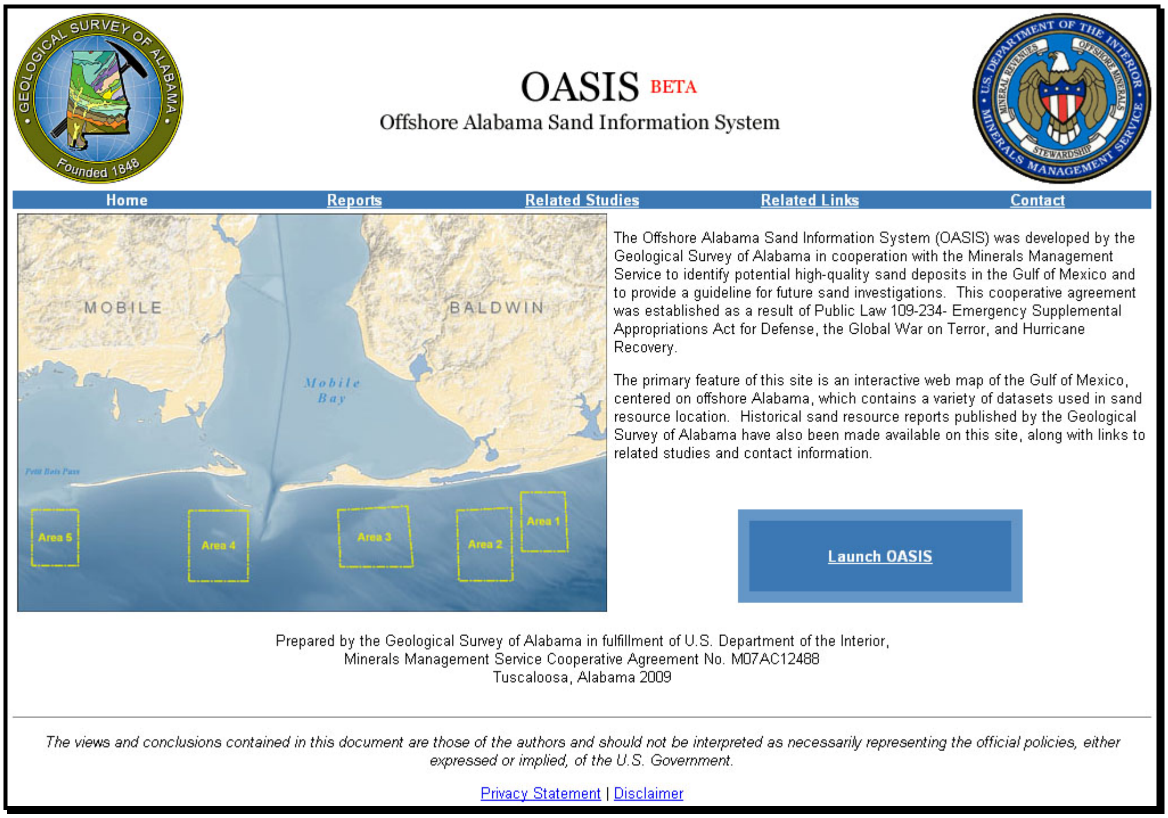

Figure 8.—The OASIS homepage.

STUDY AREA SETTING

COASTAL ALABAMA ONSHORE GEOPHYSIOGRAPHY

The coastal counties of Alabama lie within the Southern Pine Hills and the Coastal Lowlands districts of the East Gulf Coastal Plain section of the Coastal Plain physiographic province with alluvial-deltaic plain deposits confined within the Mobile River Delta (Sapp and Emplaincourt, 1975) (fig. 9). Adjoining study area waters, the Coastal Lowlands district is characterized by gently undulating to flat topography and is parallel to the shoreline of the GOM and Mobile, Perdido, and Bon Secour Bays. Alabama's coastline is restricted to Mobile and Baldwin Counties which are bordered to the west and east, respectively, by Jackson County, Mississippi, and Escambia County, Florida.

The most prominent geomorphological features above mean high tide along the Alabama coastline are Mobile Bay, Morgan Peninsula in Baldwin County, and Dauphin Island in Mobile County (figs. 1 and 9). Gulf-fronting recreational beaches align the southern edge of Morgan Peninsula and Dauphin Island. Chermock (1974) estimated at least 75 km (47 miles) of gulf-fronting beaches along the Alabama coast. In contrast, the National Atlas of the United States (2005) reports that Alabama has approximately 53 statute miles of general coastline and 607 statute miles of tidal shoreline. Regardless, all gulf-fronting Alabama beaches have been subjected to recent storm-induced erosion with beach loss and breaching still evident (Jones, 2005; Jones and Patterson, 2006; Jones and Darby, 2009). Mobile Bay, shared by Baldwin and Mobile Counties, is a main inlet and navigational thoroughfare into the GOM (fig. 1). Mobile Bay is a large submerged river valley (Chermock, 1974); the southern extent is the Mobile Bay ebb-tidal delta located at Mobile Pass. Mobile Pass is the inlet into the bay separated by Morgan Peninsula to the east and Dauphin Island to the west. Morgan Peninsula is an elongate spit or an attached progradational barrier extending from Gator Lake (western end of Little Lagoon) about 13 miles westward to the terminus within Fort Morgan State Park and is bounded by Bon Secour/Mobile Bay to the north, Mobile Bay pass to the west, and the GOM to the south (Otvos, 1997). Rodriguez and Meyer (2006) classified Morgan Peninsula as a beach-ridge strandplain characterized by two distinct oblique Holocene beach-ridge sets. Dauphin Island is a barrier island separated from mainland Mobile County by the Mississippi Sound.

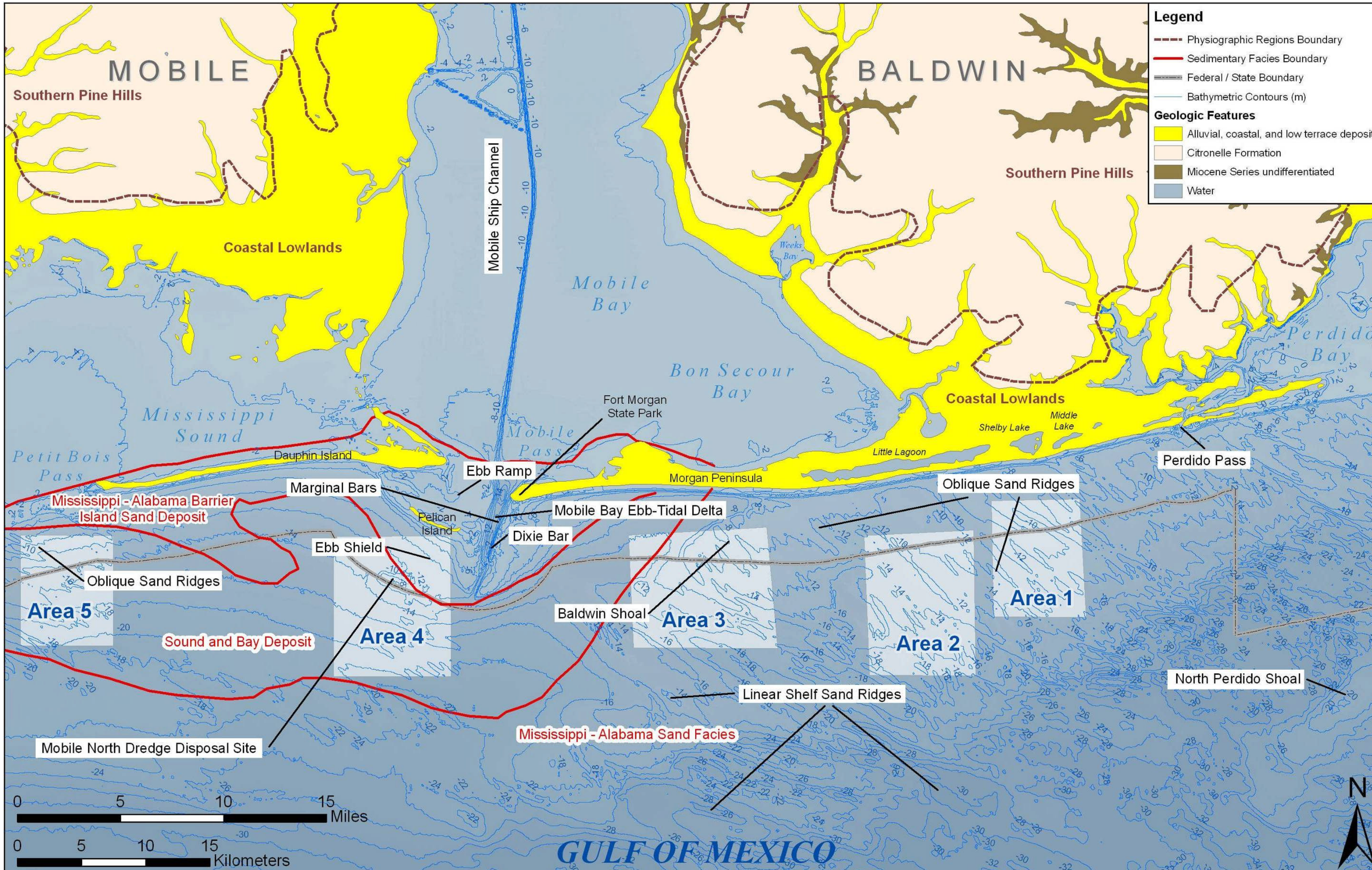

Figure 12.—Geophysiography of coastal Alabama (modified from Kopaska-Merkel and Rindsberg, 2005; Olsen 2006b; Parker and others, 1997; Sapp and Emplaincourt, 1975).

Although longshore growth of spits and development of emergent beaches offshore are the predominant modes of barrier origin (Bird, 1969), the eastern part of Dauphin Island originated as a Pleistocene hill (Vittor and Associates, 1985). The western spit is elongated primarily by the westward accretion of sand (Copeland, 1982; Jones and Darby, 2009).

OFFSHORE ALABAMA GEOPHYSIOGRAPHY

Littoral Alabama, which includes the study area, is within the east Louisiana-Mississippi-Alabama Shelf section of the Continental Shelf province (Copeland, 1982). Vittor and Associates (1985) divided the GOM continental shelf by geomorphology and classified the study area as part of the Mississippi-Alabama shelf. The shelf is characterized as broad and generally flat (5.5 feet/mile slope) and is bounded by the Mississippi River Delta to the west and Desoto Canyon to the east (Parker and others, 1997). The shelf, specifically the Mississippi-Alabama-Florida sand sheet (MAFLA) is dominantly terrigenous clastic sediments or sediments of fluvial origin reworked by coastal marine processes (Doyle and Sparks, 1980; Shultz and others, 1990; Locker and others, 1999). McBride (1997) related the sand sheet to sand deposition from an eroding shoreline during transgression.

Parker and others (1997) characterized and interpreted the inshore and foreshore sediments of Alabama's marine environment or Mississippi-Alabama-Florida sand sheet portion, subdividing the east Louisiana-Mississippi-Alabama shelf deposits into the sedimentary facies Mississippi-Alabama Barrier Island Sand deposit, Sound and Bay deposit, and the Mississippi-Alabama Sand facies (fig. 9). The Mississippi-Alabama sand facies consists mainly of well sorted medium to fine sand that occurs in areas subjected to slow deposition and erosion, where geomorphic change is predominantly by storm processes (Chermock, 1974). Dauphin Island and western Morgan Peninsula lie within the Mississippi-Alabama Barrier Island Sand deposit, central Morgan Peninsula lies within the Sound and Bay deposit, and the remainder of Baldwin County is within the Mississippi-Alabama Sand facies. MMS Study Areas 1 and 2 are within the Mississippi-Alabama sand facies, MMS Study Area 3 is predominantly within the Mississippi-Alabama sand facies with the northwest corner in the Sound and Bay Deposit facies, MMS Study Area 4 is predominantly within the Sound and Bay Deposit facies with only the northeast corner within the Mississippi-Alabama Barrier Island Sand Deposit, and MMS Study Area 5 is within the Sound and Bay Deposit facies (fig. 9).

The depositional history and stratigraphy of coastal Alabama are directly related to past cyclic recessions and transgressions (Johnson and others, 2002). Further, using core and radiometric dating, Hummell (1999) suggested that the Alabama inner continental shelf is a Holocene trangressive marine and fluvial-deltiac fill sequence overlying Pleistocene estuarine and fluvial-deltaic deposits. Holocene deposits on the Mississippi-Alabama shelf, mainly in the form of a sand sheet and sand ridges, are thought to be less than 50 feet thick (Chermock, 1974; Hummell, 1999). Prior to Holocene transgression, the inner continental shelf offshore Alabama was occupied by maritime forest, marsh habitat, and fluvial-deltaic systems (Hummell, 1996). Numerous north-, northwest- to south-, and southeast-trending late Quaternary channels or incised valleys, part of the Piedmont Mobile and Coastal Plain Fowl and La Batre fluvial systems, have been documented from seismic records on the Mississippi-Alabama shelf and beneath the Morgan Peninsula (Greene and others, 2007). Alternating transgressive and regressive processes, each terminating at various stratigraphic levels, result in different levels of channel cutting and infilling sequences. Offshore of Baldwin County, relict coastal geomorphology withstood the rising sea level, followed by Holocene fluvial-deltaic deposition and growth of oblique bars and linear sand ridges (Kopaska-Merkel and Rindsberg, 2005). The surface stratigraphy of the study area is Holocene coastal deposits of mainly fine- to medium-grained quartz sand and lesser amounts of shell fragments, silt, clay, organic debris, and heavy minerals; natural backshore and foredune surface sediment lithology consists predominantly of quartz sand ranging from 0.0626 to 2 mm in grain size (Parker, 1990; Parker and others, 1993). West of Mobile Bay Pass and on the south side of Dauphin Island, influx of sediment from Mobile Bay results in the nearshore deposition of sandy silt to silty clay; further south, silty to clayey sand is deposited (Hummell, 1996).

The most distinct submarine geomorphic features in the nearshore are the large Mobile Bay ebb-tidal delta, the “Baldwin Shoal (Ridge)” (Kopaska-Merkel and Rindsberg, 2005; Olsen, 2006b), and numerous shore-oblique sand ridges (shoreface-attached sand ridges and swales). Beach-compatible sand found in offshore Alabama has been associated with a shoreface-attached sand ridges or shoals (Olsen, 2006b). In addition to sand ridges, sand resources can occur in both relict and recent ebb-tidal shoals, compartmentalized within paleo-incised channels or as bar-finger sand, linear shoals, as well as within the nearshore sand sheet. The Mobile Bay ebb-tidal delta is channelized and has an adjoining subaqueous levee or shoal to the east (Dixie Bar) and subaerial shoaling along the western outer rim (Sand Island, Pelican Island). Observations of historical maps indicate that Dixie Bar can become subaerial and was termed Heron Island in 1825 (The University of Alabama, Geography Department; http://maplibrary.ua.edu). The largest shoal is an ephemeral, subaerial sand deposit called the "Pelican Island complex" (merged Pelican and Sand Islands) located on the western rim of the ebb-tidal delta. Because of recent northward migration, it is currently welded to Dauphin Island. Adjoining Morgan Peninsula is the Baldwin Shoal, a large relict landform (Rindsberg and Kopaska-Merkel, 2006) and the Mobile ebb-tidal delta on the west end (fig. 9). The Baldwin Shoal is thought to be a drowned spit formed with Morgan Peninsula or a relict ebb-tidal delta modified by channelization, fluvial erosion, and oblique ridge migration and sand sheet deposition (Parker and others, 1997; Rindsberg and Kopaska-Merkel, 2006). A large embayment is located north-northeast of the leading edge of Baldwin Shoal, south of Morgan Peninsula, and east of the ebb-tidal delta (Olsen, 2006b). The gulf bottom morphology is characterized by numerous oblique sand ridges superimposed on the sand sheet and relict geomorphic features, mainly offshore of Baldwin County. Oblique sand ridges, sometimes referred to as transverse bars, form mainly through storm processes (Parker and others, 1997; Kopaska-Merkel and Rindsberg, 2005). McBride (1997) divided the shelf into two zones. The project extent is within zone 1 (0 to 20 m deep) with higher order features (oblique sand ridges) superimposed on first order features (sand sheet) and zone 2 (20 to 50 m) defining the middle and outer shelf with two well-defined shoals parallel to the shelf break. Several linear ridges – an isolated ridge with a closed contour – are located within the shoreface-attached ridges and further offshore. McBride (1997) suggested mid-shelf linear shoals, such as the northeast-southwest-trending North Perdido Shoal, form as a result of relict Pleistocene topography.

The seafloor south of Dauphin Island contains few features and is best described as smooth. Within state waters, the bottom is sloping southward with a gradient between 8 and 10 feet per mile. Sediments south of Dauphin Island are predominantly fine- to medium-grained sand with grain size decreasing westward (McBride, 1997). The most prominent bottom features south of Dauphin Island are the Mobile ebb-tidal delta, shore-oblique sand ridges associated with Petit Bois Pass shoals, and the USACE dredge spoil disposal site (Mobile North) located south of Pelican Island.

RESULTS AND DISCUSSION

STUDY AREA CHARACTERISTICS

Parker and others (1993) delineated five preliminary resource sites or MMS Study Areas based on the location of receding shorelines, sediment distribution, location and subsequent analyses of surface and core sediment samples, and bathymetric maps. Surface areas were calculated for the MMS Study Areas for federal waters, state waters, and shipping fairways. The results, as determined and quantified through GIS analysis, are illustrated in figure 10 and tabulated in table 6.

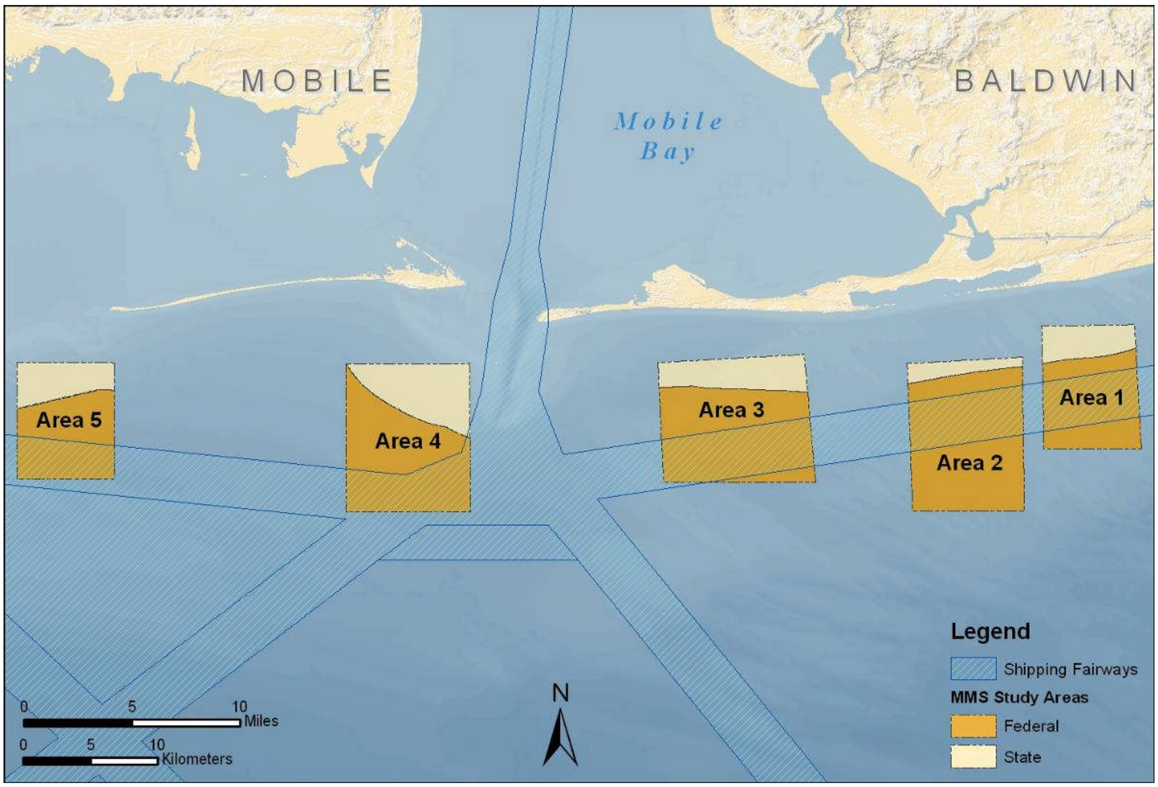

Figure 10.—Illustration of areas within federal and state waters and shipping fairways.

MMS STUDY AREA 1

MMS Study Area 1 (figs. 1 and 9) is located south of eastern Gulf Shores, Gulf State Park, and Shelby and Middle Lakes, Baldwin County, Alabama. Distance offshore from the shoreline to the northern boundary ranges between 2.9 kilometers (km)(1.8 miles (mi)) and 4 km (2.48 mi). The two-dimensional area of this site is about 5,625 hectares (ha) (21.7 square miles (mi^2)) with a perimeter of 30,604 meters (m). Of the total area, about 74.7 percent lies within federal water and 25.3 percent in state water (fig. 10; table 6).

Table 6.— Federal, state, and fairway area within each MMS Study Area.

MMS Area	Area	Acres	Hectares	Sq. Miles	Percent
Study Area 1	State	3,523.3	1,425.9	5.5	25.3
	Federal	10,377.5	4,199.7	16.2	74.7
	Total	13,900.8	5,625.5	21.7	100.0
	Fairway (Total)	5,554.2	2,247.7	8.7	40.0
	Fairway (Federal)				53.5
Study Area 2	State	1,914.4	774.7	3.0	9.4
	Federal	18,362.1	7,430.9	28.7	90.6
	Total	20,276.5	8,205.7	31.7	100.0
	Fairway (Total)	6,656.8	2,693.9	10.4	32.8
	Fairway (Federal)				36.3
Study Area 3	State	5,302.1	2,145.7	8.3	24.3
	Federal	16,479.5	6,669.0	25.7	75.7
	Total	21,781.6	8,814.7	34.0	100.0
	Fairway (Total)	8,509.5	3,443.7	13.3	39.1
	Fairway (Federal)				51.6
Study Area 4	State	6,797.7	2,750.9	10.6	31.4
	Federal	14,862.1	6,014.5	23.2	68.6
	Total	21,659.8	8,765.4	33.8	100.0
	Fairway (Total)	6,741.0	2,728.0	10.5	31.1
	Fairway (Federal)				45.4
Study Area 5	State	3,985.6	1,612.9	6.2	29.8
	Federal	9,398.7	3,803.5	14.7	70.2
	Total	13,384.2	5,416.4	20.9	100.0
	Fairway (Total)	4,438.1	1,796.0	6.9	33.2
	Fairway (Federal)	NA	NA	NA	47.2

The area within federal and state waters is about 4,200 ha (16.2 mi^2) and 1,426 ha (5.5 mi^2), respectively. The area calculated for this study was 596 ha (2.3 mi^2) lower than that reported by Parker and others (1993). The fairway area is about 2,248 ha (8.7 mi^2) or about 40 percent of the total MMS Study Area 1 and within federal water, about 54 percent. Bathymetry, relative to NAVD88, ranges between -16.2 m and -8.4 m with a mean depth of -12.3 m. Parker and others (1997) characterized bottom ridge geomorphology as shoreface-attached and detached (fig. 9) and suggested that much of the area is covered with medium- to fine-grained sand with sand deposits ranging between 4 feet thick in troughs to 13 feet thick in ridges. The three-dimensional rendering (fig. 11) developed for this study depicts several northwest-southeast-trending shoreface-attached, oblique ridges. Detached ridges are few in this study area. Illustrated in figure 12 are topographic transects A-A' and B-B' constructed normal to the trend of the oblique ridges. Profile B-B' depicts at least 7 distinct oblique ridges with variable relief between about 1 and 2 m. The offshore ridges reflected in B-B' converge northward into four distinct ridges (see A-A'), suggesting that several oblique ridges seemingly diverge further offshore. The relief ranges between about 1.5 and 4.5 m, the greatest of which is located in the northern half of MMS Study Area 2. In cross section, the ridges are generally symmetrical with an average wavelength of about 1,800 m on A-A' and decreasing southward to about 1500 m as determined from B-B'. Ridge steepness decreases northwestward as depth decreases. Although generalized as symmetrical, several ridges have weak southwesterly asymmetry which suggests southwest migration.

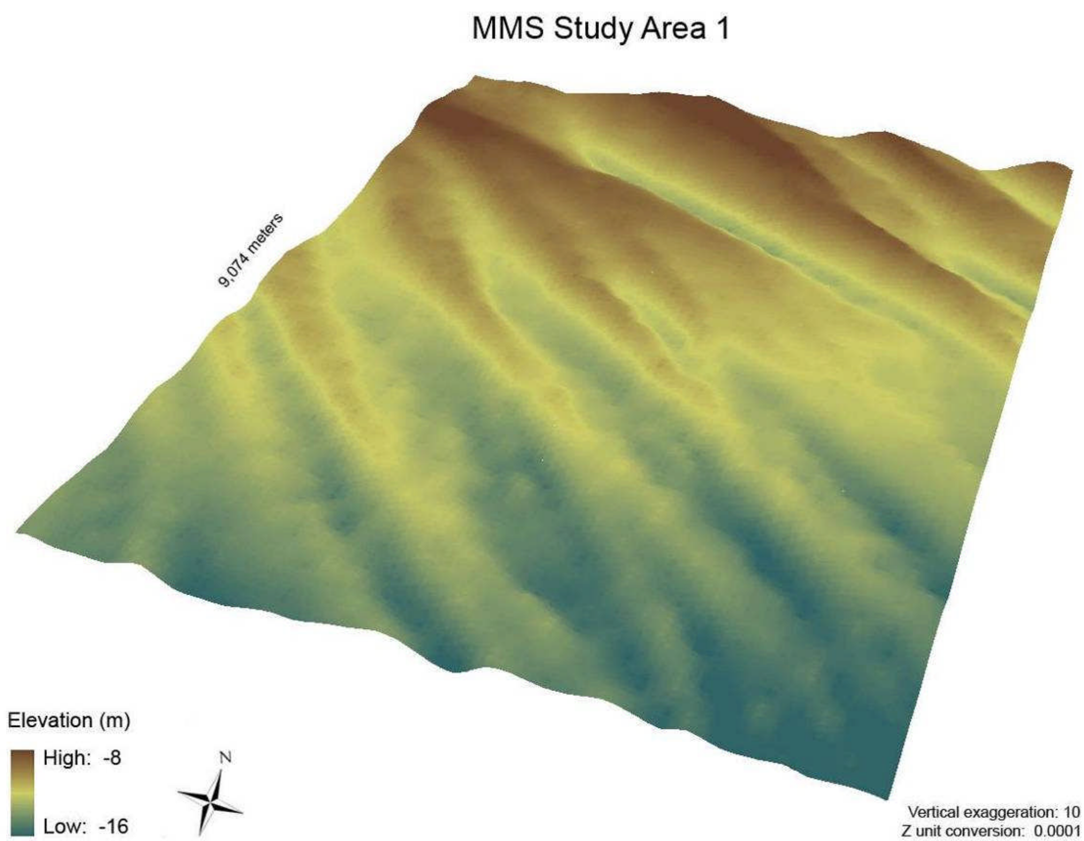

Figure 11.—Three-dimensional rendering of MMS Study Area 1.

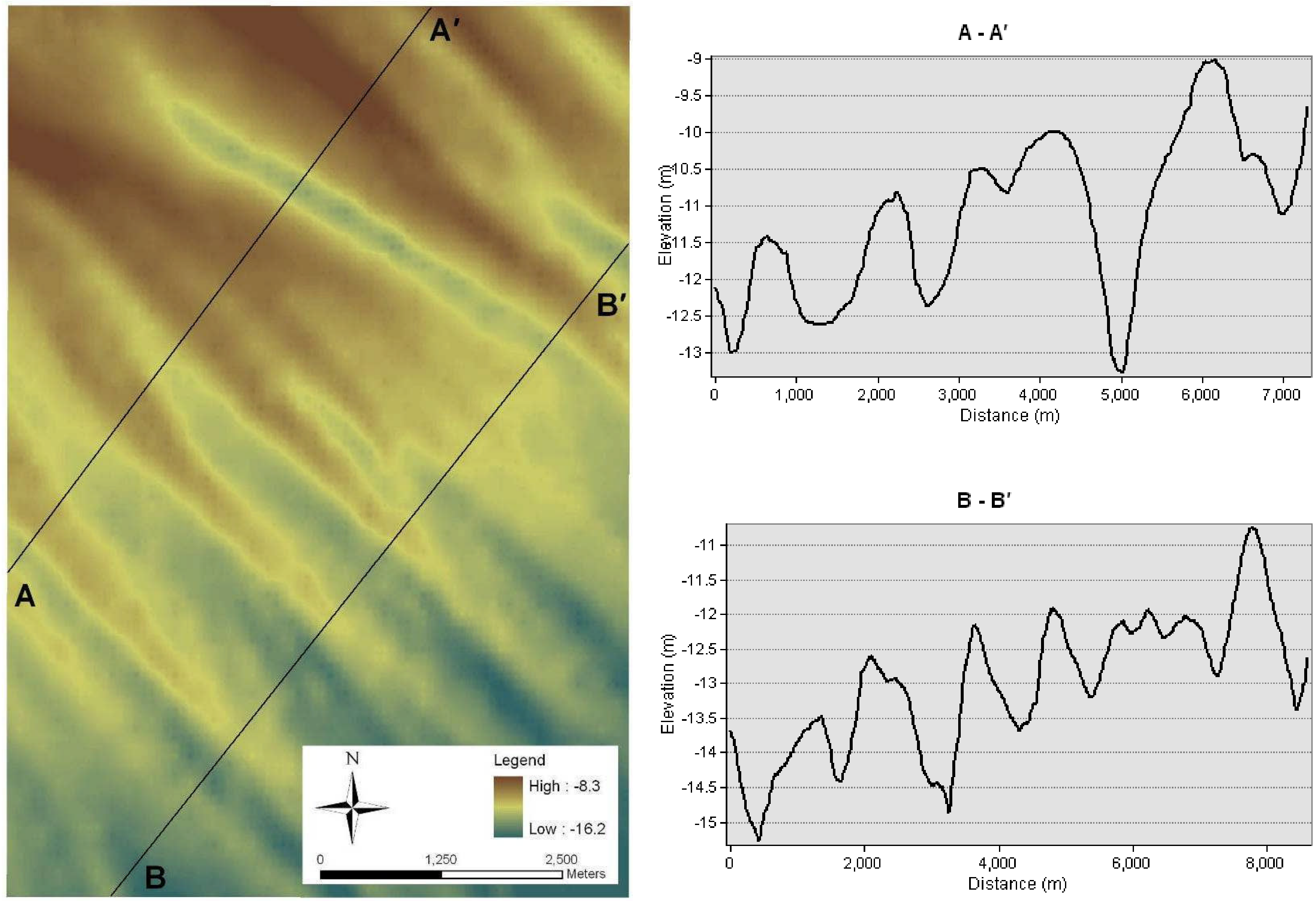

Figure 12.—Topographic profiles A-A' and B-B' for MMS Study Area 1.

MMS STUDY AREA 2

MMS Study Area 2 (figs. 1 and 9) averages about 4.5 km (2.8 mi) offshore to the northern boundary and is located south of Little Lagoon and the Gulf Shores municipality, Baldwin County, Alabama. With a perimeter of about 37,024 m, the two-dimensional area is about 8,206 ha (31.7 mi^2) and in agreement with Parker and others (1993). The area within federal and state waters is about 7,431 ha (28.7 mi^2) and 775 ha (3 mi^2), respectively. Less than 10 percent of MMS Study Area 2 is within state waters; about 91 percent lies within federal waters. The fairway area is about 2,694 ha (10.4 mi^2) or about 33 percent of the total surface area and 36 percent of the federal area (table 6; fig. 10). Bathymetry (NAVD88) ranges between -18.98 m and -9.2 m with an average depth of -13.83 m. As with MMS Study Area 1, but less abundant and mainly in the northeastern half, prominent northwest-southeast-trending shoreface-attached oblique ridges are present (fig. 13). Parker and others (1997) reported several ridges and troughs, (sand ridges and paleohighs) with much of the area covered in medium to fine sand and a range of sand thickness between about 1 and 17 ft. Numerous low relief oblique ridges are located in the southern half with increasing depth. Illustrated in figure 14 are topographic transects A-A' and B-B' constructed normal to the trend of the transverse bars. Profile A-A' reflects a moderate decrease in depth to the northeast. About seven oblique ridges are within this transect with relief ranging between 1.2 and 2.5 m and an average wavelength of about 1400 m. Profile B-B' depicts at least 12 distinct oblique ridges with variable relief between about 0.5 and 2 m and an average wavelength of about 800 m. Although a few offshore ridges reflected in B-B' converge northward (see A-A'), several taper into the nearshore as depth decreases. Most ridges are asymmetrical to the southwest suggesting westward transport of sediment and ridge migration. Ridge steepness decreases on the southwest flank as depth decreases.

MMS STUDY AREA 3

MMS Study Area 3 (figs. 1 and 9) is located south of Morgan Peninsula and the Bon Secour National Wildlife Refuge, Baldwin County, Alabama. The distance from the shoreline to the northern boundary ranges between 2.9 km (1.8 mi) and 3.9 km (2.4 mi). The two-dimensional area within federal and state waters is about 6,669 ha (25.7 mi^2) and 2,146 ha (8.3 mi^2), respectively, for a total surface area of about 8,815 ha (34 mi^2) and perimeter of 37,591 m (table 6; fig. 10). The area is in agreement with the calculated area by Parker and others (1993) of almost 35 mi^2. Like MMS Study Area 1, the federal and state distribution is about 24 percent and 76 percent, respectively. The fairway area is about 3,444 ha (13.3 mi^2) or about 31 percent of the total MMS Study Area 3 surface area or 52 percent of the federal area. Bathymetry (fig. 15; NAVD88) ranges between -18.89 and -7.1 m with a mean depth of -12.89 m.

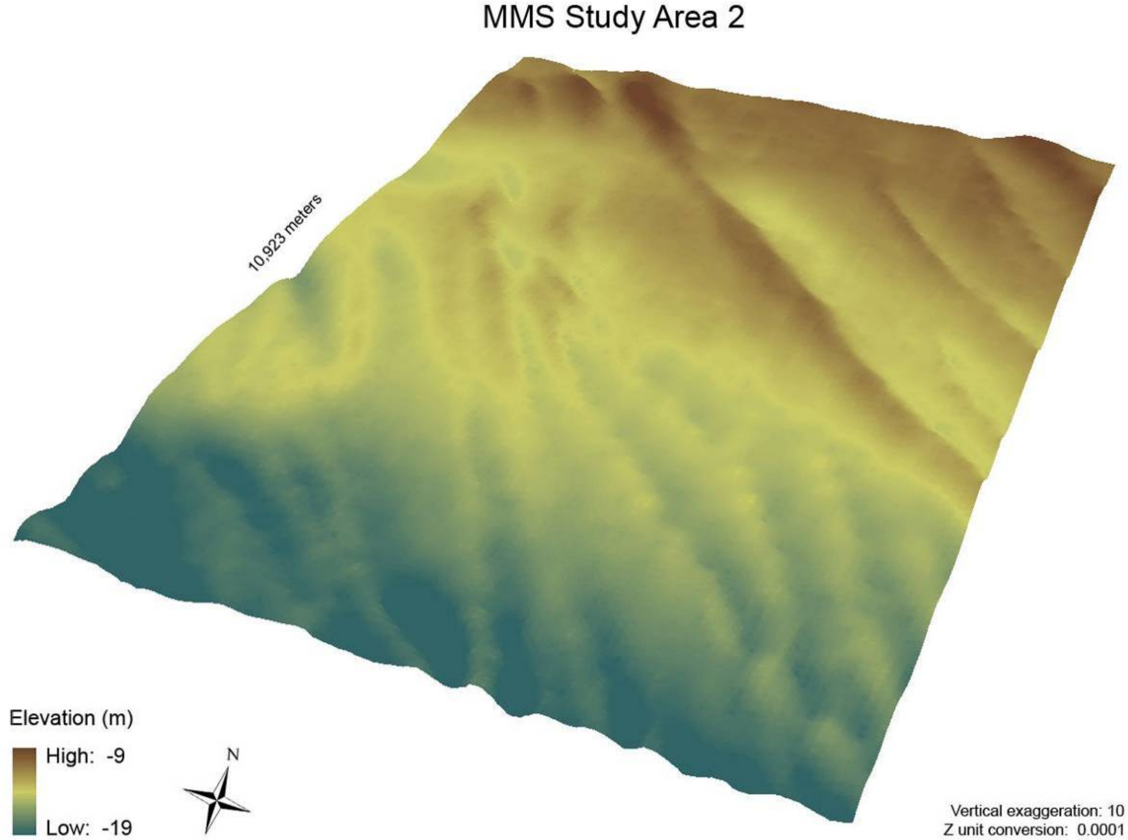

Figure 13.—Three-dimensional rendering of MMS Study Area 2.

The three-dimensional rendering (fig. 15) depicts several northwest-southeast-trending oblique ridges superimposed on Baldwin Shoal. The Baldwin Shoal predominately defines the geomorphology of MMS Study Area 3. The crest of the shoal trends southwest-northeast and is attached to Morgan Peninsula. Based on the 10-m isobath and where the shoal is flat extending from the shoreface, the shoal is about 9 km in length and varies in width from 1.3 to 3 km. Parker and others (1997) described the feature as about 9 mi in length (14.5 km) with shoal-attached sand ridges superimposed on the shoal; medium to fine sand covers much of the area while the thickest deposits are on top of the ridge and shoal. The length estimate of Parker and others (1997) is presumably based on the 14-m isobath and inclusive of the sloping southwestern extent.

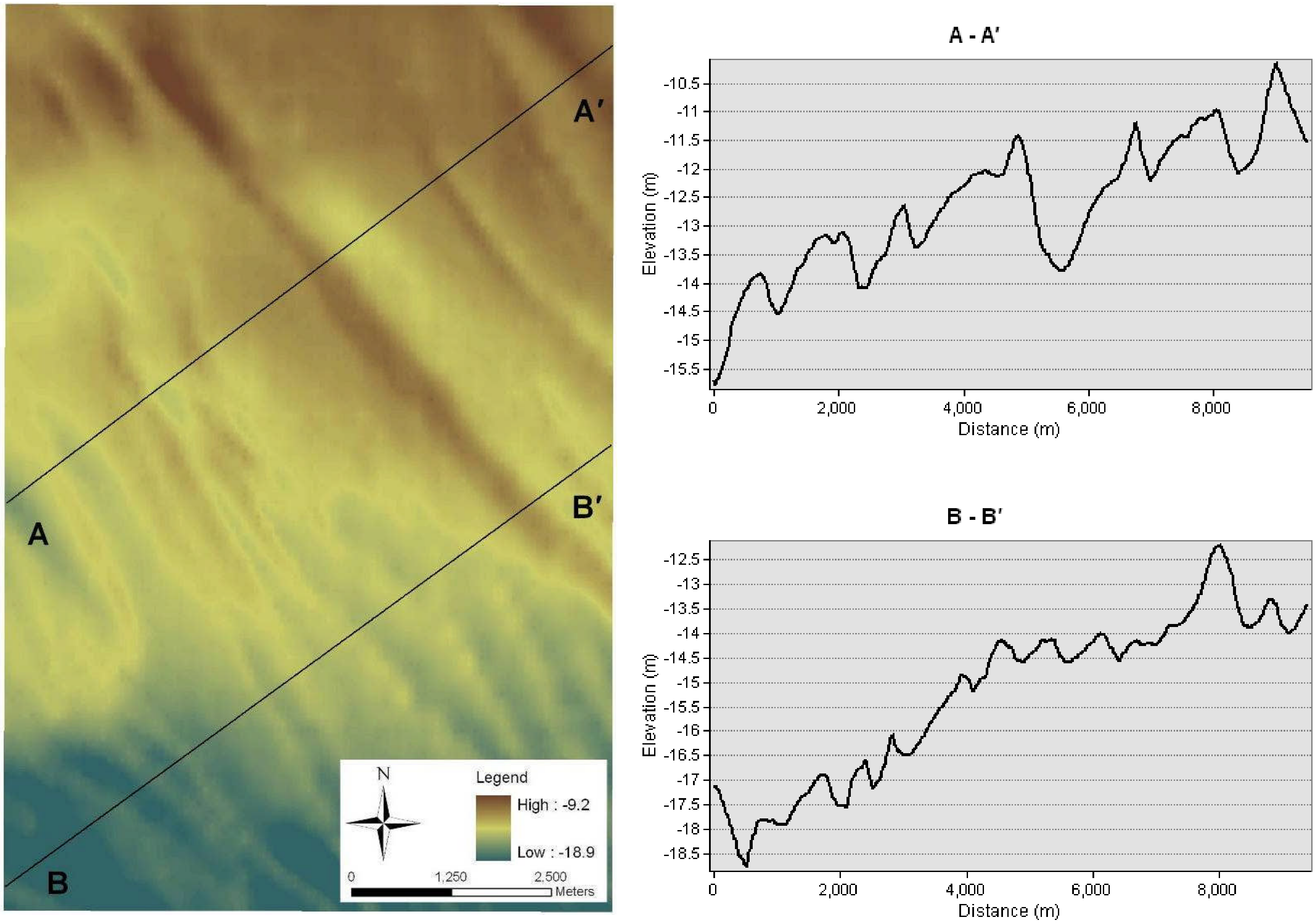

Figure 14.—Topographic profiles A-A' and B-B' for MMS Study Area 2.

Illustrated in figure 16 are topographic transects A-A' and B-B' constructed parallel and normal to the crest of Baldwin Shoal, respectively. The oblique bars, located seaward and superimposed on the shoal are normal to the shoal. Profile A-A' depicts about eight individual ridges atop the large shoal with an average relief of 2.1 m and wavelength of 1.5 km.

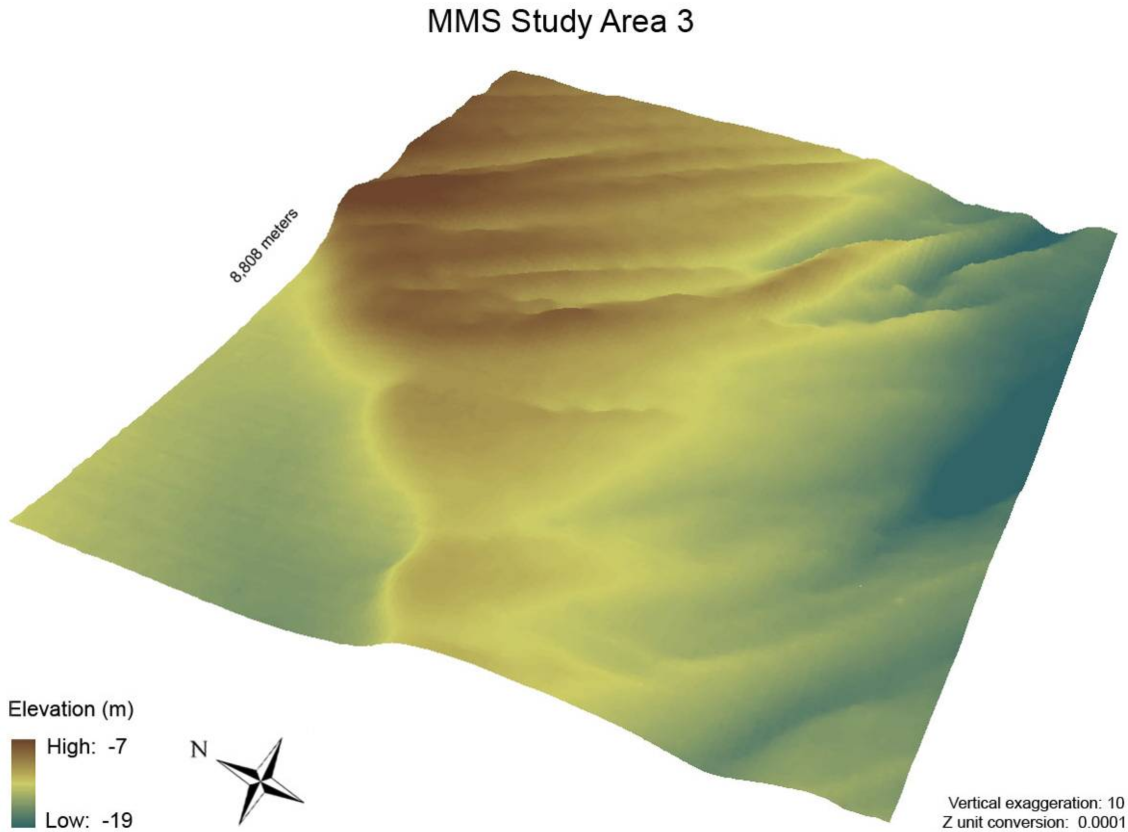

Figure 15.—Three-dimensional rendering of MMS Study Area 3.

Those bars at greater depths show weak southwesterly asymmetry which suggests southwest migration. Although profile B-B' depicts one distinct oblique bar, numerous surficial ridges are present (fig. 16). The profile transect across the shoal represents a gentle slope southwestward at about 1 m/km (1.03 ft/mi) or a slope of 0.1 percent. The northwest face slopes at about 1 m/.32 km (16 ft/mi) or a slope of 0.3 percent.

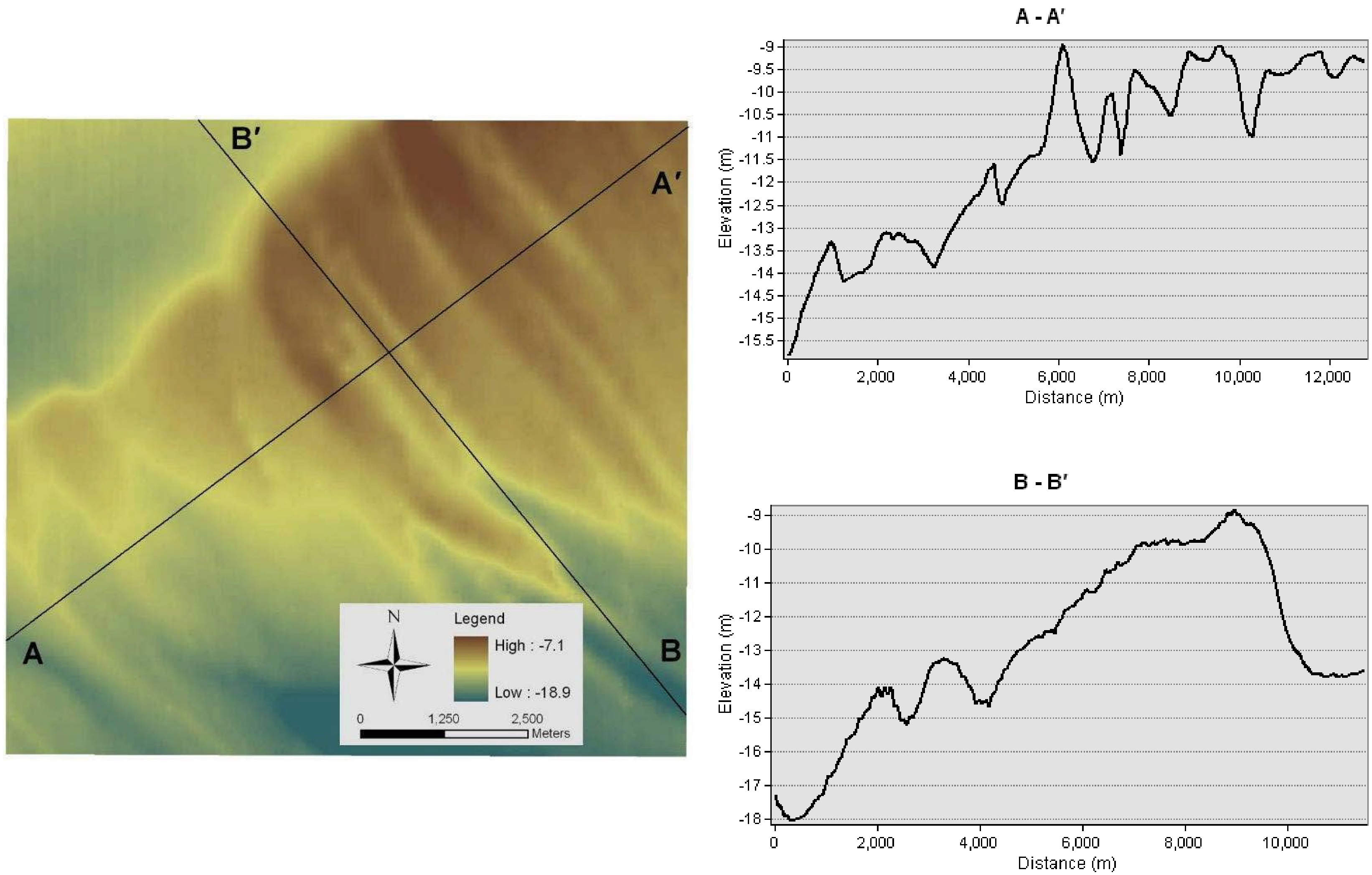

Figure 16.—Topographic profiles A-A' and B-B' for MMS Study Area 3.

MMS STUDY AREA 4

MMS Study Area 4 (figs. 1 and 9) is between 5.3 km (3.3 mi) and 6 km (3.7 mi) offshore Dauphin Island to its northernmost boundary and lies south of the developed eastern section of Dauphin Island, Mobile County, Alabama. The perimeter is about 37,934 m with a total two-dimensional surface area of 8,765 ha (33.8 mi^2). An estimated 68.6 percent of MMS Study Area 4 is within federal waters representing about 6,014 ha (23.2 mi^2) (table 6). The fairway is about 2,728 ha (10.5 mi^2) or about 31 percent and 45 percent of the total MMS Study Area 4 area and the federal area, respectively (fig. 10, table 6). About 31 percent of the total area is within state waters (2,751 ha or 10.6 mi^2). This study, using GIS, determined the area to be 33.8 mi^2, a difference of 1,605 ha (6.2 mi^2) from the area as calculated by Parker and others, 1993. Bathymetry (NAVD88) ranges between -21.3 and -3.19 m with a mean depth of -14.8 m. The increased elevation in the northeast extremity (fig. 17) reflects the study area boundary extending onto the Mobile Bay ebb-tidal delta.

The surface slopes gently to the southwest at about 3 m/km (16 ft/mi) or a 0.3 percent slope The most prominent feature is one large, high relief ridge located southwest of or on the seaward edge of the ebb-tidal delta (fig. 18). This feature is related to the disposal of maintenance dredging. The topography southwest of the ebb-tidal delta and the disposal area is essentially flat, sloping southwestward at 1 m/km (1.03 ft/mi) or a slope of 0.1 percent. A series of poorly developed northwest-southeast-trending ridges with low relief (Parker and others, 1997) are visible as modeled in the southeastern corner. Surficial sediment for the eastern part of MMS Study Area 4 and adjoining the ebb-tidal delta is medium- to fine-grained sand with increasing fines to the west; the thickest sand deposit (about 25 ft) is located on a sand ridge in the southeast quadrant (Parker and others, 1997). These ridges terminate as they adjoin the ebb-tidal delta or the offshore disposal area.

Oblique ridges are less abundant and less well defined than those identified in the previous study areas and are shoreface-attached. The low-relief bars are numerous in the southern half with increasing depth; unlike the Baldwin Shoal, they are not superimposed on the Mobile Bay ebb-tidal delta. Illustrated in figure 18, topographic transects A-A' and B-B' are constructed across the ebb-tidal delta and disposal area and normal to the trend of the oblique bars, respectively.

Profile A-A' (fig. 18) reflects an offshore disposal area with characteristics of a linear ridge; based on the 10-m isobath, the man-made ridge is about 1.8 km in length, has a relief of about 5 m, and an average width of 650 m. No natural ridges are visible. About four generally symmetrical oblique ridges are depicted on the B-B' transect; relief ranges between 0.5 and 1.5 m and an average wavelength of about 700 m. The ridges taper into the ebb-tidal shoal as depth decreases and the ridges and shoal converge.

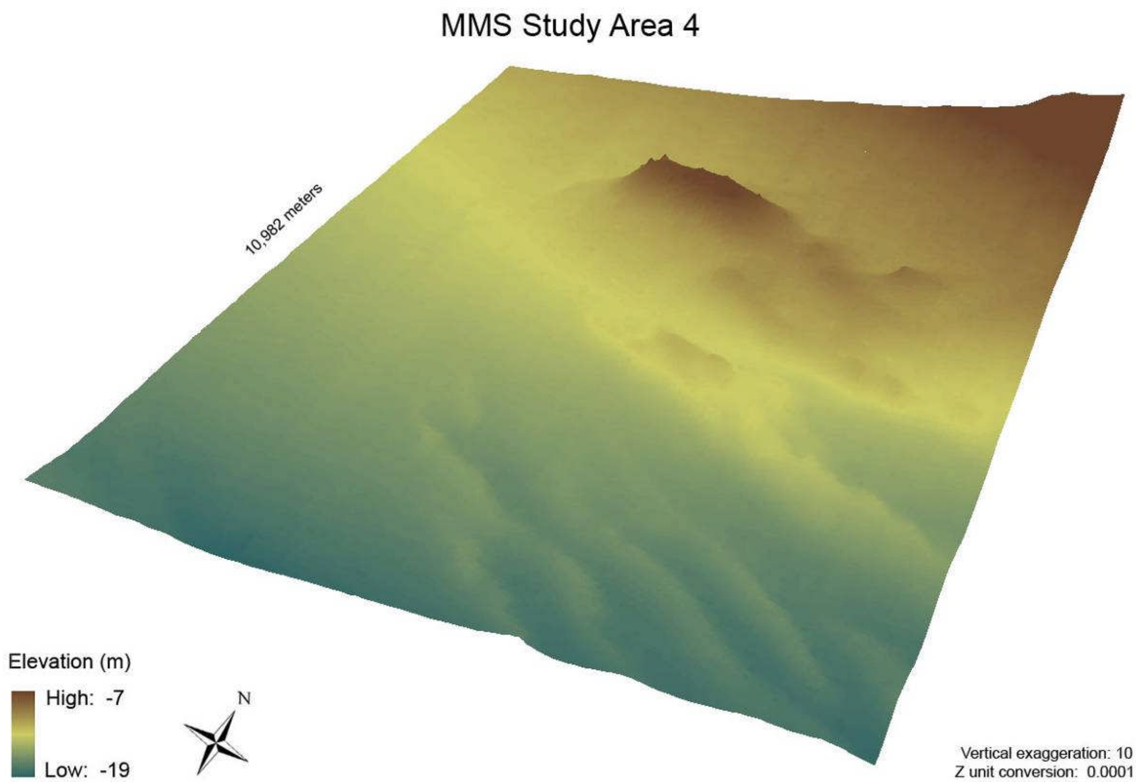

Figure 17.—Three-dimensional rendering of MMS Study Area 4.

MMS STUDY AREA 5

MMS Study Area 5 (figs. 1 and 9) is located south of the western extremity of Dauphin Island and Petit Bois Pass, Mobile County, Alabama. The distance from the shoreline to the northern boundary is about 3.5 km (2.17 mi). The total two-dimensional surface area is 5,416 ha (20.9 mi^2) with a perimeter of 29,817 m; about 3,804 ha (14.7 mi^2) or 70 percent lies within federal water and 1,616 ha (6.2 mi^2) lies within state water (table 6; fig. 10).

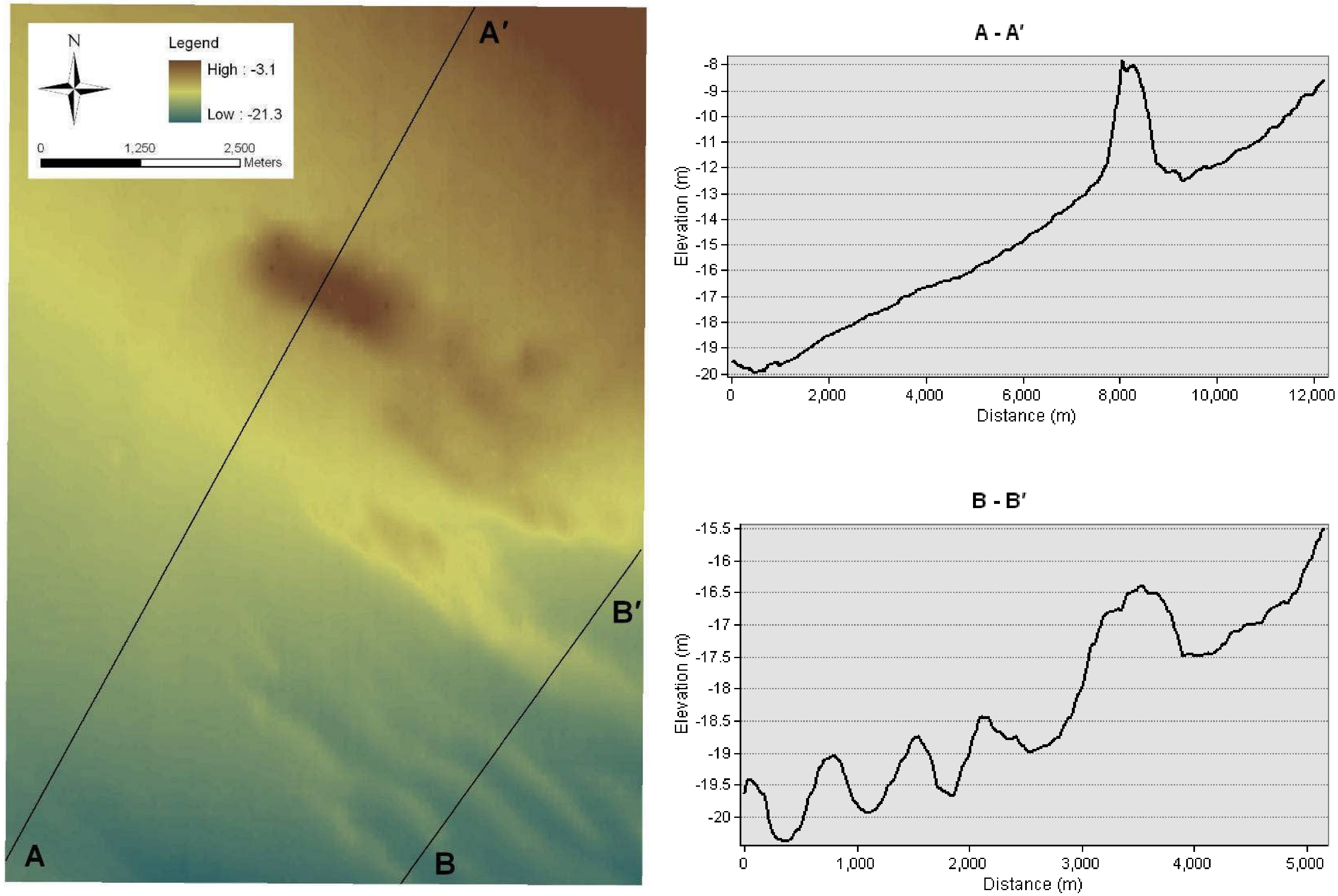

Figure 18.—Topographic profiles A-A' and B-B' for MMS Study Area 4.

Parker and others (1993) calculated a total surface area of about 17 mi^2 for MMS Study Area 5, about 4 mi^2 less than this study. The fairway area is about 1,796 ha (6.9 mi^2) or about 33 percent of the total MMS Study Area 5 surface area or 47 percent of the federal area. Bathymetry (NAVD88) ranges between -21.3 and -6.8 m with a mean depth of -15.57 m.

Earlier studies (Parker and others, 1993, 1997) described the bottom geomorphology as containing one prominent large ridge centered within a study area. Further, they described much of the surface area as medium to fine sand with an estimated thickness of at least 7 ft. Much of the central and southern sections of MMS Study Area 5 reflect low relief and generally slope to the south. The bottom geomorphology illustrated in figure 19 reveals several northwest-southeast-trending linear features. The extreme southwest corner terminates over a small portion of an offshore ridge. The prominent ridge identified by Parker and others (1993) is illustrated in the bottom third of the image. The northern end of the area depicts the shoaling associated with Petit Bois Pass with several shoal-attached ridges. The Petit Bois Pass shoals are located between the undeveloped western extremity of the Dauphin Island sandspit and Petit Bois Island in Mississippi state waters.

Illustrated in figure 20 are topographic transects A-A' and B-B' constructed about normal to bar crests found in MMS Study Area 5. Profile A-A' depicts about six individual oblique bars adjoining and superimposed on the southern extent of shoals associated with Petit Bois Pass. The topography southwest of the shoal is flat; the shoal slopes southwestward at 1.85 m/km (9.7 ft/mi) or a slope of 0.2 percent. The ridges have an estimated average height of 1 m and wavelength of 900 m. Profile B-B' depicts about 14 individual oblique bars or isolated ridges along the gentle grade south of Petit Bois Pass shoals. Essentially flat, the slope is about .09 percent or 0.875 m/km (4.9 ft/mi). The bars' heights range between 0.25 and 1.5 m and they have an estimated average wavelength of 600 m.

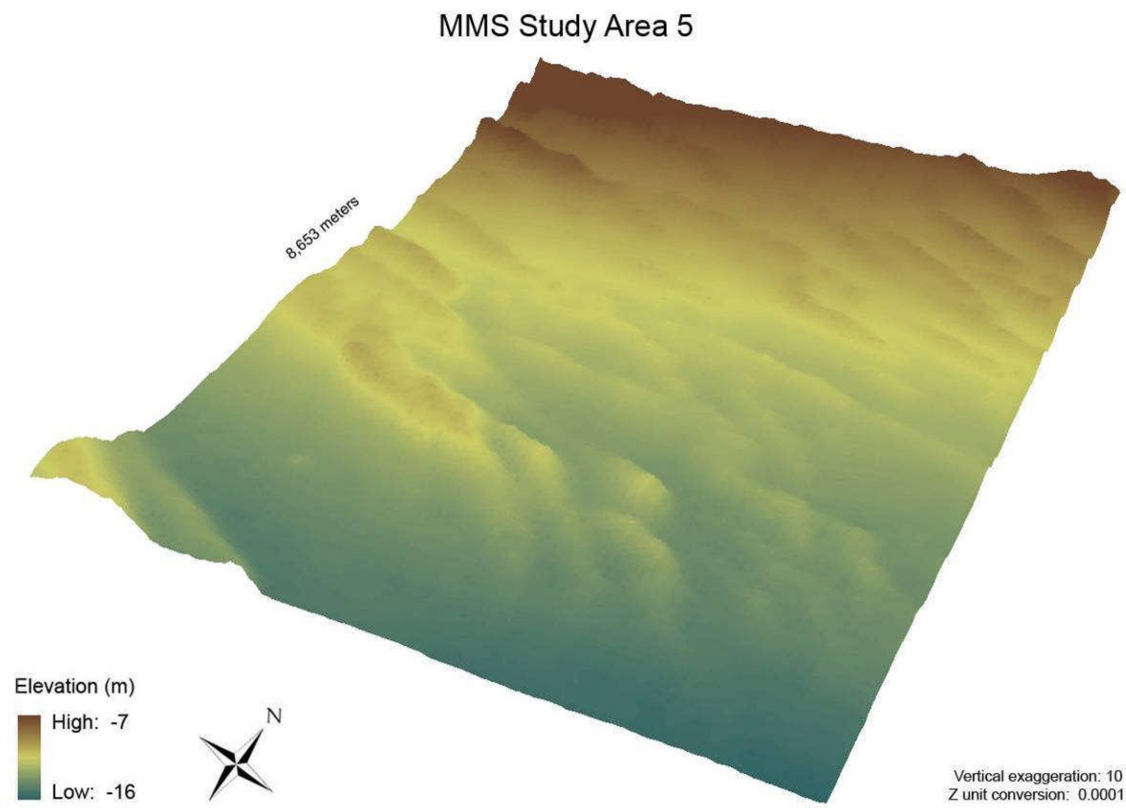

Figure 19.—Three-dimensional rendering of MMS Study Area 5.

STUDY AREA GEOSPATIAL CONSIDERATIONS

In addition to geological and geophysical data, additional geospatial themes are necessary to fully characterize the MMS Study Areas. Below is a brief synopsis summarizing the relationship between ancillary thematic layers and the five MMS Study Areas. The themes are mainly categorized under human development (administrative, energy, cultural resources, and infrastructure) and environmental (biological, designated areas, and hazards). Archaeological survey requirements are illustrated in figure 21.

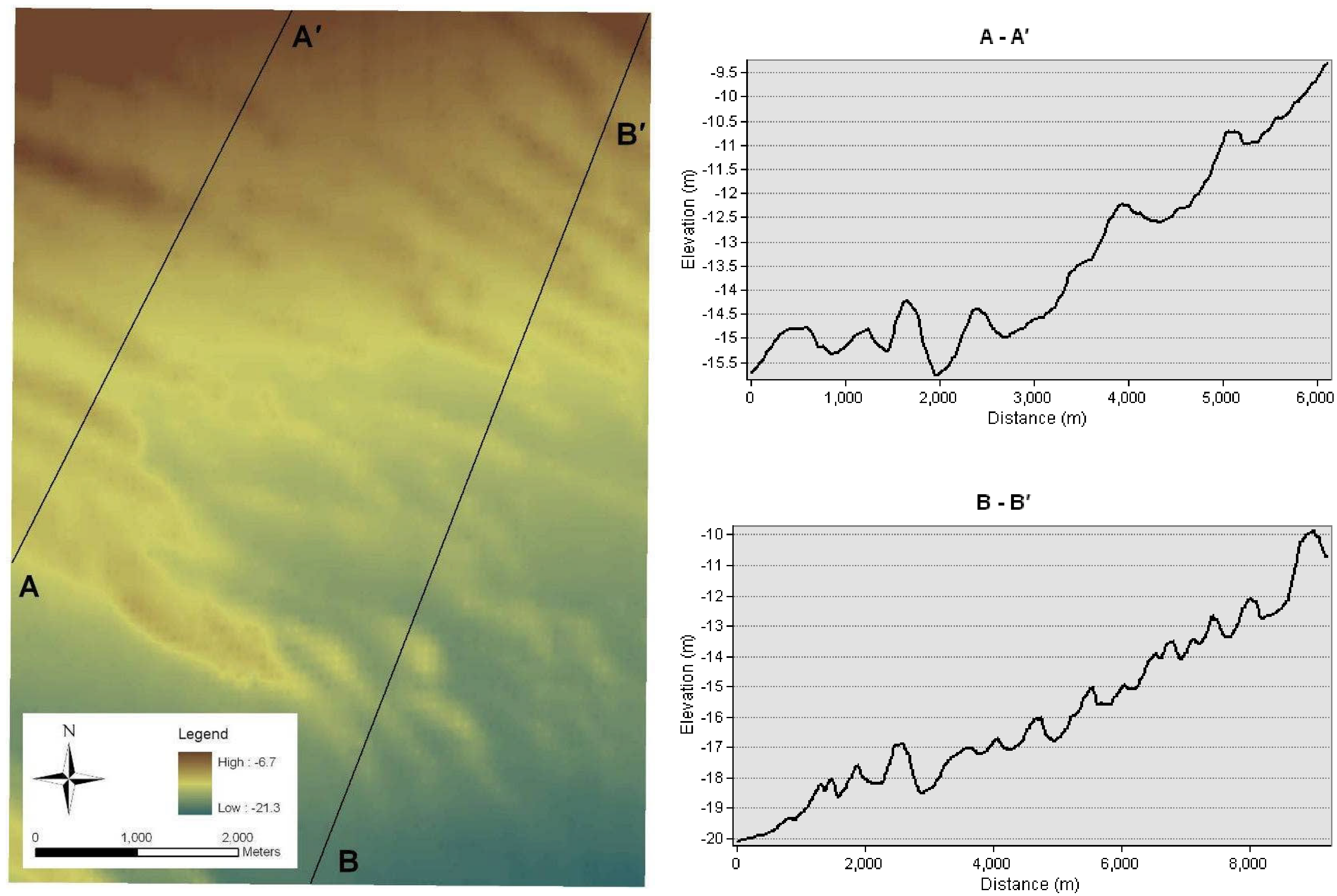

Figure 20.—Topographic profiles A-A' and B-B' for MMS Study Area 5.

Ascertained from GIS located in the "Digital Coast: Legislative Atlas" (NOAA CSC, 2008), the MMS Study Areas fall within the regulatory limits of the MMS New Orleans District, MMS Central GOM OCS Planning Area, U.S. Coast Guard District 8, U.S. Environmental Protection Agency Region 4, U.S. Fish and Wildlife Service Region 4, and the National Marine Fisheries Service Southeast Region. For state waters only, regulation includes the Federal Emergency Management Agency Region IV, National Park Service Southeast Region, U.S. Army Corps of Engineers Regulatory District Mobile, Alabama Department of Environmental Management, Alabama Department of Conservation and Natural Resources, and Alabama State Port Authority Jurisdiction. The Fishery Management Council GOM Region is confined to federal waters. Regulations or legislation for Alabama waters includes the Alabama Sale and Leasing of Sand Boundary, Alabama Gulf States Marine Fisheries Compact, Abandoned Shipwreck Act, Submerged Lands Act, the Gulf States Marine Fisheries Compact, Coastal Zone Management Act, Clean Water Act Section 404, Alabama Marine Mammal Protection Act of 1976, and the Alabama Authorization for Leasing of Certain State Lands for Oil and Gas Exploration, Development, and Production. Legislation specific to federal waters includes the Outer Continental Shelf Lands Act and the Magnuson-Stevens Fishery Conservation Act. The Marine Debris Research, Prevention, and Reduction Act, Marine Mammal Protection Act, National Environmental Quality Act, Endangered Species Act, and the Clean Water Act Sections 402 and 403 apply to both federal and state waters.

Essential Fish Habitat (EFH) polygons were created from National Marine Fisheries Service (2004) published document files. All five MMS Study Areas are EFH for migratory pelagics, reef fish, and shrimp. EFH for red drum include MMS Areas 3, 4, and 5, and the western half of MMS Study Area 2. MMS Study Areas 1, 2, and 3, the northern half of MMS Study Area 4, and about 90 percent of MMS Study Area 5 are classified as EFH for stone crab. Critical Habitat for the gulf sturgeon is north of MMS Study Area 5 in Petit Bois Pass and Mississippi Sound and for the wintering piping plovers north of MMS Study Areas 4 and 5 along Dauphin Island (NSWC PCD, 2008).

MMS STUDY AREA 1

The MMS Study Area 1 extent, which contains no oil and gas infrastructure, is made up of State lease blocks 102, 103, 121 and 122, and Federal lease blocks 751, 794, 795, 796, 838, 839, and 840 (fig. 22). Federal mineral lease blocks are within the

Pensacola protraction for the MMS GOM OCS Region; no field unit delineations or active leases are present. Two marine debris hazards, with a clearance of less than 3 m (10 ft) in depth, and three submerged obstructions were identified from the database. Other features identified proximal to this study area are a fish haven, wrecks, and the Military Warning Area (MWA) to the south and west. MMS Study Area 1 is generally clear of environmental and infrastructural concerns.

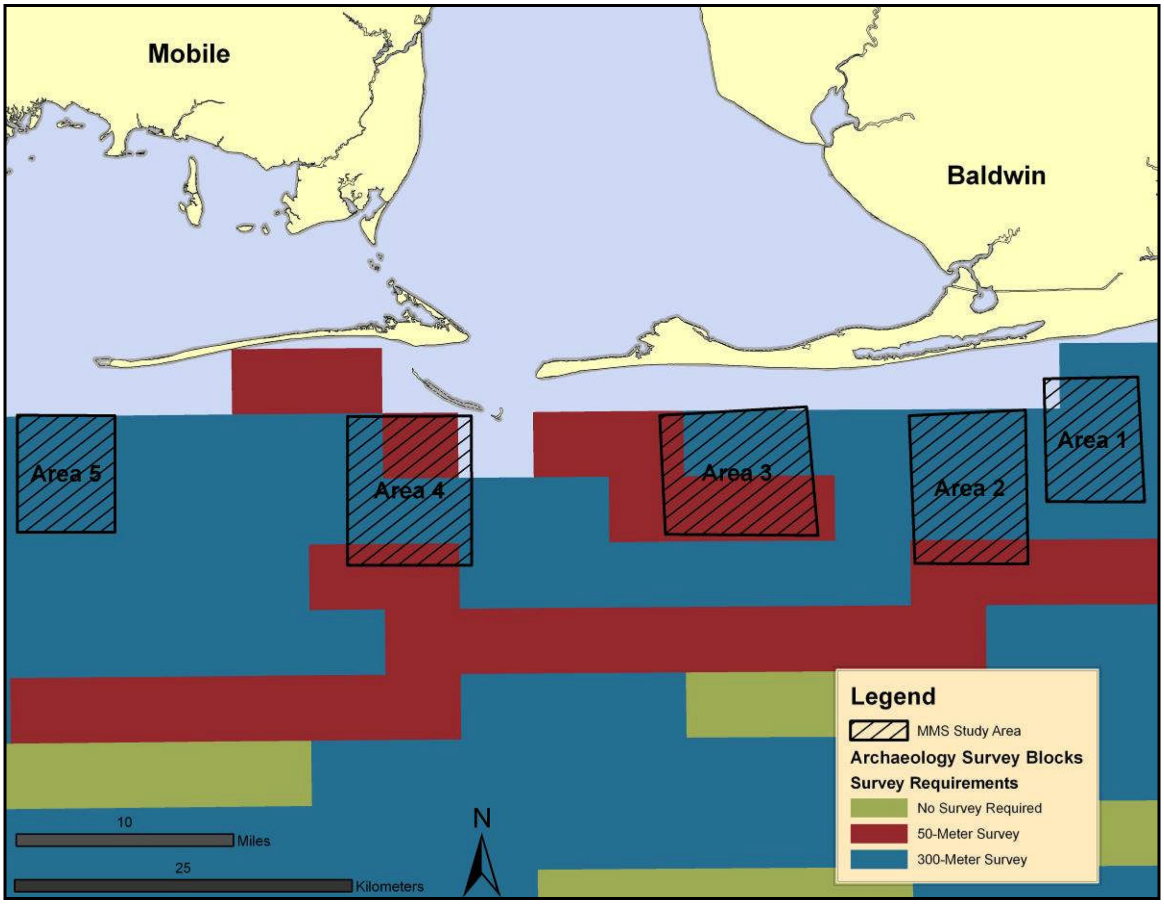

Figure 21.—Archaeological survey requirements, offshore Alabama.

Although not illustrated on figure 22, the artificial reef permit area, Don Kelley North General Permit Area, is located about 10 km (6 mi) south of the study area. Ninety-two percent of this study area (all but the northwest corner) has been designated as an area of prehistoric archaeological potential; MMS requires an archaeology survey to be conducted at 300-m line spacing (fig. 21).

MMS STUDY AREA 2

Federal Lease Blocks 793, 794, 837, 838, 881 and 882 and State Lease Blocks 119, 120, and 121 are found within MMS Study Area 2 (fig. 23). Federal mineral lease blocks are within the Pensacola protraction for the MMS GOM OCS Region. Federal lease block 881 is the only active lease. No field units are present.

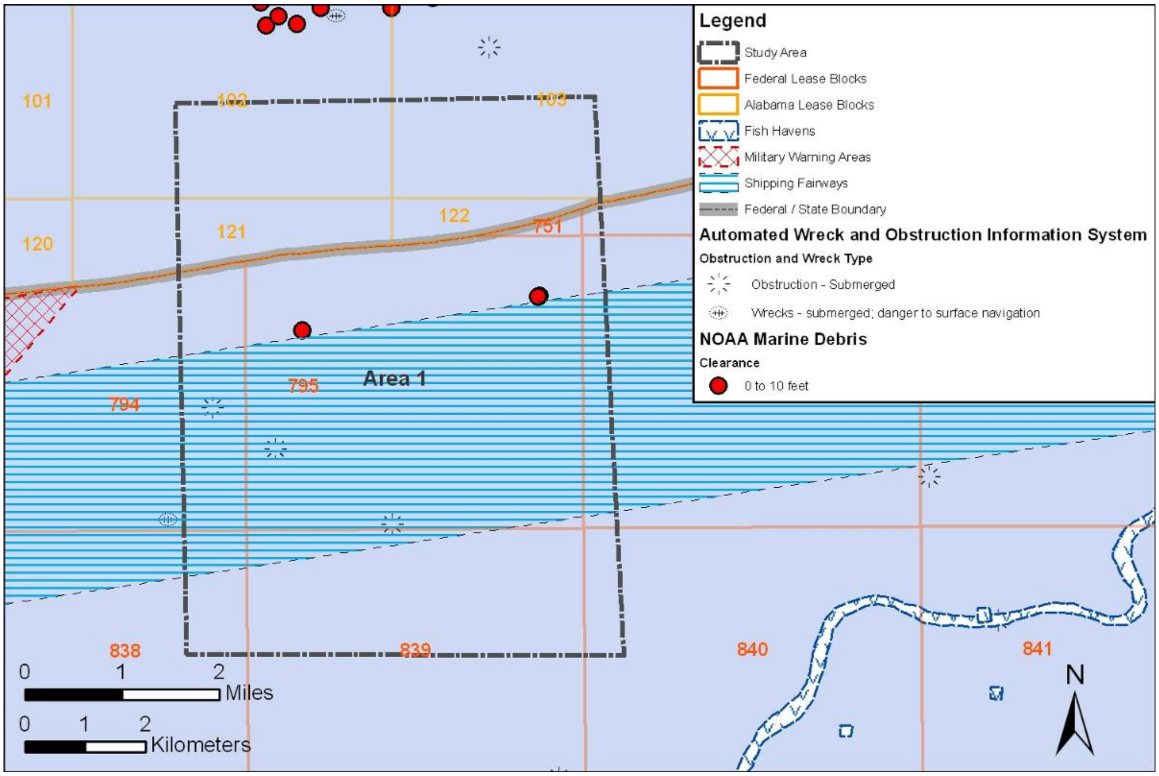

Figure 22.—Development and environmental characteristics within MMS Study Area 1.

While this study area does not contain any NOAA marine debris hazards, State Lease Block 119 does contain two obstructions less than 3 m (10 ft) from the mean water line in the southwest corner of the block, just west of MMS Study Area 2. There is one wreck posing a hazard to navigation south of the shipping fairway in Federal Lease Block 837, and one wreck just south of MMS Study Area 2 in Federal Lease Block 881. There are three fish havens in the southern portion of MMS Study Area 2, but no reefs have been identified. The Don Kelley North General Permit Area, an artificial reef area, is located 5 km (3.1 mi) south. There is a single pipeline, approximately 1,998 m (6,556 ft) in length, in the southwest corner of the study area. One federal platform is located in the southwest corner in Federal Lease Block 881 in MMS Study Area 2. Fifty-five percent of the study area is classified within the MWA. MMS has designated the southern portion (approximately 16 percent) of this study area as an historic shipwreck area, and requires surveys at 50-m line spacing. The remaining 84 percent of the study area contains prehistoric archaeological potential and requires a survey at 300-m line spacing (fig. 21).

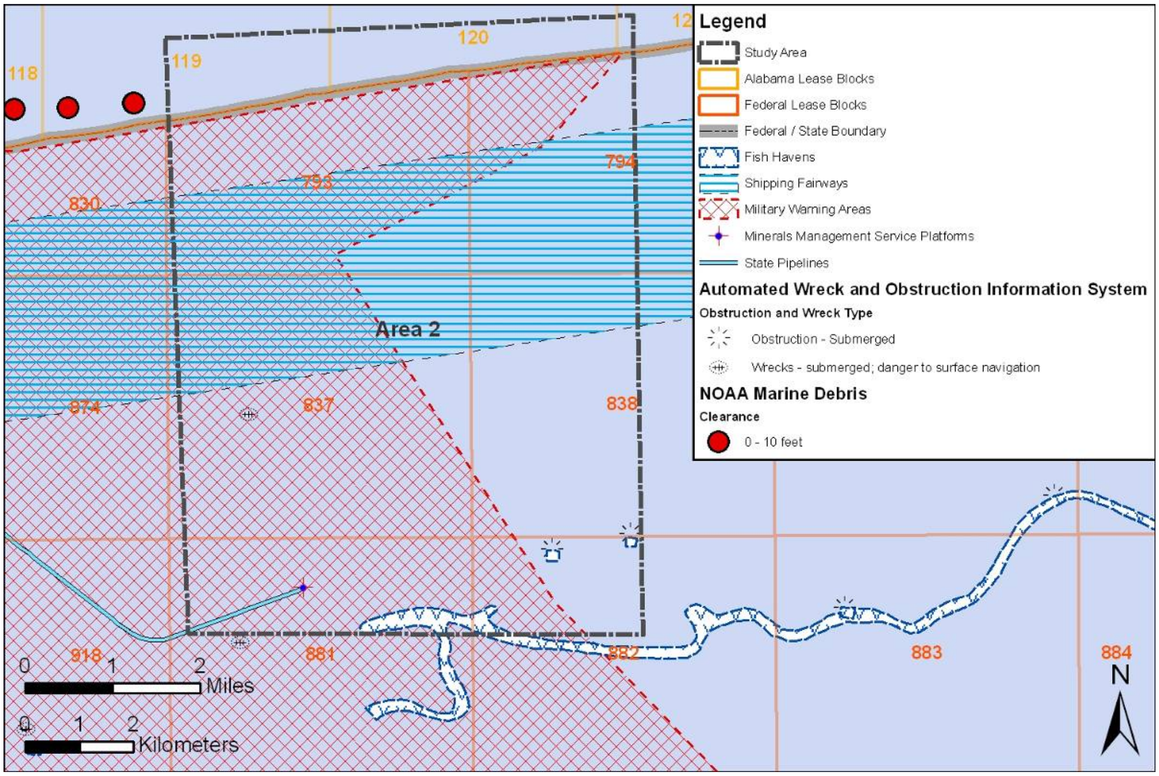

Figure 23.—Development and environmental characteristics within MMS Study Area 2.

MMS STUDY AREA 3

MMS Study Area 3 extents include State Lease Blocks 115, 116, 117 and 118, and Federal Lease Blocks 827, 828, 829, 871, 872 and 873 (fig. 24). Federal mineral lease blocks are within the Mobile protraction for the MMS GOM OCS Region. MMS Study Area 3 contains 30 obstructions that are less than 3 m (10 ft) from the mean water line, along with several that are adjacent to MMS Study Area 3. There are no wrecks or dangers to navigation in MMS Study Area 3. However, there is one wreck to the north, adjacent to MMS Study Area 3. Other features identified in this study area include a fish haven and submerged obstruction in the northwest and southwest corners, respectively. An artificial reef permit area (Don Kelley North General Permit Area) is located 9 km (5 mi) south. There are three federal platforms within and two adjacent to MMS Study Area 3. Three state platforms are also adjacent to the study area. Approximately 1 km (0.6 mi) of federal pipeline lies within MMS Study Area 3 and several adjacent to the study area. While there are no state pipelines within MMS Study Area 3, they can be found in the adjacent State Block 115. The area south of the Federal/State boundary, or 78 percent of MMS Study Area 3, is within the MWA. Fifty-six percent of this study area is designated by MMS as an historic shipwreck area, requiring surveys at 50-m line spacings (fig. 21). The remaining portion of the study area is designated as containing prehistoric archaeological potential and requires surveys at 300-m line spacings.

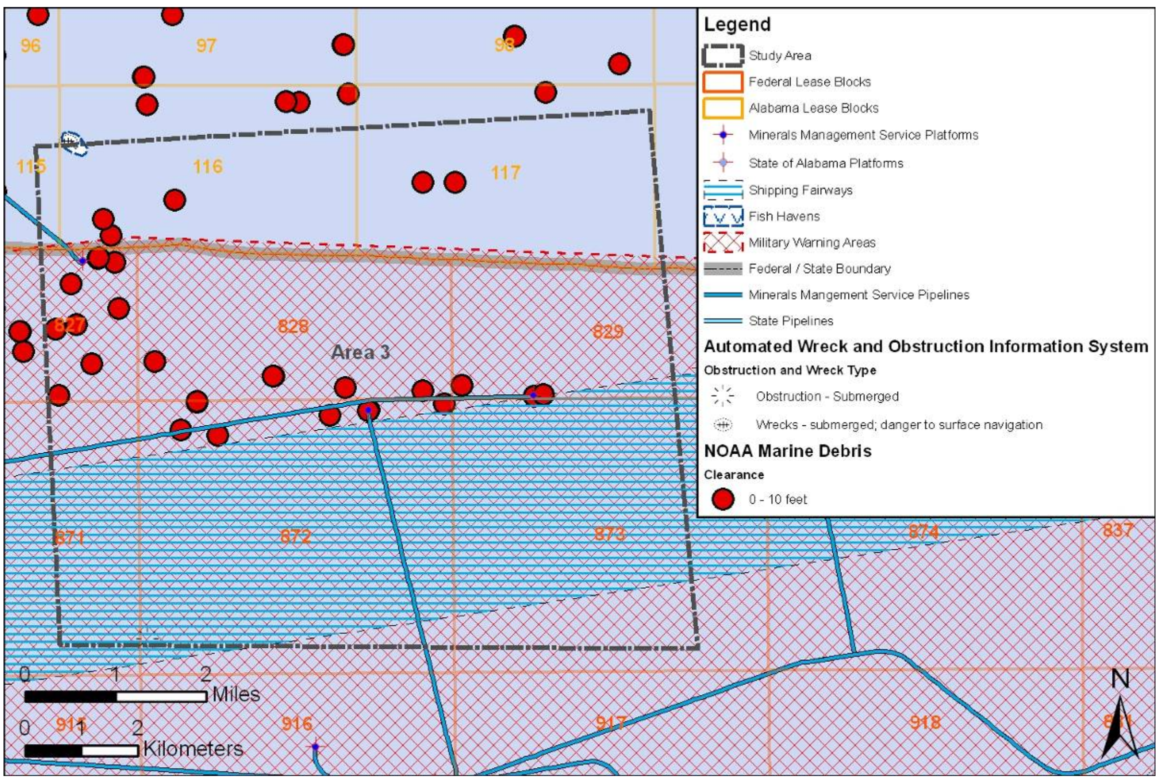

Figure 24.—Development and environmental characteristics within MMS Study Area 3.

MMS STUDY AREA 4

MMS Study Area 4 is within State Lease Blocks 111, 112, 113, 131 and 132, and Federal Lease Blocks 823, 824, 867, 868, 869, 911, 912 and 913 (fig. 25). Federal mineral lease blocks are within the Mobile protraction for the MMS GOM OCS Region. The study area is clear of obstructions, dangers to navigation, and wrecks. However, there are wrecks and safe water buoys adjacent to MMS Study Area 4. The MWA is south of the Federal/State Boundary. Artificial reefs and a hard bottom area are proximal to both the east and west of MMS Study Area 4, respectively. An artificial reef permit area (Hugh Swingle General Permit Area) is located 5 km (3 mi) south. There are three federal platforms within MMS Study Area 4 with several to the west and south. Nine state platforms are in MMS Study Area 4 with five more that are adjacent to the study area. There are 63.4 km (39.4 mi) of federal pipelines and 49.6 km (30.8 mi) of state pipelines within MMS Study Area 4, with several adjacent to the study area. Sixty-nine percent of MMS Study Area 4 is within the MWA. The USACE Mobile North Disposal Area 1987 takes up approximately 38 percent of the study area. Directly adjacent to and east of this study area is the Sand Island Beneficial Use Area, approximately 3,331.4 square km in size. An area of prehistoric archaeological potential occupies 57 percent of this study area where surveys at 300-m line spacings are required by MMS (fig. 21). Thirty-eight percent of this study area is an historic shipwreck area, with required surveys at 50-m line spacing. The remaining area, occupying the northeastern portion of the study area, is not classified as containing any archaeological designation.

MMS STUDY AREA 5

MMS Study Area 5 includes State Lease Blocks 106, 107 and 108, and Federal Lease Blocks 819, 820, 863 and 864 (fig. 26). Federal mineral lease blocks are within the Mobile protraction for the MMS GOM OCS Region. One marine debris area, less than 3 m (10 ft) from the mean water line, and two submerged obstructions are found within MMS Study Area 5. No other dangers to navigation or wrecks are found in the study area. Dangers to navigation, lateral buoys, and marine debris locations are to the north of MMS Study Area 5. There is one federal platform in MMS Study Area 5 with eight more adjacent to the study area. No state platforms are within or adjacent to MMS Study Area 5. There are 11.3 km (7.3 mi) of federal pipelines and no state pipelines within MMS Study Area 5, and several federal pipelines adjacent to the study area. The MWA encompasses 69 percent of the study area. Approximately 32 percent of this study area is occupied by the US Army Corps of Engineers' Mobile North Disposal Area 1987. The entirety of this study area is designated by MMS as an area of prehistoric archaeological potential that requires a 300-m spacing survey (fig. 21).

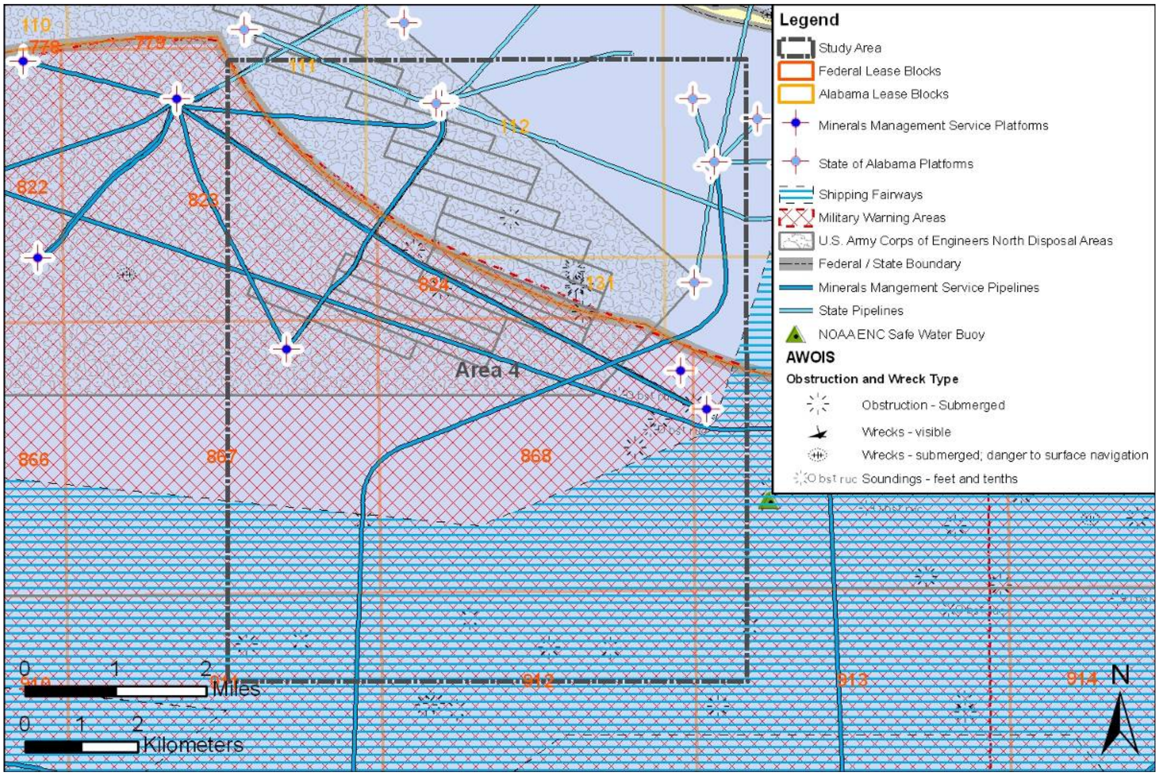

Figure 25.—Development and environmental characteristics within MMS Study Area 4.

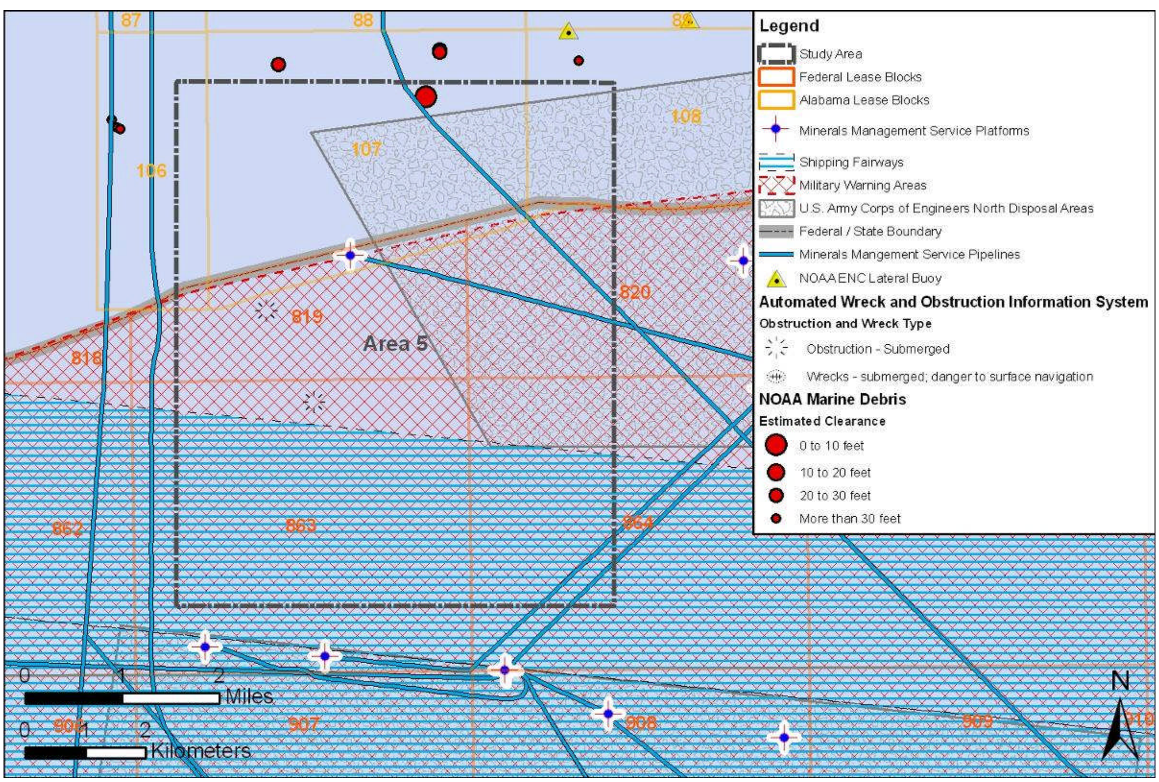

Figure 26.—Development and environmental characteristics within MMS Study Area 5.

GEOLOGICAL GEOSPATIAL DATA

SEDIMENT

Geological GIS and supporting raster data were acquired from a variety of government, academic, and private entities. The sediment datasets represent bottom grabs, shoreline grab samples, vibracores, and foundation borings collected from offshore Alabama. Following is a summary of sediment data collected for this study, divided by data source. It should be noted that the largest sets of vibracore data were collected by Olsen Associates, Inc. (Olsen, 2001, 2003, 2006b) and the GSA (Parker and others, 1993; Hummell and Smith, 1995, 1996; Hummell, 1999) and direct comparison is complicated by inconsistency in color description, sediment characterization, and method used to obtain sample coordinates. The color hues assigned to GSA and Olsen samples were primarily 5Y (Yellow) and 10YR (Yellow-Red), respectively. Most GSA sand samples were assigned a light-gray value, whereas Olsen assigned values ranging from light-gray to white. Olsen (2001, 2003b, 2006b) and Scientific Environmental Applications, Inc. (SEA, 2000, 2003, 2006) classified grain size using the Unified Soils Classification System with the primary source material being poorly graded sand (SP). GSA used a lithofacies and microfacies classification in which GSS and SHS were recommended target materials. Sample collection locations were acquired by the GSA (Parker and others, 1993; Hummell and Smith, 1995, 1996) using the LORAN-C; Olsen Associates, Inc. (2001, 2003b, 2006b) used GPS technology (AOSS, 2000, 2003, 2006).

GOVERNMENT

The National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center (NGDC) maintains a web-based archive of geological and geophysical data (http://www.ngdc.noaa.gov/mgg/mggd.html). The following sets of sediment samples within the study extent were identified: (1) National Museum of Natural History (NMNH), Smithsonian Institute (http://www.nmnh.si.edu/), (2) Seafloor Surficial Sediment Descriptions (Deck41) (http://www.ngdc.noaa.gov/mgg), (3) Mississippi, Alabama, and Florida Study (MAFLA) (http://www.ngdc.noaa.gov/mgg), and (4) U.S. Naval Research Laboratory, Naval Oceanographic Office Cores (NAVO) (https://oceanography.navy.mil/legacy/web/) (fig. 27).

NOAA, in association with the NMNH, collected and interpreted 484 (Smith McIntyre Grab) samples from 14 cruises (table 7) from 1970 to 1994 in the MMS project extent. At each grab sample location, the position of the sample site was collected using LORAN-C. A total of 89 grab samples fell within the MMS Study Areas, where 6 were collected from MMS Study Area 1, 13 from MMS Study Area 2, 26 from MMS Study Area 3, 26 from MMS Study Area 4, and 18 from MMS Study Area 5.

The Deck41 database contains 295 grab samples, sounding samples, and vibracores collected from offshore Alabama between 1855 and 1960 (table 8). An aspect of nautical chart development, the limited number of sounding grab samples were qualitatively field classified. During 1960, 149 grab samples and 135 vibracores were collected within the MMS project extent. Coordinates were collected using LORAN-C. Of the 149 grab samples collected, only a few fell within the five MMS Study Areas. Although no grab samples were collected from MMS Study Area 1, one sample was collected in both MMS Study Areas 2 and 3, and two were collected in both MMS Study Areas 4 and 5. None of the vibracores collected in 1960 were within the MMS Study Areas. Samplers for the project are unknown for the Deck41 data.

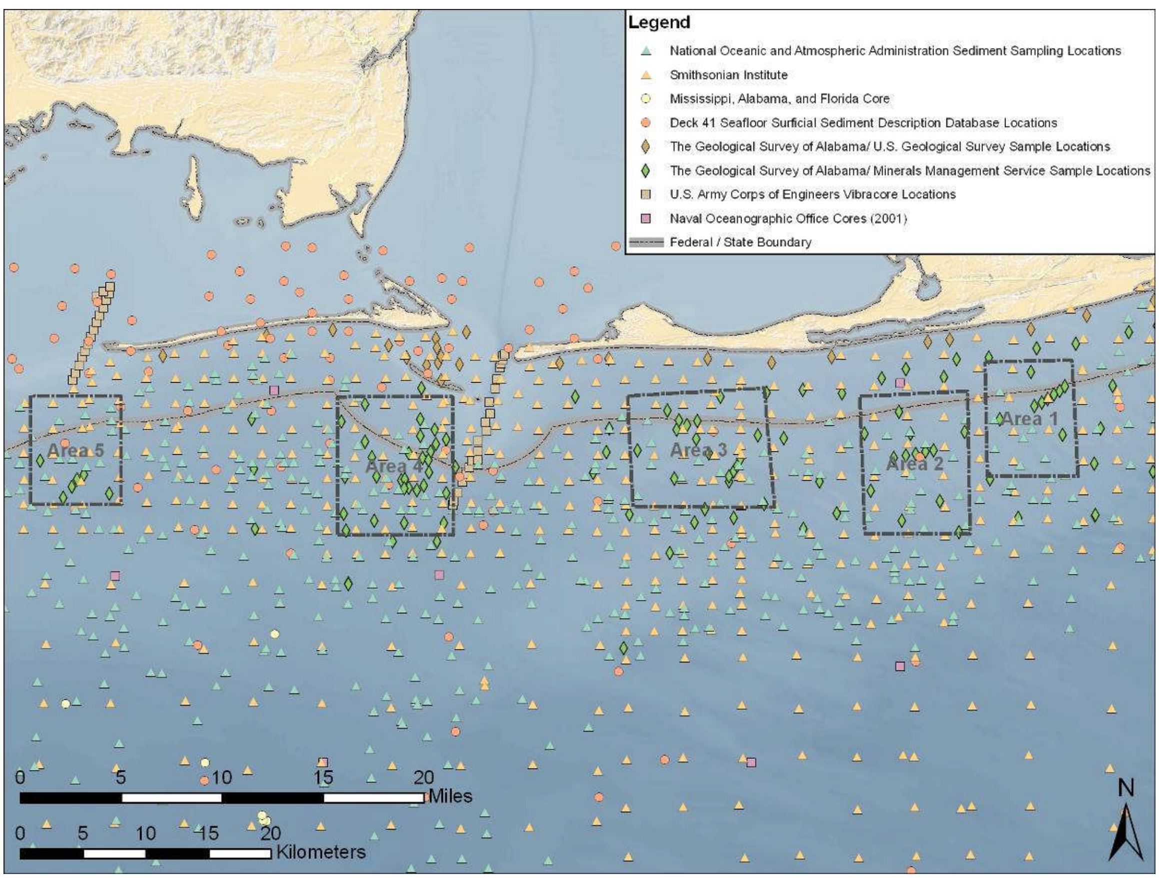

Figure 27.—Distribution of sediment samples maintained by government sources.

The MAFLA dataset represents 2,160 box core samples collected between 1974 and 1978 during eight different cruises (table 9). Sample coordinates were collected using LORAN-C. Of the total, 210 of the box cores collected fell within the MMS project extent; none fell within any of the five MMS Study Areas.

Table 7.--NOAA sediment samples collected within MMS project extent.

National Oceanic and Atmospheric Administration/National Museum of Natural History									
Date	Sampler	Sample Type	Cruise	MMS Project Extent	MMS Study Area 1	MMS Study Area 2	MMS Study Area 3	MMS Study Area 4	MMS Study Area 5
1970	Smith McIntyre	grab	NOAA Hydro Party	26	0	0	0	2	0
1983	Smith McIntyre	grab	NOAA Hydro Party	18	0	0	0	0	0
1983	Smith McIntyre	grab	Whiting	4	0	0	0	0	0
1984	Smith McIntyre	grab	NOAA Hydro Party	48	6	0	0	0	0
1985	Smith McIntyre	grab	Mt. Mitchell	46	0	0	0	0	0
1985	Smith McIntyre	grab	NOAA Hydro Party	10	0	0	0	0	0
1985	Smith McIntyre	grab	NOAA Hydro Party	64	0	13	5	0	0
1986	Smith McIntyre	grab	NOAA Hydro Party	21	0	0	6	0	0
1986	Smith McIntyre	grab	NOAA Hydro Party	41	0	0	0	0	0
1987	Smith McIntyre	grab	NOAA Hydro Party	64	0	0	0	0	0
1987	Smith McIntyre	grab	NOAA Hydro Party	52	0	0	15	24	0
1987	Smith McIntyre	grab	NOAA Hydro Party	65	0	0	0	0	8
1987	Smith McIntyre	grab	NOAA Hydro Party	19	0	0	0	0	10
1994	Smith McIntyre	grab	NOAA Hydro Party	6	0	0	0	0	0

Table 8.--Deck41 samples within MMS project extent.

National Oceanic and Atmospheric Administration Deck41 database								
Date	Sampler	Collection Type	MMS Project Extent	MMS Study Area 1	MMS Study Area 2	MMS Study Area 3	MMS Study Area 4	MMS Study Area 5
1855	unknown	sounding	1	0	0	0	0	0
1857	unknown	sounding	5	0	0	0	0	0
1880	unknown	sounding	2	0	0	0	0	0
1885	unknown	sounding	3	0	0	0	0	0
1960	unknown	grab	149	0	1	1	2	2
1960	unknown	vibracore	135	0	0	0	0	0

Table 9.--MAFLA samples collected within MMS project extent.

MAFLA									
Cruise	Date	Sampler	Sample Type	MMS Project Extent	MMS Study Area 1	MMS Study Area 2	MMS Study Area 3	MMS Study Area 4	MMS Study Area 5
Freeport	1974	box core	grab	26	0	0	0	0	0
Columbus Iselin	1975	box core	grab	20	0	0	0	0	0
Columbus Iselin	1976	box core	grab	50	0	0	0	0	0
Gyre	1976	box core	grab	10	0	0	0	0	0
Indian Seal	1977	box core	grab	45	0	0	0	0	0
Indian Seal	1978	box core	grab	34	0	0	0	0	0
Java Seal	1977	box core	grab	25	0	0	0	0	0

The NRL NAVO, under the Northern Gulf Littoral Initiative program, collected 86 samples (54 vibracores and 32 grab samples) between 1999 and 2000. The location of each sample site was collected using GPS, and the methods of collecting the cores and grab samples are unknown. Although no samples were collected within the MMS Study Areas, three grab samples and four vibracore samples fell within the MMS project extent.

The NOAA National Ocean Service sediment data were collected during hydrographic survey activities (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html). There are 1,806 sampled locations within the MMS project extent represented by hydrographic sheets H02920C (year unknown), H04000 (1917), H04021 (1917), H04139 (1920), H04171 (1920), and H04212 (1922) and are distributed within the MMS Study Areas as follows: 9 within MMS Study Area 1, 14 within MMS Study Area 2, 12 within MMS Study Area 3, 20 within MMS Study Area 4, and 11 within MMS Study Area 5. Sample location coordinates were provided by triangulation with existing geodetic and topographic control.

In order to better understand Holocene geology of the inner continental shelf offshore Alabama, the GSA, in cooperation with the U.S. Geological Survey, collected 13 nearshore vibracore samples (G-1 through 5, 16 through 22, 24) from a 30-ft long, 3-inch diameter aluminum tube core barrel aboard the R/V *Deborah-B* (Dauphin Island Sea Lab) in 1990 (GSA, 1993) (fig. 27). A grab sample was collected at G-23. Ten land vibracores (DI-1 through 10) were also collected with the GSA vibracorer in 1992. Hummell (1996) reported that 18 foundation borings were acquired from Exxon Company, U.S.A. Coordinates were by LORAN-C and sediment from grab and select core intervals was characterized using hydrometer and dry sieve granulometric analyses.

As discussed in the Previous Work, Sand Assessments, Offshore Alabama sections, the GSA has worked cooperatively with the MMS to evaluate sand resource potential within the GOM resulting in the collection of new data (fig. 27) (Parker and others, 1993; Hummell and Smith, 1995, 1996; Hummell, 1999; Kopaska-Merkel and Rindsberg, 2002, 2005). As part of an investigation to identify high-quality sand deposits offshore Alabama, Parker and others (1993) collected sediment at 59 locations (SR-1 through SR-59). Vibracore and grab (Peterson) samples were collected at each sample location; sample location coordinates were determined using LORAN-C. Vibracores were collected from the R/V *Kit Jones* (Marine Minerals Technology Center in Biloxi, Mississippi) using a vibracoring system that consisted of a 25 ft tower and pneumatic vibrator that pushed a 20 ft, 3-inch-diameter aluminum core tube (Parker and others, 1993). Of the 59 sample locations within the MMS project extent, 41 fell within the 5 MMS Study Areas (9 within MMS Study Area 1, 10 within MMS Study Area 2, 14 within MMS Study Area 3, 2 within MMS Study Area 4, and 6 within MMS Study Area 5). Sediment from grab and select core intervals were characterized using hydrometer and dry sieve granulometric analyses.

Hummell and Smith (1995, 1996) conducted a geologic assessment of MMS Study Area 4 south of Dauphin Island. As in 1993 and from the R/V *Kit Jones*, 15 locations (SR-60 through SR-74) were sampled and coordinates were determined using LORAN-C. Vibracore samples (with a sample length range between 7.7 to 20.4 ft) were collected using the above-described vibracoring system (Parker and others, 1993), and surface samples were collected using a Ponar grab (Hummell and Smith, 1995). Although all samples fell within the MMS project extent, 12 locations were within MMS Study Area 4. Sediments from grab and select core intervals were characterized using hydrometer and dry sieve granulometric analyses. Hummell and Smith (1996) collected 10 vibracore samples (SR-75 through SR-84) from the R/V *Kit Jones* using the pneumatic vibracore previously described. All ten vibracores fell within MMS Study Area 4 and coordinates were recorded in the field by GPS. Sediments from select core intervals were characterized using hydrometer and dry sieve granulometric analyses. Seven foundation borings were donated by Exxon Company, U.S.A. (84-1114, B-1; 85-1119, B-2; 0184-1015, B-1; 0201-1071-3; 1188-1314, B-III-1; 1188-1314, B-III-2; and

1188-1314, D-3A) (Hummell and Smith, 1995, 1996); 3 borings are in MMS Study Area 4 and 1 is in MMS Study Area 3.

Hummell (1999) conducted a more thorough investigation of the sand sheet south of Morgan Peninsula collecting 30 vibracores and grab samples (SR-90 through SR-119). In addition, 5 vibracores (SR-85 through SR-89) were collected within MMS Study Area 4 and in federal waters. Although LORAN-C coordinates were provided from the R/V *Kit Jones*, Hummell (1999) reported that locations were determined through GPS. Sediment texture was determined through microscopic analysis. Whereas all 30 samples collected offshore Morgan Peninsula fell within the MMS project extent, 24 samples were collected outside MMS Study Area boundaries, 1 sample was within MMS Study Area 1, 3 within MMS Study Area 2, 2 within MMS Study Area 3, and 5 within MMS Study Area 4. Seven foundation borings, donated by Exxon Company, U.S.A., were incorporated into this study (84-1115, B-1; 85-1071, B-1; 85-1072, B-1; 0183-3144, B-1; 0201-1071-1, B-1; 1188-1314, B-III-7; and 1188-1314, B-D-2 & 2A) (Hummell, 1999).

According to Parker (1990), Exxon Corporation, Inc. provided data from 50 foundation borings located in southwestern Mobile Bay, an area south of Dauphin Island on the ebb-tidal delta, and an area south of western Morgan Peninsula. Representing the ebb-tidal delta and western Morgan Peninsula, seventeen (17) borings were acquired from Hummell (1996), 3 from Hummell and Smith (1995), and 4 from Hummell (1999). One is located in MMS Study Area 3 and 3 are located in MMS Study Area 4.

Kopaska-Merkel and Rindsberg (2002) conducted native, engineered, and post-storm beach sediment and shell sampling resulting in 240 sand samples and 66 shell samples. Sand was collected at nine locations (table 10, station numbers 1 through 9), on a transect that included windrow, windrow at the beach cusp apex, windrow at the cusp swale, and storm windrow. Twenty-eight samples were characterized using hydrometer and dry sieve granulometric analyses.

In order to compare native beach sand to engineered beach and offshore sand and investigate the impact storms may have on beach sand, Kopaska-Merkel and Rindsberg (2005) expanded their work from 2002 to include 11 new beach sample locations (station numbers 6B and 10 through 19) where sand was collected from high-tide windrow, beach cusp swales, and storm windrows (table 10). Shell samples were collected in windrows. In order to investigate changes due to storms, seasonal effects, and developments, Kopaska-Merkel and Rindsberg (2005) conducted grain-size analysis on 73 samples collected from 18 sample stations representing a 3-year period.

Rindsberg and Kopaska-Merkel (2006) mainly focused on a comparison of beach sand to offshore sand and seasonal effects on beach sand. Their study involved re-characterization of cores archived at the GSA that represent MMS Study Areas 1 and 2. Peels and samples were taken from archived cores (SR-7, 22, 24, 26, 31, 33 through 36, 41, 43 through 45, 97 through 99, 100 through 103, and 109 through 115) in order to examine sedimentary structures and conduct further grain-size analysis. Forty-four (44) samples were sieved, 38 from existing vibracores (SR-98 through 103, 109 through 111) and 6 from winter beach samples collected during 2002 and 2003 (Kopaska-Merkel and Rindsberg, 2002, 2005; Rindsberg and Kopaska-Merkel, 2006). Samples were sieved in half phi increments from -2 to 4 which would retain fine gravel to very fine sand.

Table 10.--Locations of beach sediment stations. GSP = Gulf State Park

Station number	Station	Latitude	Longitude	Quadrangle
1	Alabama-Florida state line	30.27970	-87.51818	Orange Beach
2	Florida Point East (GSP)	30.27503	-87.54322	Orange Beach
3	Florida Point West (GSP)	30.27326	-87.54987	Orange Beach
4	Cotton Bayou (GSP)	30.26899	-87.58215	Orange Beach
5	Gulf Shores Public Beach (GSP)	30.24684	-87.68754	Gulf Shores
6	Pine Beach	30.22865	-87.81492	Pine Beach
6B	Little Lagoon	30.23699	-87.81815	Pine Beach
7	Fort Morgan East	30.22111	-88.00942	Fort Morgan
8	Little Lagoon Pass	30.24034	-87.73698	Gulf Shores
9	Pines public boat access	30.23864	-87.89011	St. Andrews Bay
10	Romar Beach	30.26214	-87.67070	Orange Beach
11	Gulf State Park Convention Center	30.24935	-87.66176	Gulf Shores
12	Gulf State Park Pavilion	30.25359	-87.64273	Gulf Shores
13	Cortez Street	30.23093	-87.92757	Pine Beach
14	Dauphin Island Sea Lab	30.24615	-88.07760	Fort Morgan
15	Dauphin Island Public Beach	30.24824	-88.12831	Fort Morgan NW
16	West End	30.24759	-88.19179	Fort Morgan NW
17	Alabama Highway 182 mile 2	30.23374	-87.77723	Pine Beach
18	Old pass East, Dauphin Island	30.24894	-88.13360	Fort Morgan NW
19	Old pass West, Dauphin Island	30.24959	-88.13674	Fort Morgan NW

The USGS, in cooperation with other entities, created the usSEABED, a repository for sediment and biological data (http://walrus.wr.usgs.gov/usseabed/). The usSEABED houses several sources of data that lie within the MMS project extent representing extracted (numeric data based on lab analyses), parsed (numeric data extracted from logs and other descriptions), calculated (numeric data modeled from extracted and parsed datasets), component (component numeric values), and facies (numeric values for grouped components) data (fig. 28). The usSEABED does contain data collected for this project (for example GSA, NOAA, NMNH, Smithsonian Institute, U.S. Naval Research Laboratory, USGS, University of South Florida, Florida State University, and the U.S. Environmental Protection Agency) but because of the value added, the database was left complete. Table 11 shows the number of unique entries into usSEABED for the project extent and within each MMS Study Area.

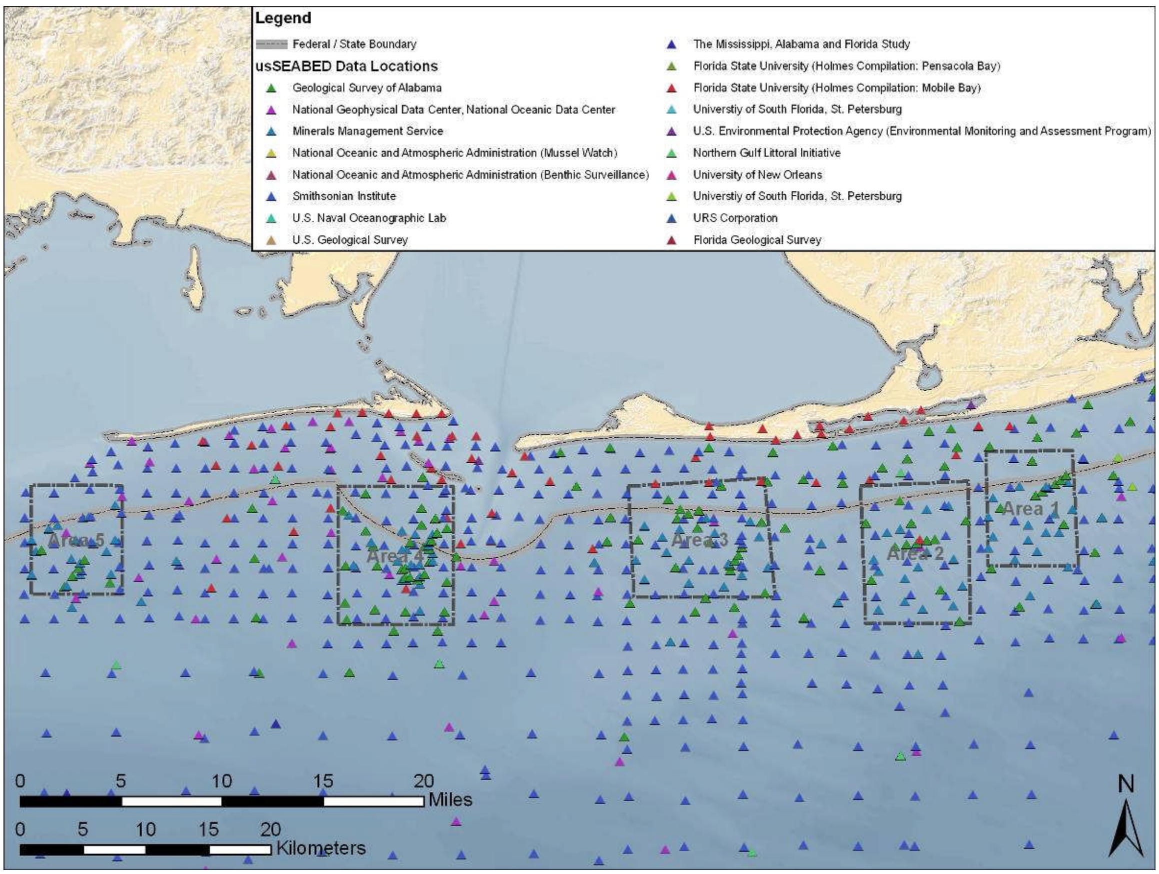

Figure 28.—Distribution of sediment samples maintained in the usSEABED.

The number of entries should not be confused with different locations but represents both single data entries and data from multiple intervals for the sample locations. Data from Mississippi Sound, Mobile Bay, and areas south of Mississippi and Florida have been excluded from the project extent.

Table 11.-- Number of unique usSEABED entries.

usSEABED						
Dataset	**MMS Project Extent**	**MMS Study Area 1**	**MMS Study Area 2**	**MMS Study Area 3**	**MMS Study Area 4**	**MMS Study Area 5**
Calculated	3,027	152	184	273	403	86
Extracted	2,245	145	181	268	392	84
Parsed	2,013	86	109	152	345	54
Facies	303	19	17	37	5	13
Component	2,242	145	181	269	393	86

The USACE (Mr. Ronald I. Nettles, Mobile District Geotechnical & Dam Safety Section, personal commun., May 29, 2006) provided a Microstation file (.dxf) showing boring locations, boundaries of several offshore subsurface investigation projects, and data from the 1985 "ALW00002 COASTAL – MOBILE HARBOR DEEPEN" project. Drilling logs, grain-size distribution or gradation curve plots, and project reports were provided for data from basic splitspoon and modified Alpine Vibracore unit subsurface sampling locations (USACE, 1985). The study was conducted in 1985 where 37 vibracores were collected within the MMS project extent and sample coordinates were collected using LORAN-C. Although none fell within MMS Study Areas, 16 cores, designated with a VBL prefix, were collected within Petit Bois Pass and north of MMS Study Area 5, and 21 cores, designated with the prefix SG, were collected east of MMS Study Area 4 and along the Mobile Pass channel (fig. 27).

ACADEMIC

In December 1986, 681 bottom grab samples were collected in state and federal waters from the inner shelf, offshore Alabama (east Baldwin County) and the Florida panhandle by the University of South Florida (Locker and others, 1988, 1999). Locations were determined using LORAN-C. Within the MMS project extent, 25 sediment grab samples were collected although none are within the five MMS Study Areas (fig. 29). The sediment south of Perdido Pass and Perdido Key was characterized as medium- to fine-grained sand based on the mean grain size (1.06 to 2.5Φ) and was moderately well to moderately sorted (Locker and others, 1999; tables 1 and 2). These data were identified on the FLDEP Reconnaissance Offshore Sand Search (ROSS) (http://ross.urs-tally.com/ims/viewer.htm) database.

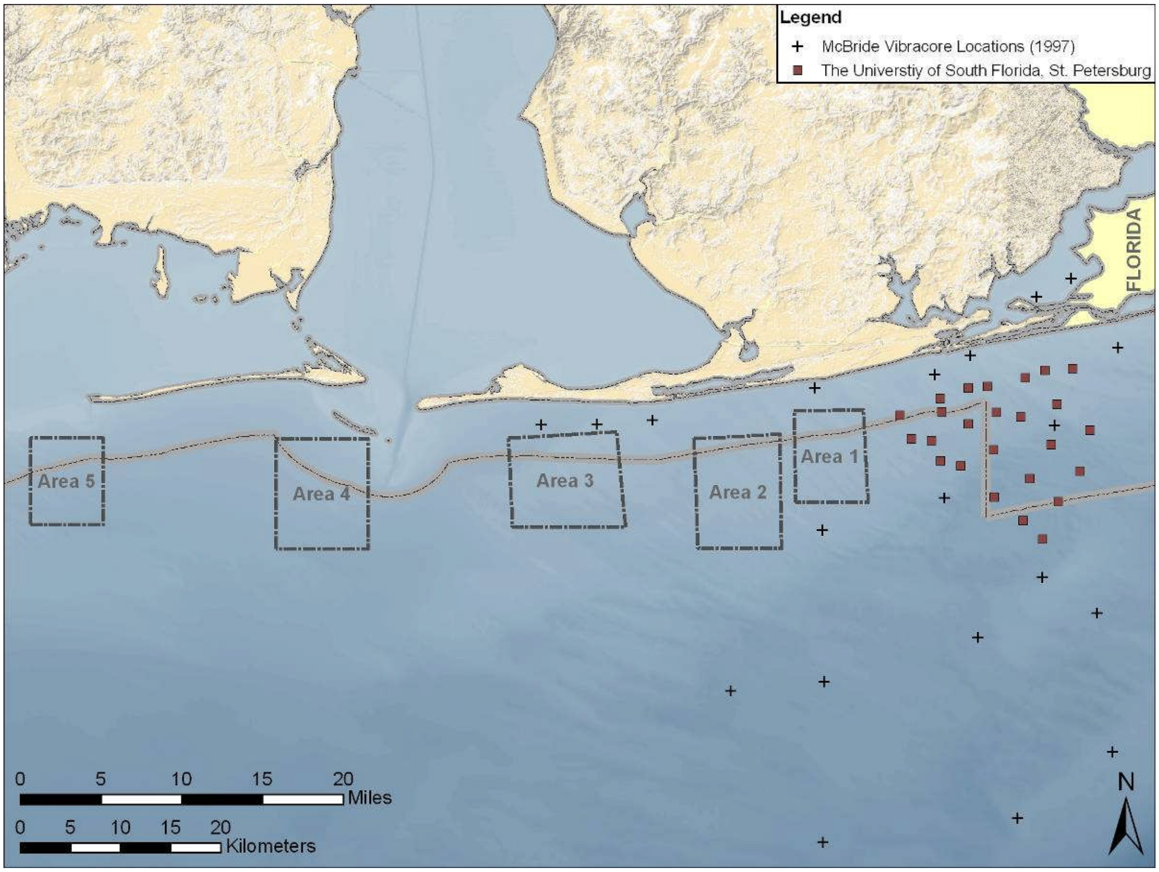

Figure 29.—Distribution of sediment samples acquired from academic sources.

McBride (1997) investigated the late Pleistocene and Holocene geology and processes on the inner continental shelf, offshore Alabama and Florida panhandle and south to DeSoto Canyon. From the R/V *Kit Jones*, McBride collected 20 vibracores in 1991 (ALA-91-1 through 3, 9, 12 through 14, 16; PEN-91-1 through 13), 7 in 1992 (PEN-92-1 through 7), and 9 in 1993 (PEN-93-1 through 3, 5, 6; ALA-93-1; PER-93-1 through 3) within the project extent (fig. 29). No cores were collected within MMS Study Areas. McBride (1997) used a pneumatic vibrator attached to a steel tripod to collect the 6-m-long, 7.5-cm-diameter aluminum vibracores. Sample site coordinates are thought to have been collected using LORAN-C. The cores were logged, photographed, and sampled for grain-size and shell characterization. Grain-size analyses were completed using a sonic sifter and samples from 25-cm increments). For this project, grain-size distribution and sieve analysis from 0.5 to 4.75 Φ, Wentworth and Unified classifications, and standard statistics (median, mean, skewness, and kurtosis) are hyperlinked to the logs for vibracores collected offshore Alabama (prefix ALA).

PRIVATE

Olsen Associates, Inc. conducted three offshore sand investigations to find suitable sand for beach nourishment, offshore Baldwin County (Olsen, 2001, 2003b, and 2006b) (fig. 30). Olsen (2001) conducted a sand search investigation for the city of Gulf Shores that included vibracore collection in November 1999. Alpine Ocean Seismic Survey, Inc. (AOSS) (2000) collected 48 20-foot cores using a 217B Alpine pneumatic vibrator from the R/V *Atlantic Twin* and provided differential GPS (DGPS) coordinates (Olsen, 2001). Scientific Environmental Applications, Inc. (SEA) (2000) logged the cores and characterized the sediment. Cores were labeled C-01 through C-25, C-27 through C-47, C-81, and C-08A. Although none fell within MMS Study Areas, all 48 vibracores were collected within the MMS project extent and north of MMS Study Areas 1 and 2 in state waters. Native beach characteristics were determined from the collection and subsequent analysis of 36 sediment samples taken from four beach transects from the crest of the longshore bar landward north of the beach berm (see Olsen, 2001).

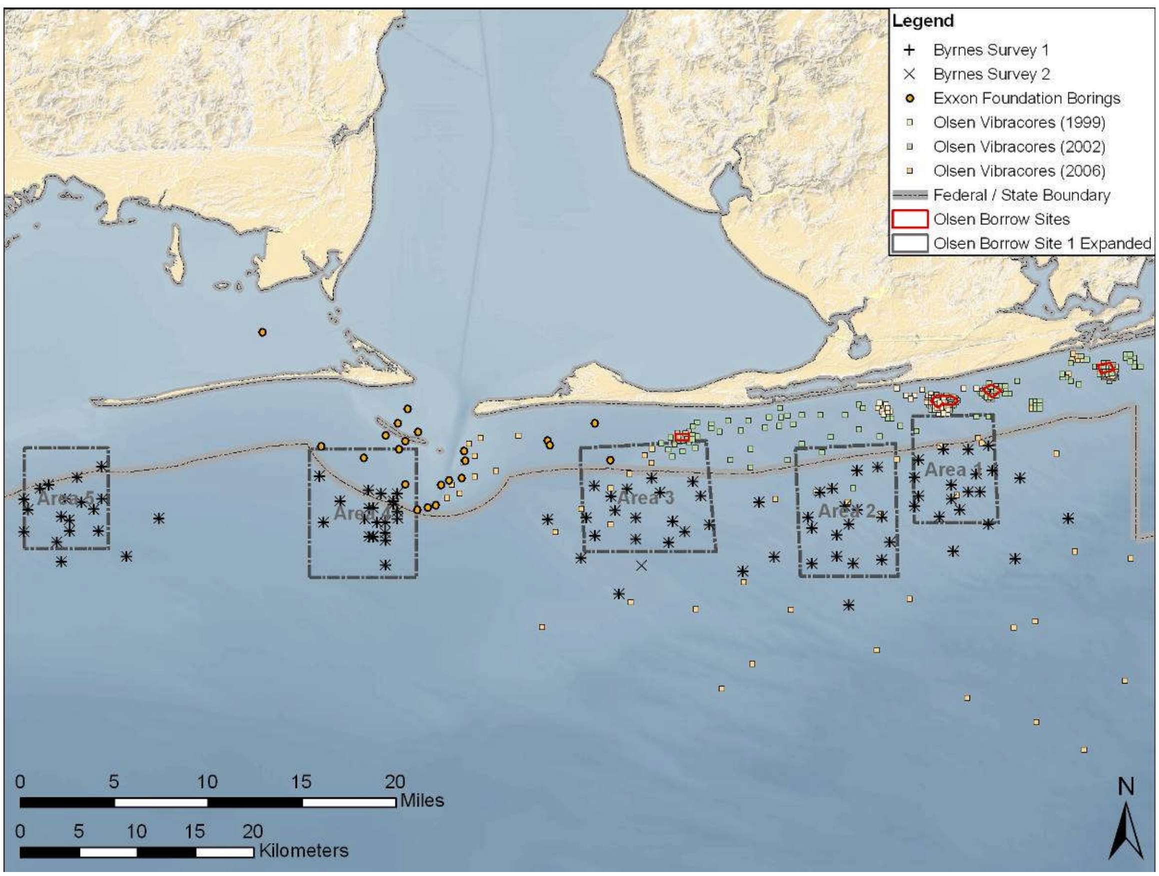

Figure 30.—Distribution of sediment samples acquired from private sources.

Directed by Olsen (2003b), AOSS (2002) collected 20-foot vibracores in December 2002 at 160 locations (BC-1 through 7, BC-8 R1 and R2, BC-9 through 40, BC-41 R1 and R2, BC-42, BC-43 R1 and R2, BC-44 through 60, BC-61 R1 and R2, BC-62 through 107, BC-108 R1 and R2, BC-109 through 112, BC-113 R1 and R2, BC-114 through 124, BC-125 R1 and R2, BC-126 through 153, BC-154 R1 and R2, BC-155 through 160) mainly within state waters (AOSS, 2003; Olsen, 2003b) from the R/V *Atlantic Twin*. Coordinates were determined with DGPS. Within this inventory, this core set is labeled as BC02-001 through BC02-160 to reflect the year and location. Core logs, photography, and sediment characterizations were performed by SEA (2003). All vibracores fell within the MMS project extent and within MMS Study Areas as follows: 3 within MMS Study Area 1, 3 within MMS Study Area 2, and 7 within MMS Study Area 3. All but two locations (BC02-129 and BC02-130) were within state waters. Beach sand characteristics (coarse- to fine-grained sand, median grain size ranged between 0.21 and 0.46 mm (2.252 - 1.12Φ), sorting coefficients between 0.47 and 0.5Φ, estimated shell content less than 1 percent, and native beach color of 10YR 9.0/1.5) were determined from the collection of 77 sediment grab samples collected from 10 beach transects (Olsen, 2003b).

Olsen (2006b) conducted an exploratory geotechnical sand search to identify or further characterize additional offshore sand reserves to support future maintenance of the engineered beaches along the Baldwin County coastline. Sample areas included the east flank of the Mobile Bay ebb-tidal delta, the Baldwin Shoal, shoals seaward of Perdido Pass, shoreface-attached and detached sand ridges, and the North Perdido Shoal (fig. 9). Within federal and state waters, 60 20-foot vibracores (labeled BC06-01 through BC06-60) were collected by AOSS (2006) from the R/V *Atlantic Twin*; coordinates were provided by DGPS. The cores were sent to SEA (2006) to be split, logged, and sampled. All 60 vibracore sample locations fell within the MMS project extent, 12 of which fell within MMS Study Areas. Four vibracores fell within MMS Study Area 1, 2 in MMS Study Area 2, and 6 in MMS Study Area 3.

Byrnes and others (1999) conducted an investigation in May 1997 and December 1997, offshore Alabama and relevant to the five MMS Study Areas, to collect sediment and ecological data in support of a comprehensive environmental survey. Coordinates for each sample location were collected using GPS. Byrnes and others (1999) collected 100 Smith-McIntyre grab samples for semi-quantitative grain-size analyses (median grain size, percent gravel, sand, silt, and clay). With the exception of samples collected in MMS Study Area 4, 16 sample locations were within MMS Study Area extents and four locations were outside. Within MMS Study Area 4, grab samples were collected at or near a previously delineated sand source (Hummell and Smith, 1995, 1996); 16 grab samples were collected at the potential sand deposit and four outside the sand source.

GEOPHYSICAL

Geophysical data were acquired from a variety of government, academic, and private entities. The geophysical dataset represents thematic layers associated with seismic acquisition, seismic imagery, and fathom sounding rolls collected from offshore Alabama. Discussions of these datasets are grouped by source.

GOVERNMENT

Bearden and others (1987) identified, evaluated, and interpreted existing LSAL6769 geophysical data (high-resolution seismic and sidescan sonar) collected from offshore Alabama and on the OCS. Of the high resolution seismic data identified by Bearden and others (1987) and completed for the USGS, only Fairfield Industries 1982 data for OCS Lease Sales 67 and 69 are within the study area. Trackline GIS data were acquired from the Marine Trackline Geophysical IMS Map System maintained by National Oceanic and Atmospheric Administration (NOAA), National Geophysical Data Center (NGDC) (http://www.ngdc.noaa.gov/mgg/mggd.html) (NOAA, 2007a). Because the Survey ID LSAL6769 trackline GIS contained no information with which to associate the seismic data start and end time and segment number, this survey data was acquired through the link at (http://www.ngdc.noaa.gov/mgg/dat/geodas/docs/mgd77.htm) (fig. 31). Although negatives exist at the GSA, the analog data (seismic and fathometer roll images) taken from microfilm were scanned and provided to the GSA on CD-ROMS (Ms. Robin Warnken, NOAA, NGDC, personal commun., November 2008). Of the 1,648 km (1,024 mi) of geophysical data collected for LSAL6769 that lie within the MMS project extent, 188 km (117 mi) were collected within three of the five MMS Study Areas. There are 42 km (26 mi) in MMS Study Area 3, 90 km (56 mi) in MMS Study Area 4, and 56 km (35 mi) in MMS Study Area 5. Data were collected from the M/V *Colorado* using an unknown signal source, and position was provided with a navigational (Type N) RAYDIST with accuracy 80 km (50 mi) offshore between 15 m (50 ft) to 30 m (100 ft) (http://jproc.ca/hyperbolic/raydist.html).

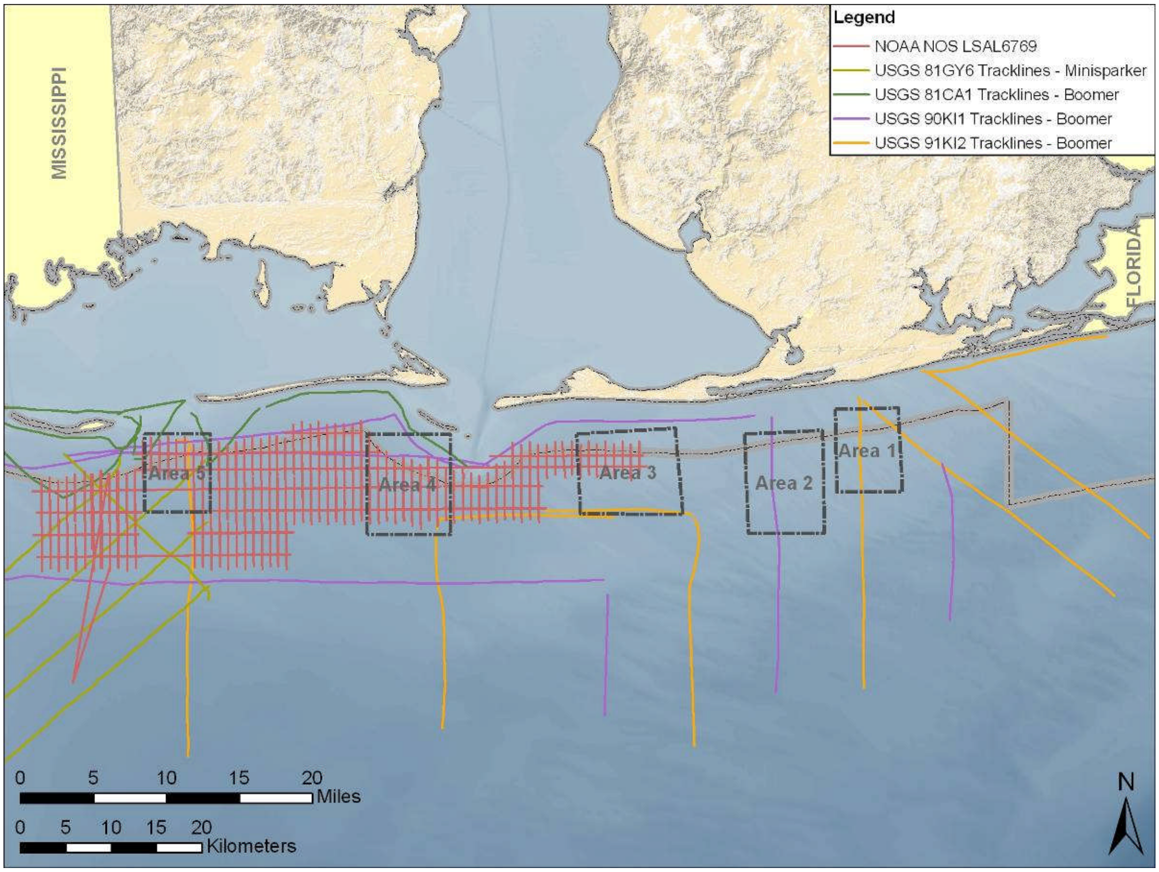

Figure 31.—Distribution of seismic data maintained by government entities.

Sanford and others (2008a) compiled an archive of digitized analog boomer and minisparker data collected from an investigation of the shallow geologic framework and hazards of the Alabama-Mississippi-Louisiana shelf (fig. 31). Work was onboard the R/V *Carancahua* and R/V *Gyre* (Texas A&M University). The R/V *Carancahua* cruise (81CA1) in 1981 collected at least 108 km (67 mi) of high resolution boomer data. From the total, 81CA1 represents 3 km (2 mi) of seismic within MMS Study Area 4 and 6 km (4 mi) within MMS Study Area 5. The R/V *Gyre* cruise (81GY6) in 1981 used a 400-Joule minisparker, 3.5 kilohertz (kHz) subbottom profiler, 12 kHz precision depth recorder, and two air guns to collect at least 145 km (90 mi) of seismic data in the project extent. From the total 81GY6 project, 8 km (5 mi) of seismic data were collected in MMS Study Area 5. Location was determined using a DAP M/FLEX PC1000 computer which implements both GPS and LORAN-C technology where the LORAN-C accuracy varied from 0.16 km (0.1 mi) to 0.4 km (0.25 mi) (Sanford and others, 2008a).

Sanford and others (2008b) compiled an archive of digitized analog boomer seismic reflection data collected from an investigation of the shallow geologic framework of the Mississippi-Alabama-Florida shelf. Work was onboard the R/V *Kit Jones* and R/V *Gyre* (Mississippi Mineral Resources Institute) (fig. 31). Surveys were conducted in June 1990 (90KI1) and July 1991 (91KI2) (Sanford and others, 2008b). The 90KI1 study collected 249 km (155 mi) of seismic data within the MMS project extent, where 11 km (7 mi) were within MMS Study Area 2, 13 km (8 mi) were within MMS Study Area 4, and 13 km (8 mi) were within MMS Study Area 5. Within the project extent, 224 km (139 mi) of the 91KI2 study were collected with 13 km (8 mi) within MMS Study Area 1, 10 km (6 mi) within MMS Study Area 3, 2 km (1 mi) within MMS Study Area 4, and 10 km (6 mi) within MMS Study Area 5. Location was determined using a DAP M/FLEX PC1000 computer which implements both GPS and LORAN-C technology, where the LORAN-C accuracy varied from 0.16 km (0.1 mi) to 0.4 km (0.25 mi) (Sanford and others, 2008b).

ACADEMIC

Brande (1983), as funded through the Mississippi-Alabama Sea Grant Consortium, the University of Alabama in Birmingham, and the U.S. Geological Survey, conducted a seismic survey of Mobile Bay, Mississippi Sound, and offshore Baldwin County to investigate the recent or shallow subsurface geological history of Mobile Bay (Brande and McAnnally, 1984) (fig. 32). In 1980, about 845 km (525 mi) of seismic reflections from minisparker and 7 kHz acoustic systems towed by the R/V *Flying Tiger* were collected. Navigation was by LORAN-C and locations were checked by Miniranger III radar and fixed navigational aids to estimate an error of 60 m (200 ft) (Brande and McAnnally, 1984). The project GIS determined 138.4 km (86 mi) of the total seismic data were within the MMS project extent. An estimated 10.9 km (6.8 mi) were within MMS Study Area 1, 16.9 km (10.5 mi) in MMS Study Area 2, and 24 km (15 mi) in MMS Study Area 3.

Seismic data from Locker and others (1988) were identified on the FLDEP ROSS database. In December 1986, 3,200 km (1,988 mi) of high resolution boomer and 100 kHz side-scan sonar data were collected in state and federal waters from the inner shelf, offshore Alabama (east Baldwin County) and the Florida panhandle (Locker and others, 1988, 1999). Position was maintained using LORAN-C. Within the MMS project extent, about 203 km (126 miles) of seismic data were collected; however, no seismic was acquired within any of the five MMS Study Areas. Although most data were collected to assess the subsurface within Florida state waters, several seismic tracklines are west of the Alabama/Florida state boundary and could provide further data for MMS Study Area

1. Selected seismic images (.jpg format) for tracklines 1, 2, 5, 6, 9, 10, and 13 were collected from the ROSS file transfer protocol site. Mr. Lyle Hatchett (URS Corporation, personal commun., August 11, 2008) provided trackline and time stamp shapefiles from ROSS from which the GSA extracted the seismic data of Locker and others (1988).

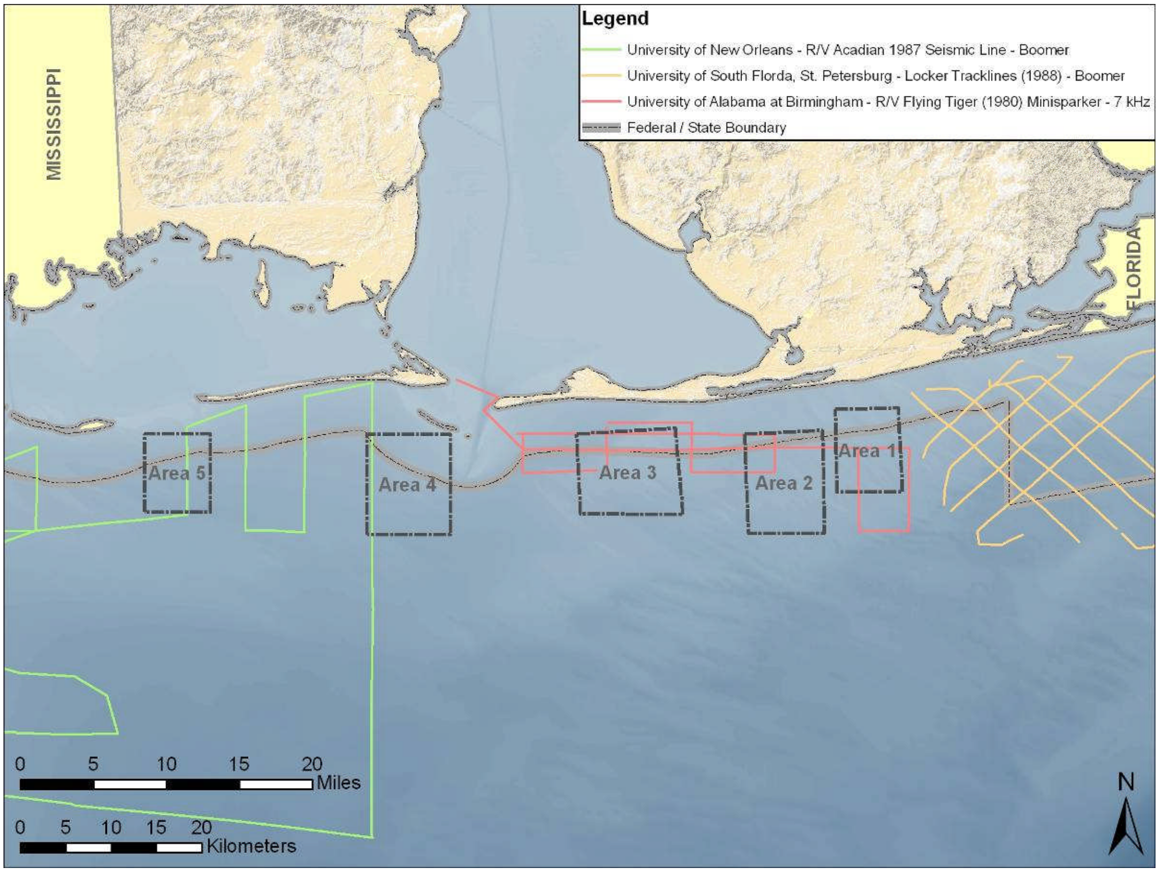

Figure 32.—Distribution of seismic data acquired from academic sources.

High-resolution seismic data collected south of Dauphin Island was acquired from Dr. Mark Kulp (University of New Orleans, personal commun., September 2, 2009) (fig. 32). The R/V *Acadiana* collected 1,640 km (1,017 mi) of seismic data in three legs with 493 km (306 mi) of leg 3 lying within the MMS project extent. Seismic data collected on June 23 and 26, 1987 included 11 km (6.8 mi) within MMS Study Area 4 and 8.6 km (5.4 mi) within MMS Study Area 5. With navigation provided by the Northstar 6000 LORAN, high-resolution seismic data were collected by Louisiana Universities Marine Consortium using an ORE Geopulse (Boomer) and an ORE 3.5 kHz Subbottom Profiler with ORE 140 Transceiver (http://quashnet.er.usgs.gov/data/1987/87023/).

PRIVATE

As part of a sand search investigation for the city of Gulf Shores during November 21-23, 1999, AOSS collected about 129 km (80 mi) of high-resolution seismic data (2-10 kHz DataSonics 6600 Chirp system) from the R/V *Atlantic Twin* (AOSS, 2000; Olsen, 2001) with DGPS navigation (fig. 33). Trackline locations, as provided by AOSS (2000), were digitized into a GIS and are located in state waters mainly north of MMS Study Areas 1 and 2. Based on the GIS, an estimated 28 km (17 mi) of seismic data were collected within the state waters of MMS Study Area 1. The 16 tracklines are oriented east-west and range from 1.6 to 9.6 km in length. Seismic imagery for lines 1 through 16 and geologic interpretations for lines 4 and 6 through 11 are hyperlinked to the trackline AOSS (2000).

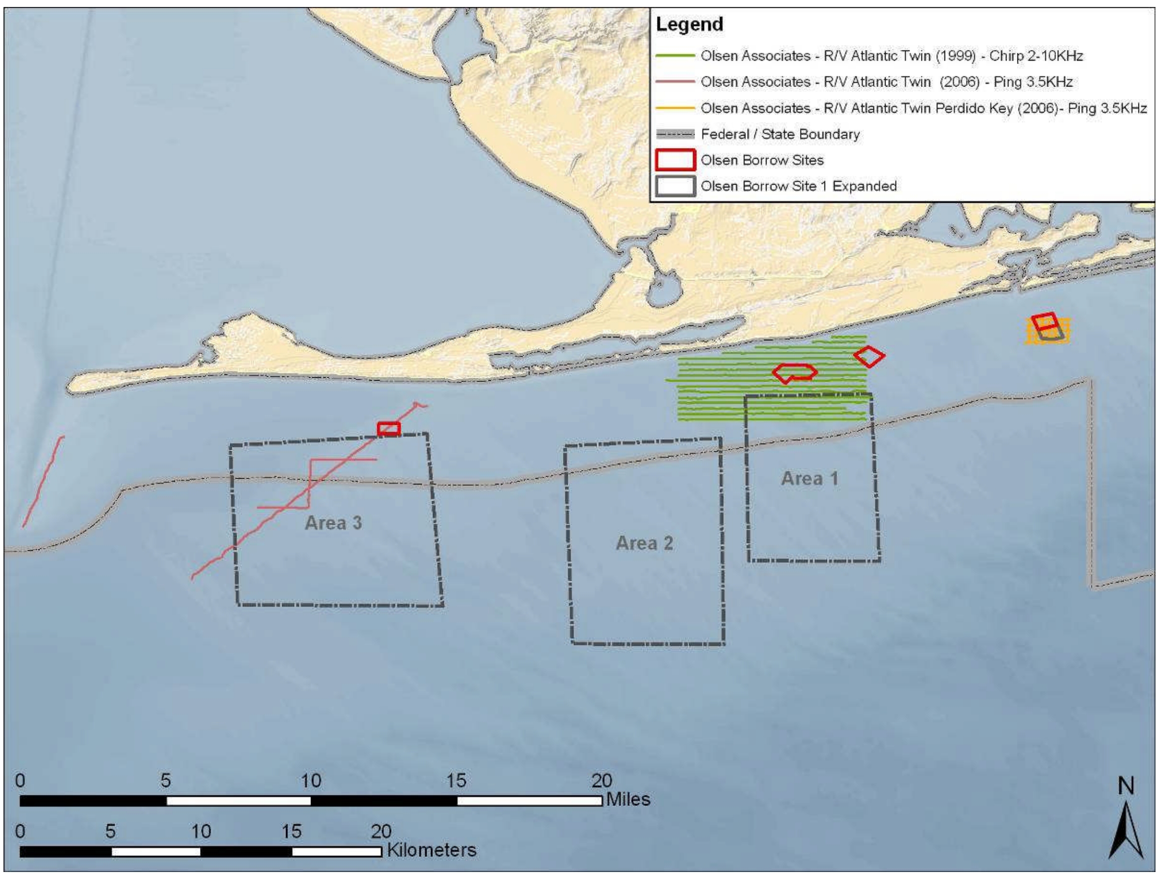

Figure 33.—Distribution of seismic data collected from the private sector.

Olsen (2006b) conducted an exploratory geotechnical sand search to identify additional offshore sand reserves and to further investigate borrow site 1 to support future maintenance of the engineered beaches along the Baldwin County coastline (fig. 33). Within federal and state waters, an estimated 48.9 km (30.4 miles) of seismic and bathymetric line data were collected by AOSS (2006) as directed by Olsen (2006b). In April 2006, AOSS collected high-resolution seismic data (GeoAcoustics GeoPulse 3.5 KHz subbottom profiler) from the R/V *Atlantic Twin* (AOSS, 2006; Olsen, 2006b) with DGPS positioning. Based on GIS, an estimated 3.5 km (2.2 mi) of seismic data were collected along Dixie Bar, 23.5 km (14.6 mi) on the Baldwin Shoal, and 19.9 km (12.4 mi) at the Olsen borrow site 1. Borrow site 1 is about 8.5 km (5.3 mi) east-northeast of MMS Study Area 1 and within state waters southeast of Perdido Pass. An estimated 17 km (10.6 mi) of seismic data were collected within MMS Study Area 3; 9 km (5.6 mi) was collected parallel to the crest or trend of Baldwin Shoal and 8 km (5 mi) was collected diagonal to the trend.

DELINEATION OF POTENTIAL SAND RESOURCE AREAS

A geographic information system was used to delineate potential sand resource areas and identify alternate areas of high potential. Using the geoprocessing and visualization functionality of GIS, the geological data were integrated with ancillary geospatial data to model potential sand resource areas.

Although it has been suggested that the surficial sand sheet contains an abundance of beach-quality sand (Hummell, 1999), sand ridges have been the primary target for beach-quality sand (Olsen, 2001, 2003b, 2006b; Rindsberg and Kopaska-Merkel, 2006) and have been dredged for previous beach restoration projects (Olsen, 2003a, 2006a). As such, figure 34 represents the delineation of prominent beach ridge and shoal crests and flanks within each MMS Study Area. Shoreface-attached oblique sand ridges occupy the areas within MMS Study Areas 1 and 2. The area within MMS Study Area 3 consists chiefly of the oblique sand ridges superimposed or shoal-attached on the Baldwin Shoal. Ridges within MMS Study Areas 4 and 5 are low-relief features south of the Mobile Bay ebb-tidal delta and the shoaling within Petit Bois Pass, respectively. It is now understood that not all sand within the surficial sand sheet is beach compatible with native Baldwin County beach sands and that the distribution of lithofacies or sand quality along ridge features can change rapidly.

Using the ArcInfo Erase command, MMS Study Area ridge polygons were modified to exclude areas with shipping fairways, USACE offshore disposal areas, shipwrecks, and gas pipelines and platforms. Although MMS Study Area 3 has eight locations listed on the NOAA Marine Debris database and MMS Study Area 4 has two submerged obstructions and one sounding location, further investigation is warranted before these locations are removed from offshore sand source consideration. Figure 35 represents potential sand source areas based on geomorphology, infrastructure, and other areas of concern. Topology was built for potential sand source polygons having determined areas as follows: (1) 19.04 km^2 (7.35 mi^2) within MMS Study Area 1, (2) 16.99 km^2 (6.56 mi^2) within MMS Study Area 2, (3) 31.98 km^2 (12.35 mi^2) within MMS Study Area 3, (4) 4.64 km^2 (1.79 mi^2) within MMS Study Area 4, and (5) 6.3 km^2 (2.43 mi^2) within MMS Study Area 5.

A sand isopach thematic layer was developed for sand deposits based on existing vibracore logs using intervals logged as poorly-graded clean sand (SP) (Olsen, 2001, 2003b, 2006b) and intervals logged as Graded Shelly Sand and Clean Sand lithofacies (Parker and others, 1993; Hummell and Smith, 1996; Hummell, 1999; Rindsberg and Kopaska-Merkel, 2006). Sand isopach maps for offshore Baldwin County and Dauphin Island are illustrated in figures 36 and 37, respectively. Sand thickness values were determined from logs using the uppermost intervals and no documented overburden; derived values were attributed to a GIS theme. A triangulated irregular network surface was developed from the shapefile based on thickness, and contours were created using Inverse Distance Weighted interpolation. Although dense around sand borrow areas within state waters, the data used to create isopach contours in the mapped areas were sparse. Preliminary contours created by GIS were finalized using bottom topography, cross sections, and borrow areas. Five (5)- and 10-foot isopach contours were developed. A sand isopach delineation representing a thickness equal to or greater than 10 feet is illustrated (figs. 36 and 37).

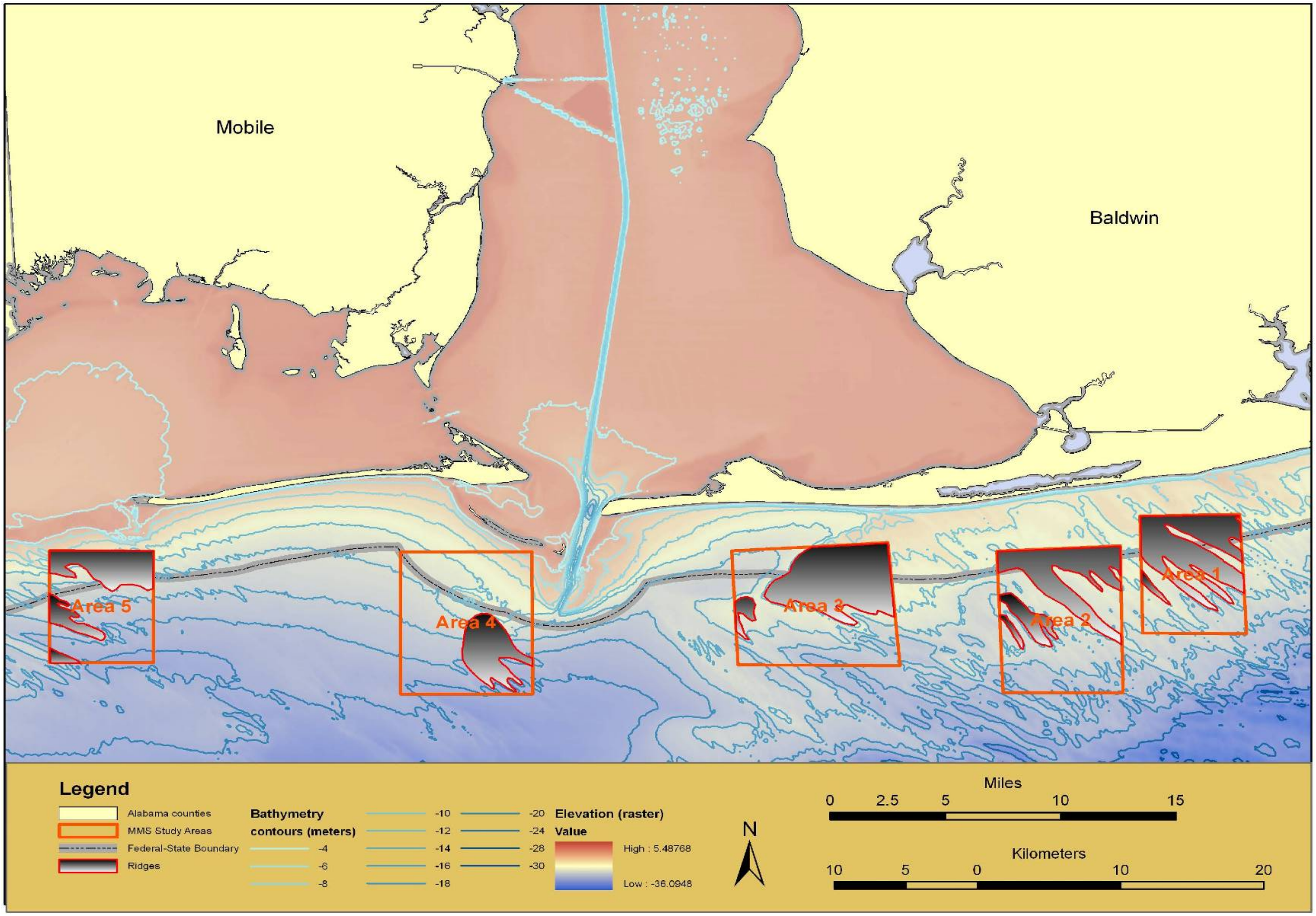

Figure 34.—Ridge and shoal delineations within MMS Study Areas.

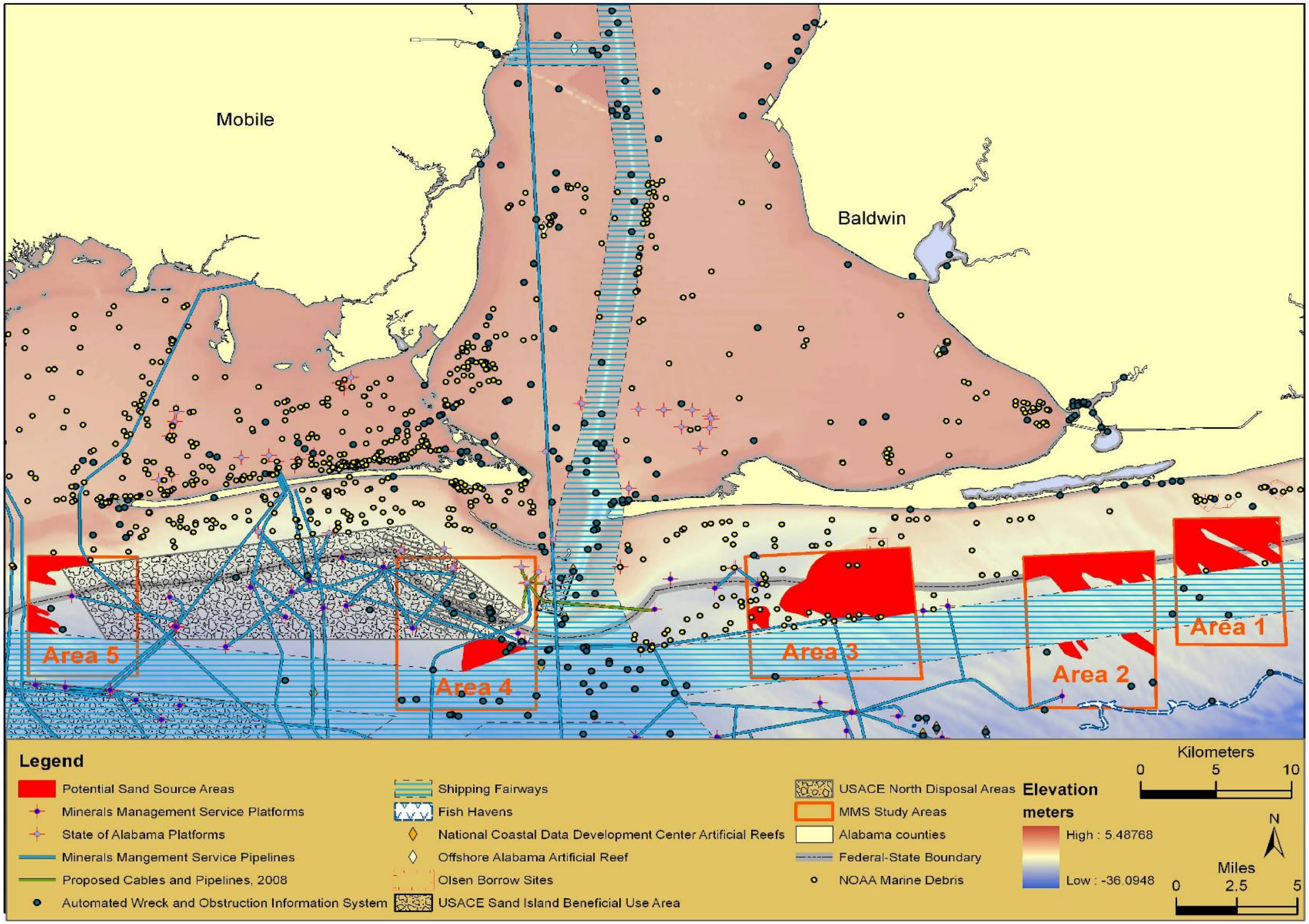

Figure 35.—Modified ridge and shoal polygons excluding infrastructure and offshore concerns.

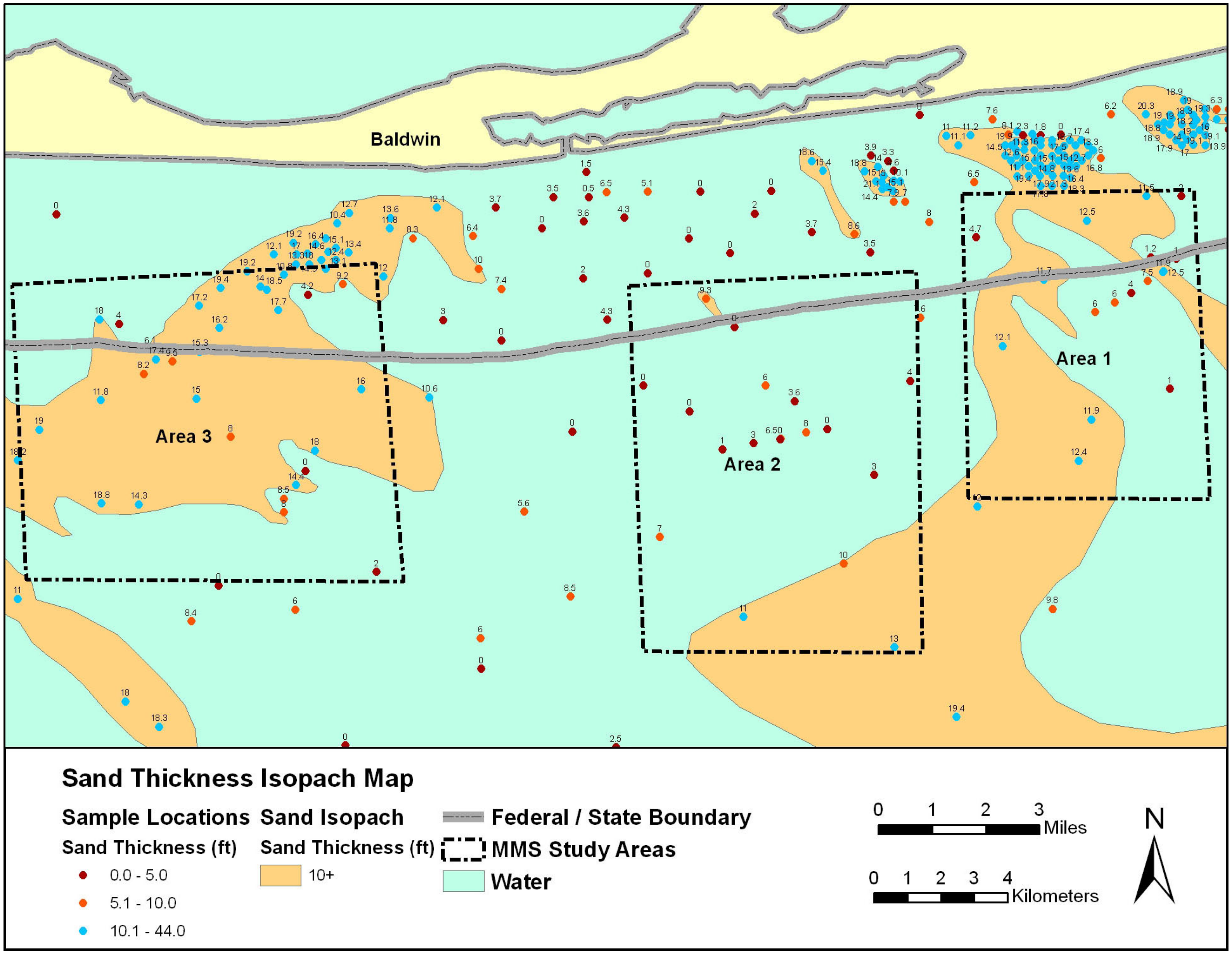

Figure 36.—Sand isopach interpretations, offshore Baldwin County, Alabama.

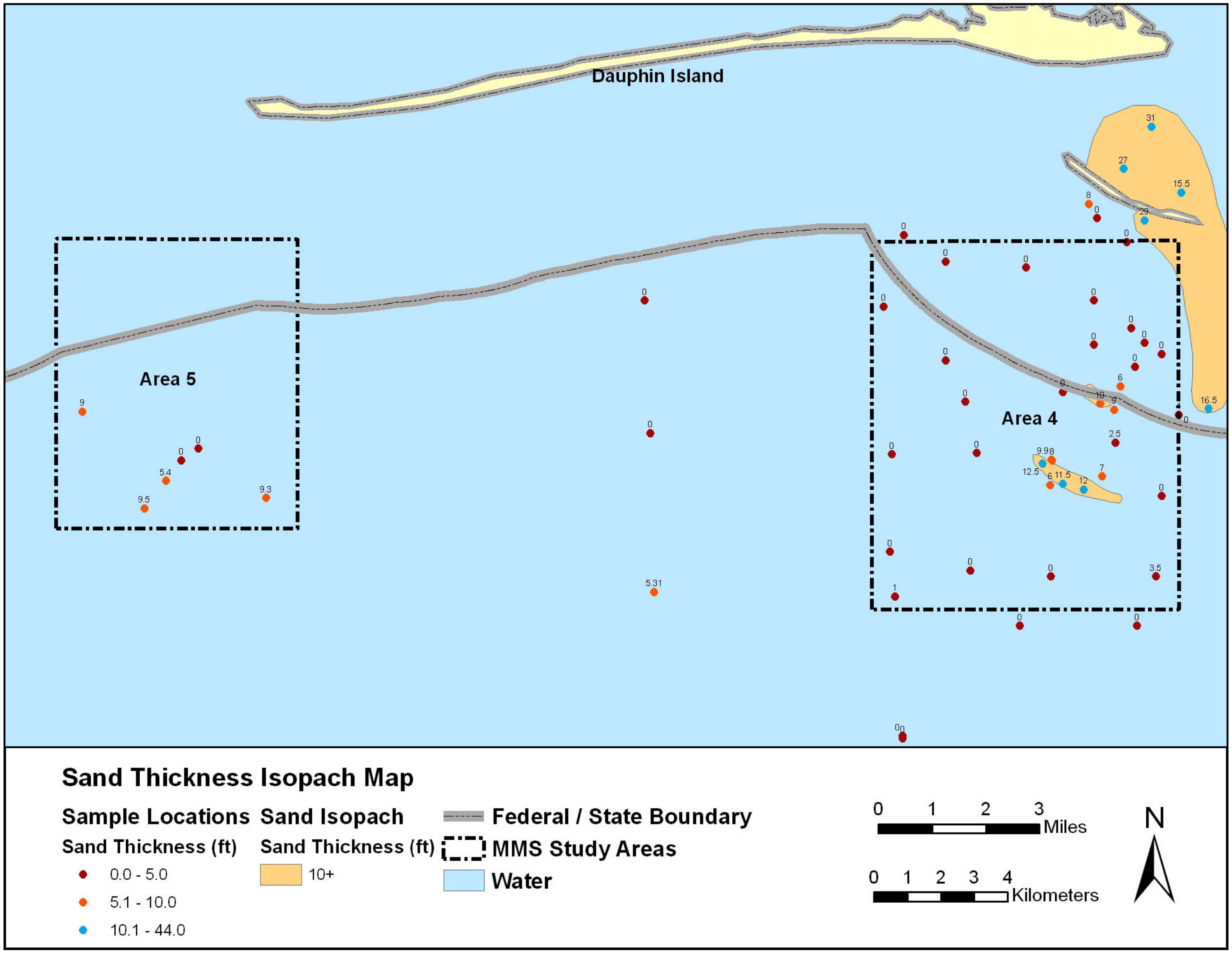

Figure 37.—Sand isopach delineations, offshore Dauphin Island, Alabama.

Delineation of potential sand source areas required examining several criteria, such as infrastructure, core logs, topographical maps, and sand isopach maps. Infrastructure areas were removed first, since permitting in those areas is problematic. The sand isopach map was then evaluated to determine if the area had enough available sand to dredge. The contours from the sand isopach map along with the topographical map that shows topographic ridges and valleys were used in conjunction with core log data to determine ridges of potentially viable sand. The core logs were used to determine color and whether or not organic material was present that would inhibit the area from being available for dredging. Examining all these criteria and assuming lithofacies transition distances, Tier 1 and Tier 2 potential sand borrow areas were delineated (fig. 38). Tier 1 potential sand borrow areas are zones where sand characteristics from vibracores indicate an area that has the potential for beach nourishment. Several criteria that make Tier 1 potentially suitable for beach nourishment include color (10 YR 9.0/1.5, a nearly white sand that has a slight tan or orange cast (Olsen, 2003b)), grain size (sand grains on Alabama beaches average about 330 μm with a standard deviation of 73 μm (Kopaska-Merkel and Rindsberg, 2005), and distance from nourishment areas. Tier 2 areas are topographically similar to some Tier 1 areas, but lack either adequate sediment thickness to qualify as a Tier 1 area or sufficient vibracore data to accurately determine sediment thickness or characteristics. These delineations align with previous delineations by Olsen Associates, Inc. within state waters for sand borrow sites just to the north of MMS Study Areas 1 and 3. These delineations are in agreement with previous delineation of sediment borrow sites by Byrnes and others (1999). MMS Study Areas 1, 2, 3, and 4 contained an estimated Tier 1 area of 4.76 km^2 (1.84 mi^2), .278 km^2 (.107 mi^2), 15.34 km^2 (5.92 mi^2), and 0.794 km^2 (.306 mi^2), respectively; MMS Study Area 5 contained no Tier 1 delineations. Combined Tier 2 area calculations for each area yielded 1.68 km^2 (0.649 mi^2), 0.464 km^2 (0.179 mi^2), 6.04 km^2 (2.33 mi^2), 0.742 km^2 (0.286 mi^2), and 4.625 km^2 (1.78 mi^2) within MMS Study Areas 1, 2, 3, 4, and 5, respectively.

Negating the effects of infrastructure and assuming hopper dredges can work within shipping fairways, alternate potential sand delineations were made based on vibracore data, geomorphology, Tier 1 and Tier 2 calculations, and suggested resource areas (Byrnes and others, 1999; Hummell, 1997; Hummell and Smith, 1996; Olsen, 2006b) (fig. 39).

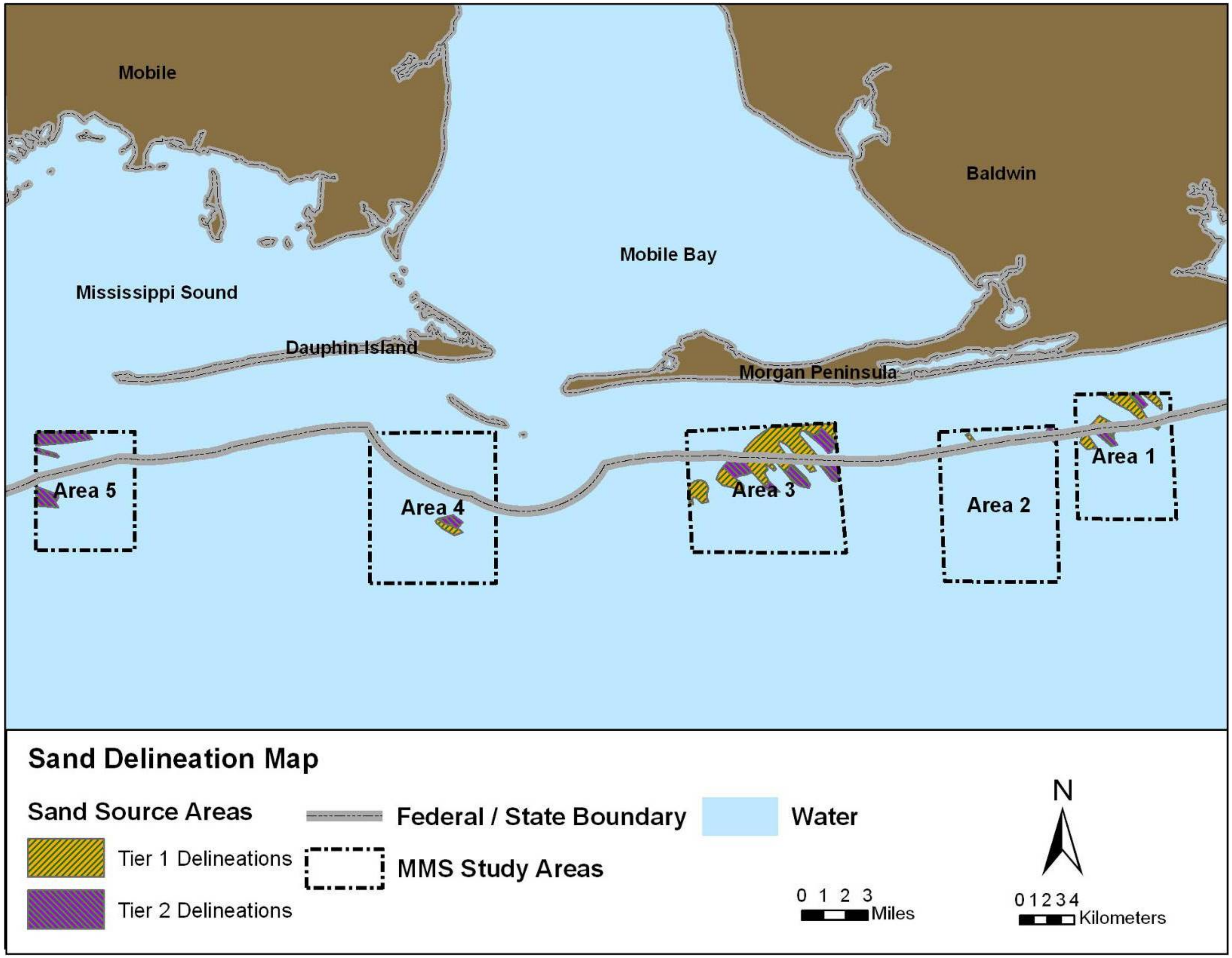

Figure 38.—Distribution of Tier 1 and Tier 2 potential sand search areas.

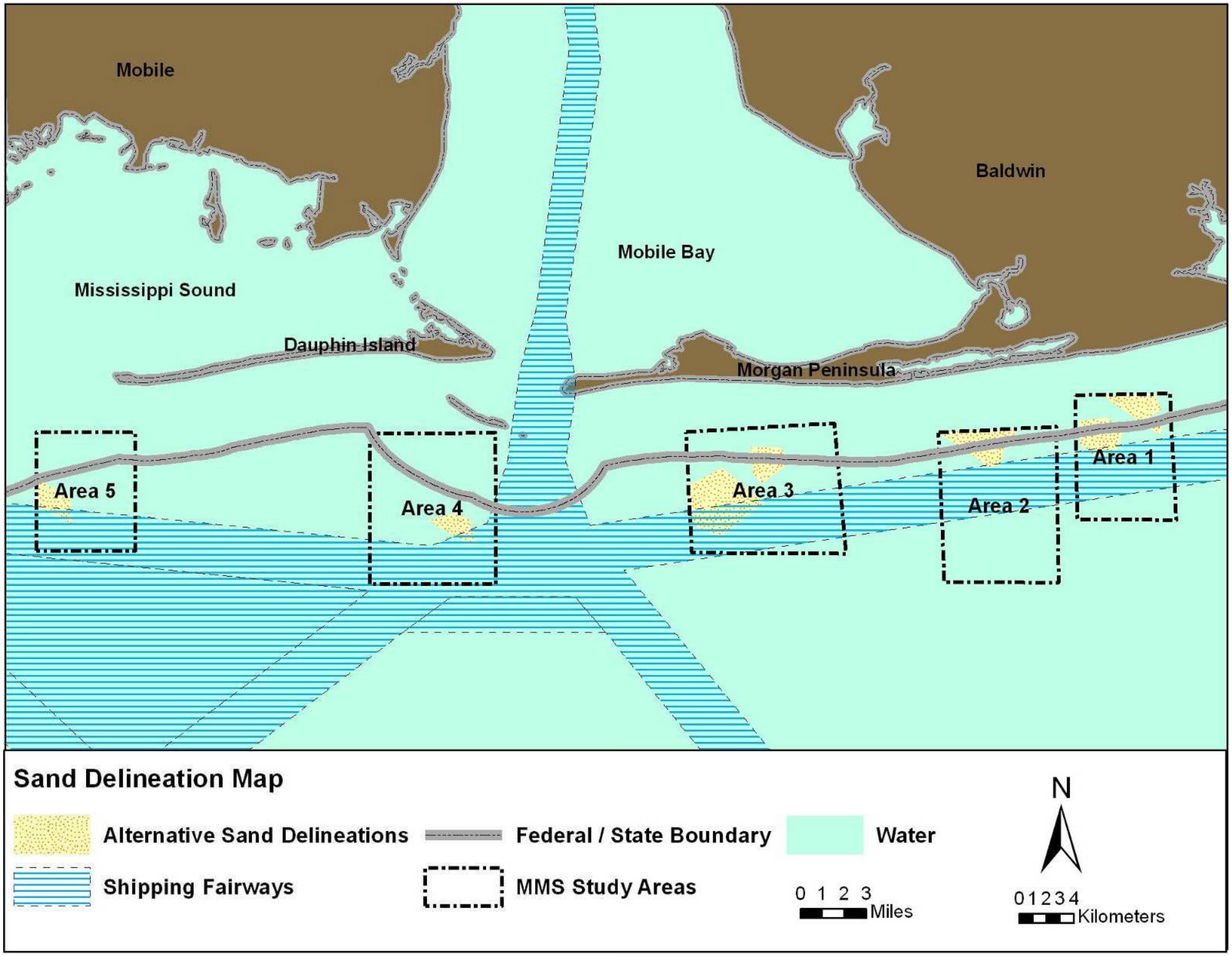

Figure 39.—Distribution of alternative potential sand search areas.

Within MMS Study Area 1, the two potential areas delineated include a 5.08 km^2 (1.96 mi^2) area located mainly within the northeast section and a 6.03 km^2 (2.33 mi^2) area located in the west-central portion of the study area. MMS Study Area 2 contained one polygon in the north and northwestern portion with an area of 7.2 km^2 (2.78 mi^2). Within MMS Study Area 3, two potential areas delineated are associated with Baldwin Shoal with a 4.53 km^2 (1.75 mi^2) area located mainly within the northeast quadrant and a 15.05 km^2 (5.81 mi^2) area located in the western half of the study area. A 3.49 km^2 (1.35 mi^2) area is located mainly within the southeast quadrant and south of the Mobile Bay ebb-tidal delta and the USACE Mobile North disposal area in MMS Study Area 4. For MMS Study Area 5, a 4.27 km^2 (1.65 mi^2) area was delineated from Tier 2 data.

CONCLUSIONS

The Offshore Alabama Sand Information System (OASIS) is an internet mapping service representing a compilation of shallow sediment, geophysical, and ancillary geospatial data. Source data implemented in this study were from government, private, and academic entities and mainly included digital legacy data as well as data recovered from an analog environment. The effort to procure offshore geological data was exhaustive. The OASIS platform was developed to promote the discovery and management of offshore data related to sand resource investigations, provide a web-based avenue of information exchange of past offshore sand source data, and provide a platform that is easily accessible and expandable.

Previous investigations in offshore Alabama have mainly included bottom sampling for potential sand sources and associated studies and shelf characterization. Data are not dense within the five MMS Study Areas so there remains a critical data gap where further sub-bottom sampling is essential to delineate a suitable sand deposit for Alabama beach placement. Although the largest sets of vibracore data were collected by the Geological Survey of Alabama and Olsen Associates, Inc., direct comparison is complicated due to variations in sample characterization (color, sediment classification), methodologies, and technology used to acquire sample site coordinates (LORAN-C versus GPS).

Potential sand resource areas within the five MMS Study Areas were delineated using two methods of evaluation. The first created Tier 1 and Tier 2 potential sand resource target investigation areas. The areas were defined based on bottom geomorphology, infrastructure, disposal areas and other offshore concerns, sand isopach delineations, and existing borrow areas in state waters. Tier 1 represents the areas most likely to prove beneficial for beach-quality sand resource delineation and permitting once an in-depth detailed sub-bottom investigation has been completed. The minimum and maximum Tier 1 areas were 0.278 km^2 (0.1 mi^2) within MMS Study Area 2 and 15.34 km^2 (5.9 mi^2) within MMS Study Area 3. In the second method, alternative potential sand delineations were determined which excluded offshore concerns but were inclusive of tiered estimates and the potential borrow areas that have been delineated and modeled (Byrnes and others, 1999; Hummell, 1997).

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