Understanding the Habitat Value and Function of Shoal/Ridge/Trough Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf

Draft Literature Synthesis

U.S. Department of the Interior
Bureau of Ocean Energy Management

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Acronyms and Abbreviations

ACS	Atlantic Continental Shelf
BOEM	Bureau of Ocean Energy Management (United States)
cm	Centimeter
EFH	Essential Fish Habitat
ESA	Endangered Species Act
FMP	Fishery Management Plan
GMFMC	Gulf of Mexico Fishery Management Council
HAPC	Habitat Areas of Particular Concern
km	Kilometer
MAFMC	Mid-Atlantic Fishery Management Council
Magnuson-Stevens Act	Magnuson-Stevens Fishery Conservation and Management Act (United States)
m	Meter
mm	Millimeter
MMS	Minerals Management Service (precursor to BOEM) (United States)
NEFMC	New England Fishery Management Council
nm	Nautical Miles
NMFS	National Marine Fisheries Service (United States)
NOAA	National Oceanic and Atmospheric Administration (United States)
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act (United States)
SAFMC	South Atlantic Fishery Management Council

1.0 Introduction

The Bureau of Ocean Energy Management (BOEM), part of the Department of the Interior, is responsible for managing the development of the energy and mineral resources on the Outer Continental Shelf (3 nautical miles [nm] offshore of most states, with the exception of Texas and the Gulf coast of Florida, where it is 9 nm). This management includes the Oil and Gas, Marine Minerals, and the Renewable Energy Programs. The BOEM Marine Minerals Program (MMP) considers proposals for use of OCS sand resources. Public Law 103-426 (43 U.S.C. 1337(k)(2)), enacted 31 October 1994, gave BOEM the authority to negotiate, on a noncompetitive basis, the rights to OCS sand, gravel, and shell resources for shore protection, beach or wetlands restoration projects, or for use in construction projects funded in whole or part by, or authorized by, the federal government. The BOEM Renewable Energy Program considers proposals for wind energy facilities on submerged lands. Offshore shoals are of scientific interest to both programs – as a source of sand for beach nourishment, coastal restoration, and shoreline protection projects and as an ideal location for renewable energy projects to take advantage of favorable bathymetric conditions.

BOEM must analyze the effects of the aforementioned activities under the requirements of the National Environmental Policy Act (NEPA) using the best available science. BOEM also routinely consults with several other federal agencies including the National Marine Fisheries Service (NMFS) (Endangered Species Act and the Magnuson-Stevens Fishery Conservation and Management Act) and the Fish and Wildlife Service (FWS) (Endangered Species Act) to ensure that the sensitive biological resources considered under these mandates are carefully evaluated.. Under the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) of 1976, with 1996 and 2007 amendments, NMFS is responsible for the identification and protection of essential marine and anadromous fish habitats. NMFS defines Essential Fish Habitat (EFH) for federally managed species, supporting a primary goal of maintaining sustainable fisheries. NMFS has identified ridgeswale and cape-associated shoal complexes as EFH and in some areas as Habitat Areas of Particular Concern (HAPC) (e.g., Frying Pan Shoals offshore of Cape Fear, NC). BOEM is interested in understanding the status of scientific research on the ecological functions and biophysical coupling of these sand features to provide for improved resource use and management.

Background

There has been an increasing demand for OCS sand due to diminishing state water resources (Drucker et al. 2004) and severe weather conditions which, coupled with chronic erosion, has led to substantial coastal damage. A number of sand sources suitable for these coastal projects have been identified along the OCS in the Atlantic and the Gulf of Mexico. There are also likely a number of unidentified sources as well that BOEM, the US Army Corps of Engineers, the US Geological Survey, states (including NJ, MD, DE, VA, NC, SC, FL, AL, LA, and TX; with current discussions involving ME and MA) and specific localities have been working to characterize. The federal and state partnerships have identified specific potential borrow areas in federal waters containing large sand quantities. These partnerships have focused on isolated, relict submerged shoals and surficial sand sheets, but are expected to expand sand investigations to buried paleochannels and shoreface-attached sand ridges (Drucker et al. 2004). Identified potential offshore sand resource areas are described in the following literature by state: New Jersey (Smith 1996, Uptegrove et al. 2006); Maryland (Conkwright and Gast 1995, Conkwright and Williams 1996, Conkwright et al. 2000); Delaware (McKenna and Ramsey 2002); Virginia (Kimball and Dame 1989, Williams 1988); North Carolina (Hoffman 1998, Boss and Hoffman 2001); South Carolina (Gayes et al 1998, Wright et al. 1998, Wright et al. 1999); Florida (Hoenstine et al 2002, Phelps and Holem 2005); Alabama (Parker et al. 1993, Hummell and Smith 1996, Rindsberg and Kopaska-Merkel 2006); Louisiana (Ramsey and Penland 1992, Kulp et al. 2001); and Texas (Morton and Gibeaut 1993, 1995; Finkl et al. 2007a; Dellapenna et al., 2006a and b; Dellapenna et al., 2009). Site-specific studies have been conducted at some of these areas to provide basic information on physical and biological characteristics and to evaluate the potential effects of sediment extraction on local wave and current regimes (Drucker et al. 2004).

Potential short-term and long-term physical and biological impacts from sand removal operations have been discussed by Maa et al. (2004), Diaz et al. (2004a), Byrnes et al. (2004a and b), and many others. The main impact concerns include: 1) altering the physical characteristics of the area (shoal topography, wave and current patterns, sediment transport regime, and sediment grain size; 2) elevated turbidity; and 3) the removal and or alteration of benthic epifaunal and infaunal communities (Drucker et al. 2004, Hayes and Nairn 2004).

Additionally, because of their relative abundance on the innershelf (0-30 m.), locations with similar geomorphic features to borrow areas are likely targets for siting of wind energy foundations in Atlantic Wind Energy Areas. Several distinctive types of sand deposits are of interest for both borrow area and wind energy siting purposes – ridge and swale complexes that are prevalent in the Mid-Atlantic, cape-associated shoals that are prevalent in the southern Mid-Atlantic to South Atlantic, and sand banks that are most prevalent in the Gulf of Mexico. Marine mineral leases for OCS sand have been issued to North Carolina, South Carolina, Virginia, Florida, and Louisiana for beach and shoreline restoration projects.

Historically, ecological studies in support of BOEM's marine minerals mining mission have focused largely on benthic communities, which are the organisms that had been considered to experience the most direct impacts from sand mining (Brooks et al. 2006; Byrnes et al. 2000, 2003, 2004; Cutter et al. 2000; MMS 2004). Carefully designed field studies that included sampling of microhabitats (e.g., troughs vs. crests of sand waves; tops vs. flanks of banks) have found differences in these communities that suggest that the distribution of benthic predators (and prey) may vary spatially (Cutter et al. 2000; Slacum et al. 2006, 2010; Stone et al. 2009). Subsequently, a few studies have focused on finfish utilization of shoal complex habitats and found definite spatial and some lifestage preferences (e.g. the preference for tops of shoals by sand lances), however these studies have also left many questions unanswered (Diaz et al. 2003,, Brooks et al. 2005, Slacum et al. 2010, Michel et al. 2013). The scientific background for determining the level of impact to these predator/prey groups along with the habitats they are associated with is incomplete. With an ever-present demand for sand and gravel resources for beach nourishment and shoreline protection along the Atlantic and Gulf of Mexico coasts, as well as potential development of these shoals for offshore renewable energy facilities, BOEM must strive to improve their understanding of the ecological values and functions of these resources, along with their physical environment. This report is part of an effort by BOEM to assimilate information that will enhance the understanding of the physical and biological dynamics of these shoal systems and assist in NEPA analyses and regulatory decisions utilizing sound science.

Approach

The BOEM MMP is convening a working group (hereafter referred as the working group) *to discuss and identify the most critical information needs and data gaps* that need to be addressed to better understand the habitat value and function of ridge-swale, shoal, and cape-associated shoal complexes to fish and fisheries on the Atlantic and Gulf of Mexico OCS.

To help focus the working group and support a productive discussion, this document presents an abbreviated Literature Synthesis (or Synthesis) that summarizes current knowledge of the topic as of June 2013. The focus of this Literature Synthesis will be on the interactions of fish, fisheries, and invertebrates of the U.S. Atlantic and Gulf of Mexico OCS with various types of offshore shoal complexes.

This Synthesis provides initial identification of information needs and data gaps for the working group. It is intended that this Synthesis be available to participants prior to the working group so that it can serve as a basis for working group discussions.

BOEM's specific objectives for the Literature Synthesis and subsequent working group are to:

- Identify the habitat value and functions of shoal/ridge/trough complexes to priority fishes on the Mid-Atlantic, South Atlantic, and Gulf of Mexico OCS;
- Summarize current scientific understanding of the habitat uniqueness, value, and function of ridge/swale and shoal complexes for benthic and fish communities, identifying critical gaps in understanding;
- Review and evaluate the effectiveness of the various scientific research methods and approaches that are used or may be used in examining these information needs;
- Identify relevant areas, space, and time scales for study, cost-effective research methods, costs, and cost-leverage study opportunities to develop appropriate duration datasets to address the critical gaps in understanding;
- Foster collaboration among federal and state agencies, industry (both alternative energy and marine minerals), and academia in addressing information needs;
- Advance the understanding of how the disturbance of benthic habitat and infaunal/epifaunal communities may (or may not) lead to cascading effects on keystone demersal and pelagic fishes;
- Identify next steps, if appropriate, for the utilization of compiled knowledge; next steps may include identification of research needed to fill data gaps in order to enhance future BOEM OCS management decisions; and,
- Identify, if appropriate, mitigation approaches to avoid impacts to priority habitats, fisheries, and fish.

Literature Search Methods

A data collection strategy that employed online commercial databases, literature search tools, and Internet search tools was used to gather data to characterize shoal habitat value and function to fish and fisheries.

The following commercial databases and search tools were used in the search for data on shoal fish habitat value and function: ASFA - Aquatic Sciences and Fisheries Abstracts, Biological Sciences, BioOne Abstract, GeoRef, and Google Scholar. In-house libraries at Normandeau were also utilized.

Key search terms and phrases were used to conduct methodical queries of databases and the Internet. All fields (title, abstract, etc.) were searched for a term that referenced shoal complexes, the taxa of interest, and/or specific areas and features of interest. Initially selected key terms and phrases provided a starting point from which a more complete list of terms was developed as the search progressed. Examples of terms and phrases used in the search include: "shoals"; "shoal complexes"; "shoal field"; "sand ridge"; "sand ridge fields"; "linear shoals"; "ridge and swale complexes"; "ridge and trough complexes"; "submerged barrier islands"; "New Jersey sand ridges"; "Maryland shoal fields"; "Fenwick Shoal"; "Weaver Shoal"; "Great Gull Bank"; "Baldwin Ridge"; "Sabine Bank"; "Ship Shoal"; "Trinity Shoal"; "Barnegat Ridge"; "Inshore Southeast Lumps"; "Diamond Shoals"; "26-Mile Lump"; "microhabitat". Reference listings from relevant documents were also used to identify important earlier work on the same topic. More recent papers that cited an original reference of interest were identified using links to these references that are provided within electronic databases.

Studies that did not specifically pertain to shoal complex fish habitat value and function were generally excluded. Published, peer-reviewed, English language studies (or those that provided English language abstracts) that are indexed in scientific databases were the primary focus of the search, although relevant government and industry technical reports, websites, and presentations were also reviewed.

Additional Literature Reviews and Syntheses

This Literature Synthesis provides a comprehensive, though by no means complete, listing of the literature on the habitat value and function of ridge-swale, shoal, and cape-associated shoal complexes to fish and fisheries on the Atlantic and Gulf of Mexico OCS. It includes citations of the most relevant literature, and highlights those studies that are most important for current and future understanding of the topic at hand. Additional literature, and many more citations, can be found in the following sources:

- Kaplan (2011) — A literature synthesis of the oceanographic resources in the North and Central Atlantic Ocean.
- Louis Berger Group (1999) — An environmental report on the use of federal offshore sand resources for beach and coastal restoration in New Jersey, Maryland, Delaware, and Virginia.

- Brooks et al. (2006) — A paper that reviews the existing literature on the benthic faunal resources for the US Atlantic and Gulf of Mexico continental shelf.
- NOAA Technical Memorandum NMFS-NE series: Essential Fish Habitat species source documents (1999-present) — Compilations of the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England and Mid-Atlantic Fishery Management Councils.
- South Atlantic Fishery Management Council (1998) — The Habitat Plan for the South Atlantic Region: Essential Fish Habitat Requirements. This document contains information on the distribution, abundance, habitat requirements by lifestage, and the distribution and characteristics of those habitats for species, species groups, and habitats managed by the South Atlantic Fishery Management Council.
- Gulf of Mexico Fishery Management Council (1998) — Information on the habitat requirements for species managed by the Gulf of Mexico Fishery Management Council.
- NMFS (2009) — Amendment 1 to the Atlantic Highly Migratory Species Fishery Management Plan designating Essential Fish Habitat. This document contains information on the life history and habitat requirements for Atlantic tunas, swordfish, and sharks managed under this fishery management plan.
- Gilmore (2008) — A regional fishery resource survey and synthesis in a Florida county for comprehensive beach and offshore monitoring program.
- Brooks et al. (2005) — A USGS synthesis of the Southeast Area Monitoring and Assessments Program's Groundfish Survey database for 1982-2000.
- Johnson et al. (2008) — A NOAA technical memorandum on the impacts to marine fisheries habitat from nonfishing activities.
- CSA International, Inc et al. (2010) — An analysis of potential biological and physical impacts of dredging on offshore shoal features.
- Michel et al. (2013) — A BOEM review of biological and biophysical impacts from dredging offshore sand.
- Dibajnia and Nairn (2010) — A BOEM investigation of dredging guidelines to maintain and protect the geomorphic integrity of offshore shoal regimes.

2.0 Geology and Geography

The Holocene geological epoch began at the end of the Pleistocene at 11,700 calendar years before present (ybp) and continues to the present (Walker et al., 2009a). During the Last Glacial Maximum (LGM), 26,000-19,000 ybp, sea level was 120 m lower than current levels (Clark et al., 2009). During the LGM, much of the entire continental shelf of the Gulf of Mexico and the Atlantic coast of North America were exposed and the landscape was eroded. Along the northern coast, as far south as the Hudson River, glaciers extended out onto the shelf and carved fjords. South of the Hudson River, during the LGM, the coastal plain was situated where the current continental shelf is, and rivers flowed across it, incising valleys. Following the LGM, sea levels rose during the late Pleistocene, continuing on into the Holocene. During the Holocene, as sea level rose, shorelines retreated and valleys filled. As shorelines retreated the shelf underwent transgressive ravinement, the act of wave-generated erosion down to the depth of the wave-base; although a highly variable process, in many cases ravinemet effectively erodes the upper 5-12 m of sediment (e.g. Wallace et al., 2010). Within the valleys, estuaries formed and in many places, transgressive ravinement exposed previously buried sedimentary sand bodies, such as bayhead deltas, fluvial deposits and tidal deltas as well as the bases of barrier island complexes and other features. Differential compaction of the surrounding sediment, as well as the erosion of this sediment would leave coarser deposits as exposed features, both creating shoals and providing the sand sources needed to source shoals (e.g. Rodriguez et al., 2001). All of the shoals are Holocene in age, with the noted exceptions of the Florida shelf, where there are Pleistocene aged reefs (e.g. Finkl and Andrews, 2008), and along the Gulf of Mexico coast, where there are the caps of the tops of salt domes (neither of which are considered in this study).

2.1 What are Shoals? Geological Considerations

A ***shoal*** is a natural, underwater ridge, bank, or bar consisting of, or covered by, sand or other unconsolidated material, rising from the bed of a body of water to near the surface. The term ***shoal complex*** refers to two or more shoals (and adjacent morphologies, such as troughs) that are interconnected by past and or present sedimentary and hydrographic processes. These complexes are also known as ***ridge and trough systems*** or ***shoal fields***. A glossary is included in Appendix A to define many of the terms used in this Synthesis to facilitate understanding of what may be new terms for some readers.

For the USA, from the mid-Atlantic, southward across the Gulf of Mexico, offshore shoals are sedimentary deposits, typically sand or gravel dominated (Finkl and Hobbs III 2009), with bathymetric relief of a meter or greater, and that provide potentially important habitat. Each of these shoals is morphologically dynamic, primarily driven by waves and currents during tropical storms and hurricanes as well as less intense, northern fronts and other lower intensity events.

Inner and mid-shelf shoals that can be used for sand extraction can be broken down into three broad categories, which are: 1) Shoals associated with stranded coastal Holocene sedimentary deposits; 2) Active and relict Cape Associated Shoals and Shoal Massiffs; 3) Sorted Bedforms, Shore Attached and non-Attached Ridges and Ridge and Swales.

A summary of the broad categories of shoals identified within the mid-Atlantic and Gulf of Mexico is provided below.

1) **Shoals associated with stranded Holocene sedimentary deposits exposed by ravinement.**

   These shoals are formed from stranded/relict coastal sedimentary deposits exposed by ravinement or are proximally sourced by these deposits. These can be further subdivided into stranded banks, which are discrete features, generally associated with a single stranded/relict feature, and shoal fields, which are typically deposits formed from proximally exposed deposits where the shoals are displaced from the source deposit.

Stranded Banks

- Sabine Bank. Situated ~26 km offshore of the Texas-Louisiana border, Sabine Bank is delineated by the 10 m isobaths. It is 50 km long, 7.5 km wide, shoals to less than 4.5 m. Morton and Gibeaut (1995) estimated Sabine Bank to contain 1.8×10^9 m^3 sandy sediment, by extrapolating the geographic extent of the bank and its depth of closure (Morton and Gibeaut, 1995). It consists of the base of a barrier island sequence, the surface of which consists largely of a lag shell deposit and sand (Morton and Gibeaut, 1995; Dellapenna et al., 2006; 2009; Figure 2-1). Rodriguez et al. (1999) identified three facies, two of which are sand bearing, Facies A and B, Facies C constitutes the basal layer of the bank, contains the bulk of the bank's volume and is mud dominated. Dellapenna et al. (2010) estimated a total of 638×10^6 m^3 of sand within the two sand bearing facies (Facies A and B).
- Heald Bank. This feature is a relict bayhead delta complex exposed by ravinement (Rodriguez et al., 1999; Figure 2-2). It is located 27 km southwest of Sabine Bank and 55 km southeast of the entrance channel to Galveston Bay. It is enclosed by the 14 m isobaths and shoals to less than 10 m, with length of ~25 km and a width of 5 km (Morton and Gibeaut, 1995; Dellapenna et al., 2009). Dellapenna et al. (2010) estimated a total of 81×10^6 m^3 of sand within Heald Bank.

Sand Shoals/Shoal Fields

- Ship Shoal. Ship Shoal formed from the re-working of a barrier island complex eroded by ravinement. Comparisons of bathymetric profiles taken between 1887 and 1983 reveal that the shoal has migrated more than 1 km landward, giving it an approximate average migration rate of 10 m/y (Penland, 1988; Figure 2-3). Ship Shoal is ~50 km long, with a width ranging from 5-7 km and a central shoal area 8-12 km wide at the eastern end. Relief varies from 5-7 m and the surface is at between the 3 and 8 m isobaths.
- St. Bernard Shoals, LA. St. Bernard Shoals consists of a series of discrete sand bodies ranging in size from 44 to 0.05 km^2 that are located 25 km southeast of the Chandeleur Islands, offshore of the southwestern side of the Mississippi Delta, in water depths of 15-18 m (Figure 2-4; Rogers et al., 2009). The St. Bernard Shoals formed by the reworking of relict Mississippi delta distributary deposits exposed on the inner to mid shelf during and subsequent to shoreface ravinement (Rogers et al., 2009)
- West Florida Shelf Sand Ridges. These are a series of ridge fields located 3-25 km offshore of Sanibel Island, FL (Figure 2-5) along the west central section of the Florida peninsula. Each ridge is about 0.5-1.5 km wide and 1-15 km long (Finkl et al., 2007b; Figure 2-5). According to Locker et al. (2003), the shelf in this area is sand starved and the sand that exists consists of a veneer only a few meters thick, sitting atop Miocene-aged limestone. The authors suggest that the sand ridges formed during the Holocene transgression and are likely related to drowned barrier island complexes and other relict geological features, but these features also continue to be reworked by shelf processes.

2) Cape Associated Shoals

Cape associated shoals are active sedimentary systems that extend from cuspate foreland promontories formed by two barrier islands (Figure 2-6) or mainland beach ridges joined at approximately right angles (McNinch and Luettich, 2000). Examples include Cape Lookout Shoal, NC; Frying Pan Shoals, NC; and Canaveral Shoals, FL. In general, cape-associated shoals form due to the convergence of two long-shore drift cells and as a result of self-organization of the coast in response to a high-angle-wave instability in shoreline shape and can also be influenced by pre-existing geological framework (Figure 2-7; Thieler and Ashton, 2011). A much more detailed explanation of their formation can be found in Thieler et al. (2014), Thieler and Ashton (2011), McNinch and Luettich (2000), McNinch and Wells (1999), and Ashton and Murray (2006). The Cape Lookout Shoals contain a series of shoals extending ~20 km offshore of the tip of Cape Lookout. The shoal is ~7-10 km wide and has a relief of up to 10 m and has migrated 8 km in ~5500 years. Cape-shoal complexes can extend for kilometers offshore following the same basic orientation as the existing shoreline. They are subject to alterations from normal current regimes and storm events.

- Shoal retreat massifs.

  Shoal retreat massifs are poorly defined sand ridges. Originally thought to have formed on the flanks of the shelf valleys and marking the retreat of the paths of the littoral-drift depositional centers on the sides of the estuary mouths (Swift et al., 1978), an alternative explanation is that at least for the Raleigh Bay section of the NC Outer Banks, they are cape associated shoals from an abandoned cape (Figure 2-7; Thieler et al., 2014; Thieler and Ashton, 2011) and further investigation may reveal many of the other shore retreat massifs may also be related to cape associated shoals. The term "massif" is used because the shoals are bathymetric highs that contain smaller scale bathymetric highs, consisting of an array of sand ridges whose axes are parallel to the shoreline, and perpendicular to the trend of the massif (Swift et al., 1978). Massifs include the Susqueshanna Massif off of the Eastern Shore of VA, the Virginia Beach Massif, the Albemarle Massif and the Diamond Shoals Massif, both off of NC Outerbanks (Figures 2-7 and 2-8). According to Swift et al. (1978), each massif consists of a series of sand ridges generally trending north-south in a comb-like array. As an example, the Platt Massif off of Oregon Inlet, along the Outer Banks of NC, has a relief on the order of 5-10 m, the entire massif is approximately 18 km wide, 25-35 km long, with each individual shoal ranging up to 4-6 km wide.

3) Sorted Bedforms

Sorted bedforms are also called rippled scour depressions. Sorted bedforms are subtle, large-scale regions of coarse sand with gravel and shell hash (widths between 100 and 200 m and negative relief of ~1m) that trend obliquely to the coast (Figure 2-9; Guitierrez et al., 2005). Because the coarse material is in the troughs and the ridges are finer grained, these types of shoals are significantly different than others discussed in this paper. Additionally, these features tend to be fairly low relief, generally with relief at or below 1 m (Van Oyen et al., 2011). In addition, these are active bedforms, in some cases they can migrate tens of meters in a month, as Goff et al. (2005) found off of Martha's

Vinyard, MA, or they can be relatively stationary, as Diesing et al. (2006) found off of the German Bight in the North Sea, with sorted bedforms that had not migrated in 26 years. According to Murray and Theiler (2004), sorted bedforms are self-organizing features due to the interaction of frictional sediment transport, bottom composition and turbulence, with bottom roughness over the troughs causing turbulence that inhibits the settling of fines within the troughs (Figure 2-9).

A field of sorted bedforms is found off of the NC Outer Banks along the inner shelf of Raliegh Bay extends between Capes Hatteras and Lookout covering over 1000 km^2 (Fig. Sorted Bedforms; Murray and Thieler, 2004). According to Thieler et al. (2014), the bedforms begin about 10 km west of Cape Hatteras and can be divided into four distinct regions, based on bedform characteristics (Figures 2-10 and 2-11). This includes: Region A) shore perpendicular and moderately assymetrical (wavelengths of 1.5 km and heights of 0.75-1.5 m) south of Cape Hateras; Region B) north-central Raleigh Bay, where they are slightly shore oblique, with very low amplitude (>50 cm); Region C) south-central Raliegh Bay where they are larger and better organized towards the southwest, converging on a wavelength of ~700 m and heights of 0.5-1.5 m, they are more symmetrical within this region and steeper than those found to the north; Region D in southern Raliegh Bay the crests and troughs of the sorted bedforms are less continuous and their orientation becomes increasingly shore oblique towards Cape Lookout, and they have the morphology consistent with shore-oblique ridges.

Although not currently addressed in the literature as sorted bedforms, the “ridge and swale” and “shoreface attached and detached sand ridges and linear shoals” have geometries consistent with those found within the Sorted Bedforms discussed above. These features will be described here using their historical classifications because these are the general terms that have been used for them in the past and they have yet to be described using the sorted bedform nomenclature.

***Ridge and Swale**

Along the mid-Atlantic coast, ridge and swale complexes are most prominent along the Delaware-Maryland-Virginia inner shelf, where they are dominant features (Hayes and Nairn, 2004; Swift and Field, 1981; Figures 2-12, 2-13, and 2-14). According to Swift and Field (1981), there are three basic types of ridge and swale morphologies found within the Delaware-Maryland system, they include shore-attached ridges, nearshore ridges and offshore ridges. Each ridge is roughly 3-4 km long and 0.5-1 km wide with ridges spaced 1-4 km apart. Relief varies depending on the type. Swift and Field (1981) state that there is a continuum in their evolution and that these features begin as shore attached ridges that extend offshore, oriented obliquely running roughly northeast-southwest, where they lose their identity along ~3 m isobaths. The shoreface ridges tend to occur in clusters and have the steepest slopes on their flanks. Nearshore ridges have lower slopes on their flanks than the shore attached, have their shallowest points on their southern ends and also bifurcate into subridges, however the swales are shallower than the shore-attached ridges. The offshore ridges have the gentlest slopes and tend to be the most asymmetrical. Swift and Field (1981) reached the conclusion that as sea level rises, shore attached ridges become nearshore ridges and then become offshore ridges, with new shore attached ridges continually being developed and maintained. Although as Hayes and Nairn (2004) point out, there are a variety of more advanced and in some cases opposing views on how inner shelf and mid shelf ridge and swales form, most invoke sea level rise as part of the formative process and in all cases, these are active sedimentary systems. In the case of the mid-Atlantic ridge and swales, they also have active bedforms both on the ridges and with the swales, with the ridges being both sand and shell lag gravel dominated and the swales containing both sand and mud. Along Maryland and Delaware, Swift and Field (1981) found that the ridges are migrating in the direction of alongshelf transport at a rate of 1 km/1000 yrs or 1 m/y.

***Shoreface Attached and detached sand ridges and linear shoals**

Well-developed ridge and trough complexes (also known as shoreface-attached and detached sand ridges; and linear shoals) oriented parallel to the prevailing wave approach direction are dominant features along the continental shelves in the Mid-Atlantic Bight, southern Florida, and the northeastern Gulf of Mexico (see examples in Figures 2-7 through 2-15 and associated citations). Waves approach from the northeast in the Mid-Atlantic Bight and from the southeast in the northeastern Gulf of Mexico. These sand ridges are generally over 1000 m long, 1 to 4 km wide with wavelengths of 1 to 11 km, with reliefs up to 12 m, and side slopes that average approximately 1° (McBride and Moslow 1991, Hayes and Nairn 2004, Byrnes et al. 2004a). These well-developed sand ridge fields are found predominantly along a mixed energy and wave dominated barrier island coastlines (McBride and Moslow 1991). The sand ridges in the Middle Atlantic Bight on the Delaware-Maryland shelf occur in all stages of formation (Figure 2-14) and demonstrate the systematic change from shoreface ridge through nearshore ridge to offshore ridge and reflect the changes in the hydraulic regime (Swift and Field 1981). Fenwick, Weaver, and Isle of Wight Shoals in the Middle Atlantic Bight (Figure 2-11); Anclote, and Captiva; and Resource Area 2 off the coast of Alabama (Figure 2-15) are examples of these ridge and trough complexes (Finkl et al 2007b, Byrnes et al. 2004a).

In general, these features have the same geometries found within the sorted bedforms found off of NC by Thieler et al. (2014) and likely most of these features are various forms of sorted bedforms, but have yet to be classified as such.

2.2 Physical Processes Governing Shoals

2.2.1 Physical Differences Between Shoal Regions

Physical oceanographic conditions differ between the different shoal settings both because of differing dominant processes as well as because of differences in shelf configuration. The inner continental shelf extends across the region immediately seaward of the surf zone where waves normally (or frequently) agitate the bed (Wright, 1995), and for most coasts this is generally between 30 and 50 m. Both the Atlantic and Gulf of Mexico coasts in North American are passive margin coasts, in terms of plate tectonics. The shape of wave dominated inner continental shelves of passive margin coasts represents an “equilibrium” balanced by the input wave dynamics and sediment transport (Wright, 1995). According to Wright (1995) the physical oceanographic processes that control sediment transport and ultimately control the fluxes of sediment and shapes of the profiles of the continental shelves include 1) wind-driven along-shelf and across shelf (upwelling and downwelling) flows; 2) surface gravity waves; 3) tidal currents; 4) internal waves; 5) infragravity oscillations; 6) buoyant plumes (positive and negative); and 7) wave-driven surf zone processes. These different types of processes are illustrated in Figure 2-16 (Nittrouer and Wright, 1994). Process gradients are steep across the inner shelf; as the shelf is traversed from deep water to the surf zone, the relative intensities and even the net directions of the different types of flows change (Wright, 1995).

Bathymetric profiles differ along the continental shelf in the Atlantic and Gulf of Mexico study areas (Figure 2-17) shows six inner to mid-shelf profiles through each of the regional settings where most of the shoal areas have been discussed in detail. Profiles A, B and C (Figure 2-17) are each from the Middle Atlantic Bight region. Note that Profile C is a short profile because it extends from the apex of the Outer Banks of NC, across a series of cape associated shoals that appear to extend to the shelf break and this is where the shelf is the narrowest. Profile A extends across the shoal fields of the Delmarva Peninsula and appears to have a break in slope around 30 m of depth. Profile B extends across the northern section of the Outer Banks and also appears to have a slight break in slope around 30 m, suggesting that the break between the inner and mid shelf is around 30 m of water depth. This break in slope represents the position where the wave orbital velocities and across-shelf sediment transport of sediment generally become depth limited (Wright, 1995). Profile D off the east coast of Florida contains a significant break in slope around 20 m, although the shelf is very narrow in this area and the outcrops of limestone on the mid and outer shelf may be a significant influence on this profile. The Mississippi-Alabama Gulf of Mexico shelf is represented in Profile E, there is a break in slope around 30 m, representing the inner-mid shelf division, the second break in slope around 40 m is proximal the shelf break. Profile F represents the Mississippi River Delta shelf, note that the break in slope for the inner-mid shelf is at around 20 m, this is a region characterized as generally low energy. The inner-mid shelf break along the western Louisianna and eastern Texas shelf occurs around 25 m.

2.2.2 Physical Oceanographic Differences Between Shoal Regions

A contrast between the Middle Atlantic Bight and the Louisiana Shelf is provided in Wright (1995) and provides a good regional contrast between the two primary regions where offshore sand banks are discussed in this synthesis.

According to Wright (1995), in regards to near-bottom flow that dominate sediment transport and morphodynamic change, the physical regime of the Middle Atlantic Bight can be characterized as being storm-dominated. The highest bed stresses and highest sediment transport rates coincide with wind events; fairweather flows and tidal currents are generally weak. The storms that dominate this region are primarily extratropical storms, typically “northeasterns,” occurring in the autumn and winter months, with each event having a significant onshore component. Although hurricanes occasionally also affect the area, they usually do not generate waves as large as those generated by northeasterns (Wright, 1995). According to Wright (1995), on a yearly basis, there is a residual southwesterly bottom drift of ~6 cm s^{-1} over the shelf of the Middle Atlantic Bight. The Gulf Stream turns eastward south of Cape Hatteras and does not directly impinge on the shelf of the Middle Atlantic Bight; however southerly flowing water over the shelf ultimately runs seaward at Cape Hatteras where it becomes entrained in the Gulf

Stream. While tidal currents are relatively weak, they act in concert with wave-driven flows and contribute significantly to the total bed stresses (Wright, 1995).

The northern Gulf of Mexico is, in general, a much lower energy regime than the Middle Atlantic Bight (Wright, 1995). Physical oceanographic processes are different east and west of the Mississippi Delta. Waters to the east of the delta are generally not affected by the buoyant Mississippi and Atchafalya River plumes, whereas waters to the west can be. Tidal ranges along the northern Gulf of Mexico coast are generally less than 40 cm, as a result, tidal currents tend to be weak. The dominant winter winds are from the north, thus, for the northeastern Gulf of Mexico coast, winds blow offshore and wind driven waves are fetch-limited. Additionally, there are no coastal jet-like currents generated by offshore winds equivalent to those found on the East Coast (Wright, 1995). Along the northwestern Gulf of Mexico coast, along the central and southern Texas coast, where the orientation of the coast is northeast/southwest, there can be a shore oblique component to the wind and the passage of northern fronts can result in higher energy conditions. In summer months a sea breeze/land breeze becomes established, resulting in generally low windshear. The major sources of energy along this coast are tropical storms and hurricanes which can cause shear stress across the entire continental shelf and result in significant sediment transport, affecting all shoals and banks within the region (e.g. Allison et al., 2010; Dellapenna et al., 2006).

Proximal to and towards the west of the Mississippi and Atchafalya River mouths positively buoyant, sediment laden water supplied by the rivers are the dominant control of morphodynamics (Wright, 1995). All of the discharge from the Atchafalaya and about 53% of that from the main Mississippi tributaries turns westward as a buoyant coastal plume of reduced salinity and this plume is the primary pathway for the fine sediment that composes the inner shelf bed (Wright, 1995). During the highest discharge periods in spring and early summer, pronounced water column stratification develops, resulting in a baroclinic coastal boundary layer that isolates the seabed from the direct effects of wind stress (Wright, 1995).

Along the eastern and central Texas coast, there is a 1.1 m mean wave height (McGowen et al., 1977). These waves generally trend northeast-southwest, approaching the shore in a northwest direction, resulting from predominately southeasterly winds (Rodriguez et al., 2000). As a result net longshore drift is from the east to the west (Seelig and Sorensen, 1973). The direction of the longshore drift can fluctuate throughout the year as a function of wave direction, where waves from the southeast and from the south create a westward and eastward flowing longshore drift, respectively (Seelig and Sorensen, 1973), and semipermanent surface currents in the northwestern Gulf of Mexico. Most of the year the coastal current in this part of the Gulf of Mexico flows counterclockwise (east to west) from the Mississippi River to the southern Texas coast. This nearshore current is primarily forced by wind stress. Beginning in May wind stress begins to change, causing the current to switch so that it flows from South Texas towards the Mississippi River. This direction persists through the summer months, primarily July and August, and by September both the wind stress and currents have returned to a counterclockwise flow (Curray, 1960; Nowlin Jr et al., 2005).

Two storm sources dominate the creation of large wave events along the Texas coast-winter storms and tropical cyclones. Hayes (1967) reported that the frequency of tropical storms crossing the Texas coast was 0.67 storms per year. Other than tropical cyclones, the most energetic events are the passage of winter cold fronts, which occur from October to April. On the average, there are 46 cold fronts per year that pass through the Northern Gulf of Mexico (Henry, 1979). Cold fronts occur at 3-10 day intervals in a given year and are characterized by a pre-frontal phase of high-energy southeasterly winds for 1 to 2 days, followed by a 12 to 24 hour period of strong northwesterly to northeasterly winds following the passage of the front (Co-ops, 2005). A mean significant wave height of 5.1 m has a return interval of five years due to tropical storm activity along the Texas coast (Abel et al., 1989). Sediment transport among cape associate shoals is primarily controlled by water depth, shallow cape shoals are active features still forming, deeper-water cape shoals are largely relict feature trapped below fairweather wave base. There may be sediment transport on the surfaces of these features, but the shoals themselves are not actively migrating.

2.2.3 Variability of sediment transport between shoals

Along both the central and southern Atlantic and gulf coasts of the US, wave generated sediment resuspension is the major control on sediment transport (Wright, 1995). Along much of the central and southern Atlantic coast, the primary wave generating events are northeasters (Wright, 1995), which are macro-scale storms characterized by winds coming out of the northeast quadrant. 20-40 northeasters strike the east coast each year and normally at least 2 of them are major storms (Davis and Dolan, 1993). Consquently, these northeasters produce significant sediment transport on the inner shelf of the East coast each winter/spring. In contrast, although there is an average of 46 northern fronts a year passing through the Gulf of Mexico, because of the orientation of the gulf coast, in general, the impact of these storms is not as significant as the northeasters (Wright, 1995). The Gulf of Mexico is generally impacted by a hurricane or tropical storm at least once each summer, in many years there are multiple storms. On the average, for example, the Texas coast is impacted by a hurricane every 1.5 years and for an individual location, the strike recurrence is ~25 years. Although it does not take a direct strike to create significant sediment transport on banks within the Gulf of Mexico, overall, the frequency of events is more sporadic, for example, three hurricanes, including Hurricane Ike impacted Sabine and Heald Banks in 2008 and between 2009 and 2013 there were no significant hurricanes to impact the area. An individual storm, if directly passing over an area can create the equivalent of decades worth of non-storm-strike sediment transport and erosion, however on an annual basis, non-storm years have much lower sediment transport rates on the inner shelf than the East coast. So, in terms of sediment transport and recovery, predicting recovery rates along the Gulf of Mexico will be much more difficult than along the east coast.

Recovery rates among similar shoal types are also a matter of sediment transport rates, fluxes and process. In terms of energy, wave generated resuspension is the biggest influence on sediment transport for the inner shelf for both the east coast and gulf coast. Consequently, water depth is going to be the major factor determing sediment transport and flux rates. Along most shoal types, given similar conditions and grain size distributions, it can generally be expected that sediment transport will be comparable at comparable water depths, but across shoals, water depths will vary and so will wave generated currents, sediment transport rates and fluxes.

Recovery rate between different shoal types is going to relate specifically to the shoal type as well as water depth. For example, sorted bedforms are sedimentary bedforms that are actively migrating. Migration rates as high as tens of meters in a month have been observed off of Martha's Vineyard (Goff et al., 2005) while shoal migration off of NC was found to be as high as nearly 4 m/y (Thieler et al., 2014). Alternatively, they can be relatively stationary, as, with sorted bedforms that had not migrated in 26 years as found off of the German Bight (Diesing et al., 2006). Among sand shoals and shoal fields, both Ship Shoal and St. Benard Shoals, although arising from Holocene sand bodies, are actively migrating features. Ship Shoal migrated at an average rate of 10 m/y from 1887-1983 (Penland, 1988). It appears the West Florida Shelf Sand Ridges have largely remained in fixed positions. The large stranded sand banks off of Texas/western Louisiana, including Sabine and Heald Banks and Freeport Rocks, largely have remained in fixed position since their formation. This is not to say there has not been sediment migration across the surface of the banks. Hurricane Rita exposed large, low relief gravel ridges on the surface of Sabine Bank immediately after the passage of the storm, but they were covered seven months later (Dellapenna et al., 2006).

2.2.4 Assessing Potential Impacts and Recovery of Sand Mining of Shoals: a Geological Perspective

How much sand can be removed from a shoal such that the shoal can recover (i.e. return to a habitat comparable to that which existed prior to the removal) and at what rate the shoal will recover is primarily a matter of sediment transport rates and fluxes. Assessing this requires an understanding of the pre-mining conditions and processing occurring on the shoals and numerical modeling. Modeling inputs will include the detailed surface morphology of the shoal; surficial and subsurface sediment type and geotechnical property distributions; benthic boundary measurements of the shoal for different energy conditions; physical oceanographic time series data for currents and waves; and meteorological time series of wind, pressure and temperature and climate data on how these meteorological conditions vary on internannual and decadal time scales.

The surface morphology of the shoals is normally assessed using swath bathymetry, typically using multibeam, interferometric or phase and contrast swath bathymetry systems. This is often done in concert with side scan sonar, to acquire higher quality backscatter imagery than produced by multibeam or interferometry alone. Phase and contrast systems are typically depth limited to less than 20-30 m, but collect side scan sonar and swath bathymetry in a single co-registered unit (e.g. Teledyn Benthos C3D®). Subsurface extent and distribution of strata is accomplished with high-resolution seismic surveying coupled with submersible vibra coring. Because the shoals of interest are sand dominated, vibra coring is required rather than gravity coring because gravity cores typically cannot penetrate sandy strata. Geotechnical properties, such as shear strength, compressibility, Atterberg Limits, permeability, water content, grainsize distribution can all be assessed from the sediment cores. In addition, a new approach that could be included is profiling of $^{239+240}$Pu in sediments. Kuehl et al. (2012) demonstrated that $^{239+240}$Pu can be used as a geochronological tool in sand deposits, comparable to ^{137}Cs geochronology, allowing for direct measurement of the modern accumulation of sand on decadal timescales. This tool, although new and not widely applied, would potentially allow for a quick assessment of the time integrated rate of sediment transport and provide a good estimate of sediment accumulation/flux rates across the shoal.

To assess benthic boundary layer dynamics, instrumented benthic boundary layer pods are deployed to measure *in situ* benthic boundary layer current structures and sediment flux rates. Physical oceanographic and meteorological time series data of windspeed, atmospheric pressure, currents and waves are typically collected from ocean observing buoy systems, such as those maintained by the NOAA Data Buoy Center (http://www.ndbc.noaa.gov) or state operated buoy systems such as the Texas Automated Buoy System (TABS; http://tabs.gerg.tamu.edu) and Wave-Current-Surge Information System for Coastal Louisiana (WAVCIS; http://www.wavcis.lsu.edu).

A variety of numerical modeling packages exist through both public domain and the private sector and will not be discussed further or advocated here. Once the model is built and tested, various mining and recovery scenarios can be tested.

2.3 Distribution of Shoals in BOEM OCS Planning Areas

Two main regions of interest are covered in this review: the Atlantic Outer Continental Shelf (OCS) Region, and the Gulf of Mexico OCS Region. The OCS is defined as all submerged lands, subsoil, and seabed lying from the seaward extent of State jurisdiction out to approximately 200 nautical miles (nm) (370 kilometers (km), federal jurisdiction). State jurisdiction generally extends from shore out to 3 nm (5.6 km), except for the Gulf Coast of Florida and Texas where the boundary is 3 marine leagues (9 nm, 16.7 km). The Atlantic OCS ranges from Maine southward to the Straits of Florida. The Gulf of Mexico OCS extends from the area off the western coast of Florida through Texas. Each of these regions has its own physical and biological characteristics, along with a host of species and fisheries that are both ecologically and economically important. A summary of EFH, fisheries, and species of particular regulatory interest (e.g., endangered, threatened, species of concern, or candidates for listing) is provided in Appendix A.

2.3.1 Atlantic OCS Region

The Atlantic OCS region is divided by BOEM into four planning areas: North Atlantic, Mid-Atlantic, South Atlantic, and Straits of Florida (Figure 2–18). In the North and Mid-Atlantic regions, the shelf extent generally coincides with the 100-m isobaths. The North and Mid-Atlantic areas are separated by the Georges Bank Basin in the north and the Baltimore Canyon Trough in the south. Historically, BOEM has not had interest in OCS sand sources in the northern portion of the North Atlantic Planning Area. Therefore, for the purposes of this analysis, only the southern portion of the North Atlantic planning area (extending from southern New Jersey to the south shore of Long Island NY) is of interest. Sorted bedforms, including sand ridge and trough complexes also characterize the continental shelf in this region, 245 shoreface-attached and detached sand ridges have been identified from Long Island to North Carolina (McBride and Moslow 1991; Figure 2-19).

The South Atlantic Region is dominated by three physical features; from the coastline: the Florida-Hatteras Shelf, the Florida-Hatteras Slope, and Blake Plateau. The Straits of Florida connects the Atlantic Ocean to the Gulf of Mexico and its physiography is influenced by reef structure and sediment along with the Florida Current (part of the Gulf Stream). The southern Florida inner continental shelf has 14 identified large and well developed sand ridges (McBride and Moslow 1991; Figure 2-19). A detailed summary of the characteristics of the Atlantic OCS is found in the Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf (Chapter 4 in MMS 2007).

2.3.2 Gulf of Mexico OCS Region

BOEM has divided the Gulf of Mexico OCS region into three planning areas: Eastern Gulf of Mexico, Central Gulf of Mexico, and Western Gulf of Mexico (Figure 2-20). The Gulf of Mexico OCS contains three of the seven Gulf of Mexico physiographic provinces: the South Florida Continental Shelf and Slope, the Northeast Gulf of Mexico, and the Northern Gulf of Mexico. The South Florida Continental Shelf and Slope is the submerged section of the Florida peninsula that extends along the west Florida coast from Apalachee Bay southward to the Straits of Florida. The Northeast Gulf of Mexico contains the West Florida Shelf and Terrace which extends from the eastern side of Apalachee Bay FL to just east of the Mississippi River Delta. The West Florida Shelf is separated from the deeper Gulf Basin by the Florida Escarpment. The Northern Gulf of Mexico contains the Mississippi-Alabama Shelf and the Texas-Louisiana Shelf. The Mississippi Fan, which extends from the Mississippi River Delta to central abyssal plain, is the major geologic feature in this province. The eastern side of the Texas-Louisiana Shelf is cut by the Mississippi Canyon to the southwest of the Mississippi River Delta. A detailed summary of the characteristics of the Gulf of Mexico OCS is found in the Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf (Chapter 4 in MMS 2007).

Ebb-tidal shoals and sand ridge fields have been identified on the West Florida Shelf; sand ridges and swales (likely sorted bedforms) have been identified along the Mississippi-Alabama Shelf east of the Mobile Bay (AL) entrance. Banks are the major features on the inner continental shelf of the northwest Gulf of Mexico that represent relic depositional environments with origins in an estuarine environment. Oyster beds and other shell fragments are dominant characteristics in these features (Wells et al 2009).

2.4 Summary

Several distinctive types of sand deposits are of interest for both borrow area and wind energy siting purposes – ridge and swale complexes that are prevalent in the Mid-Atlantic, cape-associated shoals that are prevalent in the southern Mid-Atlantic to South Atlantic, and sand banks that are most prevalent in the Gulf of Mexico. Each type is somewhat distinct in terms of its genesis, physical dimensions, and current status of reworking or migration. These distinctions suggest that the different shoal types would also differ in terms of the likelihood that sand accretion would restore the original contours (and, presumably, habitat use) after dredging. Restoration of habitat after sand removal is one of the major concerns raised during discussions on shoal alteration. As discussed in the following chapters, the value and function of shoal habitats must first be understood before the implications of impacts to these habitats may be thoughtfully considered.

3.0 Value and Function of Shoal Habitat

3.1 Value of Shoal Habitat

Habitat is the space occupied by an organism, population, or community. Shoals and shoal complexes provide habitat to a wide range of marine organisms. These features provide habitat and micro-habitats that vary in type from the high-energy crests to the low-energy troughs often found in shoal complexes. Since all marine habitats have value to those organisms that occupy and rely on them, determining the "value" of shoal habitat requires a judgment based on attributes such as:

- Productivity
- Biodiversity
- Numbers of ecologically important species
- Numbers of economically important species
- Numbers of species of conservation importance
- Numbers of species unique to shoals
- Rarity of the habitat
- Ecosystem services provided by shoals

These attributes must be considered in a relative sense, by comparison of shoals to other marine habitats. The spatial distribution of organisms on shoal habitat versus non-shoal habitat provides the basis for this comparison. Based on reported information for shoal habitats of the U.S. Atlantic or Gulf of Mexico OCS, there is site-specific variation in the value of shoals, but overall patterns suggest a unique importance of shoals to fish and invertebrate communities (see Sections 4.1 and 4.2).

Although comparisons of biological communities among shoal and non-shoal habitats can help to characterize the value provided by shoals, understanding the function of shoal habitat is essential for preserving that value. How shoals function to provide habitat is the product of a complex mix of connections between biological processes and physical factors or biophysical coupling. This biophysical coupling results in the observed patterns of faunal distributions related to shoals and shoal complexes. Associations between physical factors and the distribution of marine organisms provide insight into these connections, and these associations are discussed in Section 3.2.

3.2 Biophysical Coupling and the Function of Shoal Habitat

In coastal marine environments, interactions between marine organisms and landform development processes are an important factor in structuring benthic habitat. These interactions related to biogeomorphology may be biologically dominated or physically dominated. In some biologically dominated habitats such as coral reefs, serpulid (Polychaeta: Serpulidae) worm reefs, or mussel beds, the biogenic structures formed by marine organisms provide the essential structure of the habitat. Much of the low energy soft-bottom habitat of the ocean floor is biologically dominated, with infaunal organisms influencing sediment texture, boundary-layer flow, sediment transport and sediment oxygen levels through burrowing and feeding activities and the formation of biogenic structures (Snelgrove and Butman 1994).

In contrast to these biologically structured habitats, shoal habitats are physically dominated, and occur in high energy environments. Shoals are morphologically dynamic features. Change in these features is driven mostly by waves and currents during episodic weather events such as northeasters (or "nor'easters"), tropical storms, and hurricanes as well as other lower intensity weather events. The small scale morphodynamics relevant to shoal formation and re-working involves sediment transport processes including suspended load (sediment in water column) and bed load (sediment on or near bottom) transport.

The same unique hydrodynamic conditions that result in shoal formation or re-working provide water flow conditions and a disturbance regime that influences biological processes (e.g., food availability, feeding strategies, dispersal strategies, community succession). Shoal crests are more shallow than the surrounding sea floor, creating an island of lower bottom depth that may provide a refuge from hypoxia (Dubois et al. 2009) or sufficient light levels to support higher densities of benthic diatoms (Grippo et al. 2009). Both fish and benthic invertebrates are directly sensitive to oxygen levels. And the density of benthic diatoms can influence species composition and productivity of faunal communities at multiple higher trophic levels. Sediment organic content as a measure of food availability can directly influence the distribution of benthic organisms.

A number of physical factors have been associated with the distributions of marine benthic organisms and demersal fishes. Important factors at spatial scales relevant to understanding how shoals function include:

- Hydrodynamic regime
- Bottom depth
- Sediment conditions (e.g., sediment texture, organic content)

Identifying causal relationships among potentially important physical, chemical, and biological factors is complicated by the fact that many of these factors often co-vary. Wave generated currents are higher on the shallow crests of shoals than in the troughs. This typically results in larger sediment grain sizes on the crests than in the lower energy environments below shoal crests (although this pattern may be reversed in shoal types such as sorted bedforms). Organic content is inversely correlated with grain size of the sediments (Hyland et al. 2005), and both light and temperature are among the parameters that co-vary with bottom depth (see Section 4.1). Thus, although the distribution of fish and benthic invertebrate communities is often associated with bottom depth and sediment texture, the relative importance of potential causal mechanisms behind these associations is difficult to identify.

In addition to the challenge of identifying causal relationships among potential forcing factors that may be associated with the biological communities found on shoals, there is also the reality that many conditions of shoals (e.g., particular flow rates, bottom depth, or sediment texture) are found elsewhere in the marine environment. Therefore, it is helpful to ask the question: "What characteristics are both relatively unique to and universal among shoals? Shoals are an area of greater relief than elsewhere on the surrounding seafloor. Shoals are composed of unconsolidated sediments that often vary in texture by location within the shoal habitat. Relief offers organisms access to a wider range of bottom depths over shorter distances than is found in areas of flat bottom. Habitats in close proximity at different bottoms depths within a shoal complex also offer different hydrodynamic and sediment conditions, providing habitat complexity and nearby refuge from higher energy hydrodynamic conditions. In considering factors that may affect the function of shoal habitat it may also be helpful to ask: “Are there dominant forcing functions to which other factors or processes associated with shoal ecology can be traced?” For example, hydrodynamic conditions may be the driving factor behind both the formation and ecology of certain shoals.

Investigations of these associations can provide insight into biophysical coupling mechanisms that are most influential in determining the value of shoal habitat. Many of these connections are poorly understood and the relative importance of each may vary spatially from one shoal habitat to another or over time at a particular shoal.

4.0 Biological Resource Usage of Shoal Habitats

4.1 Benthos

Benthic invertebrate communities are diverse and productive components of Outer Continental Shelf (OCS) ecosystems. These communities are an essential part of marine food webs, and perform important functions such as filtering large volumes of suspended particles from the water column, cycling nutrients in the sediments, and providing a food source for fish and other organisms. Spatial and temporal variation in benthic prey items can affect the growth, survival, and population levels of predator species at all higher trophic levels. Therefore, understanding the value of shoal habitat to benthic communities is essential to understanding potential impacts to this habitat from sand and gravel mining or offshore alternative energy development.

Benthic invertebrates in soft-bottom habitats are grouped based on whether they normally live within, or on the surface of the sediments. Infaunal organisms live within unconsolidated sediments, while epifauna reside on the surface. Benthic organisms are further delineated based on body size into different sub-components of the benthic community. Megafauna (greater than 1 cm), macrofauna (greater than 0.5 mm), meiofauna (less than 0.5 mm), and microfauna (less than 0.05 mm) are typically considered separately based on differing ecological roles and sample collection methodologies. Despite this classification, benthic studies are rarely designed to strictly delineate a particular component of the benthic community. Grab samples capture both epifauna and infauna, and a 0.5-mm-mesh screen (often used for macrofaunal surveys; although 0.3-mm and 1-mm screens are also used) retains both megafauna and macrofauna (along with some meiofaunal organisms). Comparisons among studies therefore require careful attention to the details of sampling and processing methodology. Although most surveys of soft-bottom benthos on the Atlantic or Gulf of Mexico OCS have focused on macrofauna (Brooks et al. 2006), epibenthic megafauna are collected in bottom trawl surveys, and are often reported along with fish data (Bonzek et al. 2008). Based on available research, most of this benthos review focuses on macrofaunal and megafaunal invertebrates.

4.1.1 Habitat associations and spatial distribution

The spatial distribution of benthic invertebrates relative to shoal complex habitat (both shoal versus non-shoal and ridge versus swale) provides insight into the value and function of this habitat for benthic communities. The extent to which species or assemblages are found exclusively on shoals, the relative diversity and productivity of benthic communities on shoals in comparison to nearby habitat, and the use of shoals by economically or ecologically important species and species of conservation concern, are all relevant to understanding the value and function of shoal habitat.

Distribution of benthic organisms and assemblages is influenced by a number of physical and biological factors. The factors associated with observed patterns of faunal distribution vary at different spatial scales. At large spatial scales, faunal distribution varies with geography (e.g., latitude) and bathymetry (Wigley and Theroux 1981; Theroux and Wigley 1998). At this scale, Large Marine Ecosystems (LMEs) have been delineated based on bathymetry, hydrography, productivity, and trophically related populations (Sherman et al. 2004). Three LMEs have been identified for the U.S. Atlantic and Gulf of Mexico: (1) the Northeast Shelf, (2) the Southeast Shelf, and (3) the Gulf of Mexico. Each of these LMEs can be further divided into subareas. For example, the Northeast Shelf LME, which extends from Cape Hatteras, North Carolina, to the Scotian Shelf (in northeastern Gulf of Maine), can be divided into four subareas: (1) the Gulf of Maine, (2) Georges Bank, (3) Southern New England, and (4) the Mid-Atlantic Bight (Aquarone and Adams 2009). Although many species have broad geographical ranges, occurring in multiple LMEs, the species composition of benthic faunal assemblages will vary considerably over these large geographic spatial scales. Hence, the species composition of benthic invertebrate communities from shoals in the Mid-Atlantic differs from those in the Gulf of Mexico.

Brooks et al. (2006) reviewed the available literature on benthic faunal assemblages associated with shoals in the Atlantic and Gulf of Mexico. Macrofauna were the target of most survey efforts, and the composition and distribution of macrofaunal assemblages was described by this review. In those references that identified dominant species from the Atlantic OCS, the spionid polychaete *Spiophanes bombyx* was most often cited as the numerical dominant. The amphipod genera *Ampelisca* and *Unicola*; the bivalve genera *Ensis*, *Nucula*, *Tellina*, and *Astarte*; the archiannelid genus *Polygordius*; and the echinoid *Echinarachnius parma* were also commonly reported as dominants (Brooks et al. 2006). In surveys from the Gulf of Mexico, the spionid polychaete *Prionspio pinnata* was most often cited as the numerical dominant. Other dominant taxa from the Gulf of Mexico included the polychaetes *Sigambra tentaculata* and *Magelona phyllisae*, the amphipod genera *Ampelisca,* and the bivalve, *Mulinia lateralis* (Brooks et al. 2006). Thus, at the species level, macrofaunal assemblages of shoal habitats differ over large spatial scales. These differences result from the large scale, long-term physical (e.g., continental drift; variations in sea level, climate change, ocean current patterns) and biological (e.g., speciation, extinction, organismal dispersal capacities) processes that determine the biogeography of individual species. Nonetheless, benthic ecologists have long recognized similarity in community structure at higher taxonomic levels among similar bottom habitats across broad geographic scales (Thorson 1957). Although shoals of the Atlantic may be occupied by different species than shoals of the Gulf of Mexico, the overall composition of shoal communities considered at higher taxonomic levels is very similar. For example, Brooks et al. (2006) reported that polychaetes were listed as the dominant taxon in infaunal surveys from both of these regions. And the numerical dominant most often cited from each region is a spionid polychaete.

Key questions related to the value and function of shoal habitats are addressed by assessing these smaller spatial scales, comparing shoals to nearby habitat and within-shoal faunal distributions. Within LMEs and subareas, habitat features occur at multiple smaller spatial scales. Patterns of benthic faunal distribution in marine systems are known to vary with differences in depth (Wigley and Theroux 1981, Theroux and Wigley 1998), and assemblages occur in patchy distribution over a kilometers-wide scale on the seafloor, with additional within-patch substructure (Zajac 2008). Greene et al. (1999) classified marine benthic habitats based on the size of their features as mega (larger than one kilometer), meso (tens of meters to one kilometer), macro (one to ten meters), and microhabitats (centimeters in size and smaller). Shoals are typically megahabitats, and are often composed of different meso, macro, and microhabitats defined by such factors as exposure, sediment texture, depth, and rugosity.

Byrnes et al. (2000) reported that infaunal assemblages found on shoals off New Jersey differed from those occurring in adjacent troughs. Cutter et al. (2000) and Slacum et al. (2010) reported similar differences between shoals and troughs; uniform bottom areas in troughs next to Fenwick Island and Weaver shoals (off Delaware and Maryland) were found to be more biologically productive than areas on the crests of those shoals. Species composition also differed between the habitats, with sand dollars and filter feeding epibenthos more prevalent on shoal crests than in troughs (Cutter et al. 2000). Shoals and troughs differ in terms of depth, sediment composition and hydrodynamic regime. The crests of shoals may be shallower than troughs by five meters or more (Byrnes et al. 2000), consequently wave generated currents will be higher, resulting in a graded substrate where much of the muds (i.e. silt and clay) have been preferentially removed, leaving a coarser substrate (often a mixture of shell lag deposit, silicaclastic sands, gravels and concretions).

In contrast, the troughs will have a comparatively lower energy regime, both resulting in a lower rate of erosion of muds and potentially an environment where muddy sediments occasionally accumulate. At the scale of these features, sediment composition and hydrodynamics appear to be more important than depth in determining faunal-habitat associations (Byrnes et al. 2000). Even within shoals, faunal assemblages are known to differ based on relative percentages of sand versus gravel. Byrnes et al. (2000) reported that the sand versus gravel composition of surficial sediments was the most influential factor (as determined by canonical discriminant analysis) associated with the distribution of infaunal assemblages found on the shoals off New Jersey. Numerically dominant gravel-affiliated taxa included the bivalves *Astarte castanea*, *Crenella decussata* and *Mytilus edulis*, the gastropods *Crepidula fornicata* and *Mitrella lunata*, and the polychaetes *Harmothoe imbricata*, *Hemipodus roseus*, and *Pisione remota*; infaunal taxa that were affiliated with sand included the polychaetes *Caulleriella* sp. J (= *C. cf. killariensis*) and *Spiophanes bombyx*, archiannelid *Polygordius*, bivalve *Tellina agilis*, amphipods *Acanthohaustorius millsi*, *Pseudunciola obliquua*, *Protohaustorius wigleyi*, and *Rhepoxynius hudsoni*, and tanaid *Tanaissus psammophilus* (Byrnes et al. 2000). Associations between sediment composition and faunal assemblages on shoals and nearby habitat have been reported for numerous areas including offshore Louisiana and elsewhere in the northern Gulf of Mexico (MMS 2004), and in the Atlantic offshore North Carolina (Byrnes et al. 2003), Maryland (Cutter et al. 2000), Delaware (Cutter et al. 2000), New Jersey (Byrnes et al. 2004, Byrnes et al. 2000) and New York (Byrnes et al. 2004). Thus, sediment texture has been widely identified as an important microhabitat feature associated with faunal distribution. Where depth and sediment composition (and also water column attributes such as dissolved oxygen, temperature, and salinity) are equivalent, there is little indication that benthic faunal assemblages found on shoals are unique. Slacum et al. (2006, 2010) reported that most epibenthic invertebrates (trawl-caught megafauna including gastropods and hermit crabs) found on shoals off of Delaware and Maryland had no preference for shoals, and were typically more abundant in flat bottom habitats. Although invertebrate assemblages that are unique to shoals have not been reported, some evidence of preferential use of shoal habitat over surrounding areas exists for individual species and for assemblages. The blue crab (*Callinectes sapidus*) is a notable example of a species that has been identified as preferring shoals over surrounding habitat (see Section 3.1.3; Condrey and Gelpi 2010, Gelpi 2012, Slacum et al. 2006, Stone et al. 2009). Ship shoal, off Louisiana, has been identified as an important habitat for benthic macroinfauna in the northern Gulf of Mexico.

Stone et al. (2009) reported that Ship Shoal appears to provide a refuge from the seasonal hypoxia that affects the areas surrounding the shoal. High biomass of benthic diatoms was also reported, and was attributed to light availability on the shallow shoal (5 to 11 m depth) that potentially allows for year-round benthic primary production. These conditions allow for a taxonomically diverse macroinfaunal community with high biomass, that may act as a "seed bank", contributing larvae for annual recolonization of surrounding areas, and serve as a link between sandy habitats along the coasts of Florida and Texas (Stone et al. 2009).

Patterns of association between benthic communities and sediment grain size composition have long been recognized by benthic ecologists (Petersen 1913, Sanders 1958), and are widely reported in faunal surveys (Wigley and Theroux 1981, Theroux and Wigley 1998). Nonetheless, the causal mechanisms underlying animal-sediment relationships are not fully understood. Along with the direct influence of grain size on certain benthic species, causal mechanisms are likely to include factors such as hydrodynamic conditions that affect boundary-layer flow and sediment transport processes, along with biological factors such as predation and competition (Diaz et al. 2004b, Snelgrove and Butman 1994). Important physical and chemical factors co-vary with sediment texture. High energy, erosional environments result in larger sediment grain sizes, while low energy, depositional environments result in smaller grain sizes. Organic content of the sediments is inversely correlated with grain size (Hyland et al. 2005). Both hydrodynamic conditions and organic content of the sediments influence faunal distributions (e.g., based on food availability, and species-specific feeding and dispersal strategies). Additional factors, such as those associated with bottom depth (e.g., light, temperature), add further complexity to the mix of forcing functions that result in observed patterns of faunal distribution. Thus, the relative contributions of specific physical, chemical, and biological factors that are most influential in determining community composition may defy simple generalizations and are likely to vary among shoal habitats based on site-specific conditions (Diaz et al. 2004b, Snelgrove and Butman 1994).

4.1.2 Habitat associations and temporal distribution

The spatial distribution of benthic invertebrates may change over time. Therefore, to understand the value and function of shoal habitat for benthic communities, temporal patterns in the distribution of benthic invertebrates must be considered. Changes in faunal distribution over time may be cyclical and somewhat predictable such as diel or seasonal patterns associated with life history attributes of individual taxa. Other changes may be less predictable; related to changes in the environment, such as a decrease in dissolved oxygen, or biological factors, such as an increase in predation. Environmental changes may occur over long time scales (e.g., climatic and sea level changes) or may unfold over the course of days or even hours. Episodic storm disturbance is a major factor influencing the morphology of shoals, and the benthic invertebrate inhabitants of the most dynamic features are adapted to the changing conditions in these physically-dominated systems.

Benthic communities on the OCS are known to vary seasonally (Maurer et al. 1976). This seasonal variation becomes less apparent with distance offshore and increasing depth (Boesch et al. 1979). Slacum et al. (2006) surveyed mobile benthic species on shoals and nearby habitats off Delaware and Maryland (16 to 25 km off the coast, in 5 to 22 m depth) and found significant seasonal variation in assemblages at both shoals and reference sites. Species richness and abundance were both highest in summer and fall, and lowest in winter. A total of 17 invertebrate species, including seven decapod crustaceans and 10 other species (including sea stars, heart urchins, gastropods, cephalopods, and horseshoe crabs) were collected during the surveys. Only two of those species (a right-handed hermit crab and a sea star) were present throughout all of the seasonal surveys. The authors attributed this to the extreme seasonal temperature ranges that occur within the region (Slacum et al. 2006).

4.1.3 Species of special conservation or fisheries importance

No invertebrate marine species associated with soft-bottom habitats on the OCS of the U.S. Atlantic or Gulf of Mexico are currently listed as federally threatened or endangered (NMFS 2013a). However, a number of benthic invertebrates in these regions support valuable commercial fisheries. Commercially important invertebrates from the Atlantic include American lobster (*Homarus americanus*), sea scallop (*Placopecten magellanicus*), hard clam (*Mercenaria mercenaria*), Atlantic surfclam (*Spisula solidissima*), white shrimp (*Litopenaeus setiferus*), brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*F. duorarum*), ocean quahog (*Arctica islandica*), and blue crab (*Callinectes sapidus*). Examples from the Gulf of Mexico include brown shrimp (*Farfantepenaeus aztecus*), pink shrimp (*F. duorarum*), royal red shrimp (*Pleoticus robustus*), white shrimp (*Litopenaeus setiferus*), Florida stone crab (*Menippe mercenaria*), gulf stone crab (*M. adina*), spiny lobster (*Panulirus argus*), and slipper lobster (*Scyllarides nodif*). EFH has been designated for most of these species (i.e., sea scallop, Atlantic surfclam, ocean quahog, stone crab, and brown, pink, royal red, and white shrimp) (NMFS 2013b). In addition to their commercial value, the large, dominant species that support invertebrate fisheries play important ecological roles in benthic communities.

Commercially important invertebrate species are found in shoal habitats off the U.S. Atlantic coast and in the Gulf of Mexico. In the sandy shoals off New Jersey, the Atlantic surfclam has been reported as a common and often abundant member of benthic communities, dominating the faunal biomass in some areas (Burlas et al. 2001, Byrnes et al. 2000). The Atlantic surfclam is the most economically important benthic species in or around the shoal habitats of the New York/New Jersey region. Byrnes et al. (2000) recommended that surfclam populations should be assessed, and if commercial quantities are found, surfclams should be harvested prior to any sand extraction from shoals being used as borrow areas. Further south in the Mid-Atlantic Bight, squid (unspeciated), Atlantic rock crab (*Cancer irroratus*), and blue crab have been reported from shoals off of Delaware and Maryland (Slacum et al. 2010). Squid were among the most abundant organisms captured over two years of surveys comparing seasonal distribution of fish and invertebrates on shoals and nearby flat-bottom habitat (Slacum et al. 2010). Slacum et al. (2010) reported that squid were not found on shoals during winter, were slightly more abundant on shoals than flat-bottom in spring, and were less abundant on shoals than nearby flat-bottom during summer and fall. Atlantic rock crab were also less common on shoals than flat-bottom during most of the year, while blue crab were captured in low numbers on shoals, but were not found on flat-bottom at all (Slacum et al. 2010).

Blue crab has also been identified as an important commercial species associated with shoals in the Gulf of Mexico (Condrey and Gelpi 2010, Gelpi 2012, Stone et al. 2009). Condrey and Gelpi (2010) reported that during April through October, abundant concentrations of spawning and foraging female blue crabs were found on Ship and Trinity Shoals off the coast of Lousiana.

Although spawning and hatching are typically reported to occur in estuarine environments, Gelpi (2012) reported that the shoals off Louisiana are being used for these important life functions. Condrey and Gelpi (2010) also reported finding blue crabs spawning, hatching, and foraging in offshore habitat (non-shoal) between and surrounding Ship, Tiger, and Trinity Shoals. The highest blue crab densities were found on the shoals, and Gelpi (2012) suggests that the crests of shoals may provide a refuge from hypoxic conditions in deeper waters surrounding this habitat. Condrey and Gelpi (2010) concluded that Louisiana shoals and surrounding habitat support a large segment of the Gulf of Mexico blue crab fishery. This same study found little evidence that white or brown shrimp, two other invertebrate species of national fisheries importance, are abundant on the Ship, Trinity, or Tiger Shoals (Condrey and Gelpi 2010).

4.1.4 Recovery from disturbance: Recruitment and Colonization

The magnitude and duration of potential impacts to coastal systems from sand and gravel mining or offshore alternative energy development in shoal habitats depends, in part, on benthic community recovery times. Recovery time following physical disturbance of the benthos is dependent upon colonization processes, including larval transport, settlement, recruitment, adult migration, competition, and predation (Osman and Whitlatch 1998, Snelgrove et al. 2001). These processes may vary with location and habitat type. For example, communities found in sandy bottoms of high-energy environments tend to recover more quickly than those occurring in lower-energy environments with a higher percentage of fine particles (Dernie et al. 2003). Faster recovery in shallow high-energy environments may reflect the adaptation of communities that ocurr in these habitats to frequent disturbance from episodic storm events. Reported recovery times are also dependent upon the particular community indices being considered (Brooks et al. 2006). Abundance may recover quickly, while diversity followed by species composition may take several years or more to recover (Brooks et al. 2006).

Brooks et al. (2006) reviewed times for recovery from sand mining in U.S. Atlantic or Gulf of Mexico coastal waters. Reported recovery times generally ranged from 3 months to 2.5 years, with one study (Turbeville and Marsh 1982) reporting changes in community parameters five years post-dredging. Time scales for recolonization also varied by taxonomic group. Polychaetes and crustaceans recovered most quickly (several months) while deep burrowing molluscs were slowest to recover (several years) (Brooks et al. 2006).

Several practices have been suggested to reduce recovery times for benthic communities following sand or gravel mining. Ensuring that dredging activities do not create a depression in which fine sediments deposit and collect, which may change the sediment composition and associated infaunal assemblages, is essential for recovery and recolonization (Byrnes et al. 2004). Timing of dredging prior to the peak recruitment period of spring and summer, along with the preservation of local refuge patches to maximize the rate and success of benthic recolonization have also been suggested to improve recovery times (Byrnes et al. 2004, Brooks et al. 2006).

4.2 Fishes

The Atlantic and Gulf of Mexico OCS support a variety of fish species and finfish assemblages that are associated with various depths (Moore et al. 1970, Grosslein and Azarovitz 1982, Colvocoresses and Musick 1984, Overholtz and Tyler 1985, Gabriel 1992, Mahon et al. 1998, Methratta and Link 2006) and exhibit a pattern of increasing species diversity from northern to southern latitudes (Love and Chase 2007) . Species composition and distribution patterns have been determined for several regional fish assemblages (Moore et al. 1970, Colvocoresses and Musick 1984, Overholtz and Tyler 1985, Gabriel 1992), and a number of summary and multidisciplinary publications have documented linkages between finfish species and habitat types and/or features within these assemblages (SAFMC 1998, GMFMC 1998, Collette and Klein-MacPhee 2002, NMFS Technical Memorandums, EFH Source Documents series, and NMFS 2009). Seasonal and interannual variation in species diversity and abundance also are common in the OCS. For example, in the Mid-Atlantic Bight, the majority of the fish migrate seasonally with boreal species present in the winter and warm-temperate/sub-tropical species present in the summer due to the extreme seasonal differences in water temperatures (Musick et al. 1986). As a result, the highest diversity of demersal and pelagic fishes typically occurs in the early fall and the lowest diversity occurs in the winter to early spring (Colvocoresses and Musick 1984).

To characterize distribution, abundance, biomass, and diversity of fishes, a number of sampling methods have been used in the Atlantic and Gulf of Mexico. The particular sampling method utilized is often determined by the species and life stage under investigation, site-specific habitat characteristics, or other environmental factors. Many articles and books have been written to describe fisheries sampling methodologies and protocols (e.g., Zale et al. 2013). Shoals and ridge/trough complexes characterize large areas of the Atlantic and Gulf of Mexico OCS; however, these habitats and their use by marine organisms are among the least studied of all offshore marine habitats because the focus of fish assemblages in relation to habitat has been on reef-associated and deep continental shelf communities or on individual species lifestage specific habitat utilization (Walsh et al. 2006, Gilmore 2008, Slacum et al. 2010). The sampling methods that have been used to investigate marine organism utilization of shoal complex habitats include: hydrological multiparameter sondes, plankton nets, various types and sizes of trawls, benthic sleds (with nets or cameras), gillnets, remotely operated vehicles, sediment profile cameras, split-beam bioacoustic systems, and Global Positioning System intergrated side-scan sonar, (Auster et al. 1995, Steves et al. 1999, Diaz et al. 2003, Szedlmayer and Lee 2004, Brooks et al. 2005, Able et al. 2006, Slacum et al. 2006, Walsh et al. 2006, Mikulas and Rooker 2008, Vasslides and Able 2008a, Wells et al. 2009, Zarillo et al. 2009, Slacum et al. 2010). Table 3-1 provides a summary of sampling approaches for some of the studies included in this Synthesis.

4.2.1 Description of fishes associated with shoal and ridge/trough complex habitats

A diverse number of fish species utilize shoal and ridge/trough complex habitats in the Atlantic and Gulf Mexico OCS (Diaz et al. 2003, Brooks et al. 2005, Walsh et al. 2006, Gilmore 2008, Vasslides and Able 2008a, Slacum et al. 2010,). These species are usually common members of the local shallow continental shelf fish assemblage including several economically and ecologically important species (Diaz et al. 2004a, Brooks et al. 2005, Geary et al. 2007, Gilmore 2008, Stone et al. 2009, Wells et al. 2009). The diversity and abundance of fish species utilizing shoal and ridge/trough complexes is believed to vary with geographic area from north to south and from inshore to offshore in response to regional environmental factors and ecological processes (Walsh et al. 2006, Vasslides 2007, Gilmore 2008). Spatial variation in fish habitat utilization within a shoal may also exist (Diaz et al. 2003, Vasslides and Able 2008a), especially if the shoal extends from the beach to several miles offshore (Gilmore 2008).

Multiple life stages (eggs, larvae, settled juveniles, and adults) of a number of fish species have been documented in shoal and ridge/trough complexes, indicating that these habitats may be important to specific ontogenetic periods depending on species (Auster et al. 1997, Diaz et al. 2003, Able et al. 2006, Walsh et al. 2006, Geary et al. 2007, Gilmore 2008, Mikulas and Rooker 2008, Vasslides and Able 2008a, CSA International, Inc et al. 2010). Shoals and ridge/trough complexes may serve as: 1) refuges for juvenile fishes and schooling planktivores, 2) habitat for benthic invertebrates and vertebrate species that are adapted to dynamic substrate and serve as a trophic base for demersal fish assemblages, and 3) spawning sites for some demersal species and schooling planktivores (Gilmore 2008, CSA International, Inc et al. 2010). A number of fish species (Northern Stargazer, Snakefish, sand lances, Inshore Lizardfish, Harvestfish, and Spanish Mackerel in the Mid-Atlantic, and Bluntnose Stingray in the northwestern Gulf of Mexico) have been found to be associated only with the shoal areas in these complexes compared to the trough or non-shoal control areas (Diaz et al. 2003, Brooks et al. 2005, Vasslides and Able 2008a, Slacum et al. 2010). Northern Stargazer, Snakefish, sand lances, and Inshore Lizardfish generally occur over or burrow into sandy substrates, and are therefore likely to be found on sand shoals.

Shoal complexes have been designated EFH for a number of fish species including: Haddock (adult and spawning adult), Cobia, Spanish Mackerel, King Mackerel and Red Drum (SAFMC 1998, NMFS 2013b). Thirty-six Atlantic highly migratory species (tuna, swordfish, billfish, small and large coastal sharks, and pelagic sharks) have designated EFH that contain shoals areas in the Mid-Atlantic, South Atlantic, Straits of Florida, and/or Gulf of Mexico (Table 3-2; NMFS 2009). CSA International, Inc et al. (2010) identified twenty-six managed (federal, state, and regional) fish species and five managed invertebrate species that may utilize offshore sand shoals in the Mid-Atlantic Bight (Table 3-3). The sandy shoals of Cape Lookout, Cape Fear, and Cape Hatteras (NC) that extend from the shore toward the edge of the Gulf Stream are considered HAPCs for the coastal migratory pelagic species group. These features are designated as HAPCs due to their ecological function, which includes affecting longshore coastal currents and interaction with Gulf Stream intrusions to produce local upwelling; rarity of habitat; and threat from development activities (SAFMC 1998, SAFMC 2010). Other bottom features (e.g. Charleston Bump, SC; Hump off Islamorada, FL; and Marathon Hump, FL) that interrupt, cause changes in flow direction, and/or propagate downstream eddies of the Gulf Stream have also been designated as HAPCs along with their associated oceanographic phenomena (e.g. Charleston Bump Complex) for the coastal migratory pelagic species group, including Dolphin, Wahoo, and the snapper-grouper complex (SAFMC 2009).

The Atlantic OCS

The North and Mid-Atlantic

Studies conducted in shoal and ridge/trough complexes in the North and Mid-Atlantic have documented 107 species of fish collected in these habitats including the Atlantic Sturgeon (ESA status: endangered species) and Dusky Shark (ESA status: candidate species; Table 3-4). CSA International Inc et al. (2010) presented by life stage the fish species documented near Beach Haven Ridge (NJ) and the Delmarva shoal complex from studies in the 1970’s, 1990’s, and early

2000's. The combined studies documented 10 demersal and 4 pelagic egg species; 33 demersal and 7 pelagic larval species; and 64 demersal and 30 pelagic juvenile and adult species.

At a southern New Jersey ridge/trough complex the fish assemblage was found to be dominated by Atlantic Butterfish, Bay Anchovy, Striped Anchovy, Spotted Hake, Atlantic Croaker, and Weakfish during mid-summer months (Vasslides 2007, Vasslides and Able 2008a). Species abundance and richness showed a bimodal distribution from inshore to the offshore transects with the highest values observed on either side of the Beach Haven Ridge (Vasslides 2007). Juvenile Smallmouth Flounder (mean total length 27 mm and 35 mm) represented 70% of the individuals collected at the top of Beach Haven Ridge. Northern Stargazer and Snakefish occurred in small numbers only at the top of the ridge (Vasslides and Able 2008a).

Multiple studies have been conducted at the Delmarva shoal complex in the Mid-Atlantic Bight (Figure 2-1). Slacum et al. (2010) collected 31 fish species from shoal areas and 41 fish species from non-adjacent flat-bottom (non-adjacent trough) areas. This study found 3 fish species (Inshore Lizardfish, Harvestfish, and Spanish Mackerel) only at the shoal sites, while 12 fish species were collected only in flat-bottom areas. The shoal fish assemblages were dominated by Scup in the spring; American Sand Lance, Scup, and Clearnose Skate in the summer; and Striped Bass, Spiny Dogfish, and Little Skate in the fall (Slacum et al. 2010). Five species, including Smallmouth Flounder, Spotted Hake, Summer Flounder, Windowpane, and Winter Skate, were collected during all four seasons at the shoal areas (Slacum et al. 2010). An earlier study by Diaz et al. (2003) noted that species composition was dominated by Sand Lance, other benthic fishes, and Bay Anchovy. Sand Lance were found to be associated with very specific habitats, occurring mainly on the top and flanks of shoal areas that were dominated by coarse sand and larger bedforms (10 cm crest height). In contrast, Spotted Hake and Smallmouth Flounder showed less habitat preference and occurred in multiple adjacent habitats on Fenwick Shoal (Diaz et al. 2003).

At Sandbridge Shoal off the coast of Virginia sampling conducted on and immediately adjacent to the shoal found that searobins (*Prionotus* spp.), Spotted Hake, Butterfish, Pinfish, and Smallmouth Flounder were the most abundant fish species. Large variations in abundance were observed between years and sampling strata which prevented detection of significant differences among the dominant species (Diaz et al. 2006). The absence of a strong association between fishes and sampling strata appeared to be related to low variation in sediment grain-size and similar bedform structure among strata and the low occurrence of biogenic structure over the entire area (Diaz et al. 2006).

The South Atlantic and Straits of Florida

Studies conducted in shoal and ridge/trough complexes in the South Atlantic and Straits of Florida have documented 215 species of fish collected in these habitats including the Dusky Shark (ESA status: candidate species) and Smalltooth Sawfish (ESA status: endanged species; Table 3-5). Cape Canaveral (FL) nearshore and offshore waters (Southeast Shoal) appear to function as EFH for many of the Atlantic highly migratory species including several shark species (Reyier et al. 2008, NMFS 2009).

On unconsolidated sediments off the continental shelf of Georgia 121 taxa of juvenile fishes were collected, including several commercially and recreationally important species (Walsh et al. 2006). Abundance patterns indicated a cross-shelf fish assemblage gradient that varied seasonally. Sampling was not stratified by sediment characteristics so the role of specific habitats, such as ridge/trough complexes, could not be determined (Walsh et al. 2006). However, 19 of these species were collected in shoal and ridge/trough complex habitats in the North and Mid-Atlantic while an additional 53 species have been documented in these habitats along the east Florida continental shelf suggesting that ridge/trough complex habitats may have been present in the study area.

Along the northeast Florida coast Zarillo et al. (2009) collected a total of 77 taxa within or adjacent to five shoals that have been identified as potential offshore borrow sites. The dominant families were Paralichthyidae (large tooth flounders, 11 species), Sciaenidae (drums and croakers, 8 species) and Triglidae (searobins, 7 species). The collections were dominated by pelagic and demersal soft-bottom species (Striped Anchovy, searobins, Inshore Lizardfish, and juvenile whiffs), which have wide ranges over the Florida continental shelf. Species important to commercial and recreational fisheries in northeast Florida, including sea basses, Southern Kingfish, grunts, flounders, and Weakfish, were also collected in small numbers. The authors found that fish catch composition varied considerably among seasons and suggested that seasonal changes in fish abundance and community composition due to spawning, recruitment, and mortality patterns were of greater importance than spatial differences in habitat between the shoals and adjacent open bottom in structuring the fish assemblage. Ichthyoplankton surveys conducted at these sites collected 36 distinct taxa which were dominated by gobies (Gobiidae), anchovies (Engraulidae), and herring (Clupeidae). The majority of the larvae were benthic and pelagic forage species that are common throughout Florida estuarine and shelf waters (Zarillo et al. 2009).

Gilmore (2008) identified 185 species that have been documented in shoal habitats on the east Florida continental shelf (Table 3-6). Of these species 24 were relatively abundant; 35 were common; 36 occurred occasionally; 20 were rare; and 70 were documented but the relative abundance was unknown. Pierce Shoal off the coast of east central Florida has been indicated as the primary spawning site for clupeid fishes: menhaden, Red Ear and Scaled sardines, Atlantic Thread Herring, and Spanish Sardine. Biologists and fishermen have each reported King Mackerel, Red Drum, Tripletail, and Goliath Grouper in spawning aggregations on shoals or adjacent to shoals from Cape Canaveral to Jupiter Island. Shoals further offshore may be potential spawning sites for Striped and Silver mullet since their eggs and larvae have been collected in the Florida Current boundary (Gilmore 2008). The east central coast of Florida has prolonged seasonal spawning patterns for many of the species due to the subtropical to tropical climate that differs significantly from the areas north of Cape Canaveral and the eastern Gulf of Mexico, which have warm temperate and subtropical climates. Offshore spawning migrations have been documented in the fall-winter for warm temperate species and at various times throughout the year for subtropical species (Gilmore 2008). Juvenile Lemon Sharks aggregations have been documented at several surf zone locations (longshore troughs) between the tip of Cape Canaveral (Southeast Shoal) and the Port Canaveral Jetty with the smallest juveniles observed in the shallowest waters (Reyier et al. 2008). Reyier et al. (2008) suggested that Cape Canaveral nearshore waters are a Lemon Shark nursery meeting the criteria of a shark nursery described by Heupel et al. (2007). The nearshore waters of Cape Canaveral appear to also serve a nursery function for neonate Spinner Shark, neonate and juvenile Blacktip Shark, neonate Scalloped Hammerhead, and neonate and juvenile Atlantic Sharpnose Shark (Aubrey and Snelson 2007, Adams and Paperno 2007; See EFH paragraph above).

The Gulf of Mexico OCS

Studies conducted in shoal and ridge/trough complexes in the Gulf of Mexico have documented 136 species of fish collected in these habitats (Table 3-7).

Eastern Gulf of Mexico

Along the west coast of Florida, Zarillo et al. (2008) collected 50 taxa of fish within and adjacent to three proposed sand borrow sites that included two ridges in the Toms' Hills shoal system and Siesta Shoal. Hard bottom substrate was found adjacent to Siesta Shoal. The dominant families collected were: Ophidiidae (cusk eel, 6 species), Serranidae (sea basses and groupers, 5 species), Triglidae (searobins, 4 species), and Paralichthyidae (largetooth flounders, 4 species). The collections were dominated by the benthic species including the Barred Searobin, Leopard Searobin, Sand Seabass, juvenile grunts, and Twospot Flounder. Pelagic fishes, though less abundant, were also collected including Atlantic Bumper and Atlantic Thread Herring. Five species associated with hard bottom were also collected, with Sand Perch being relatively common. Ichthyoplankton surveys conducted at these sites collected 17 identifiable taxa from 14 families with most larvae from pelagic forage or small-bodied demersal species that are common in estuarine and shelf waters throughout Florida.

Central Gulf of Mexico

Byrnes et al. (1999) collected 40 taxa of fish from five identified sand resource areas off Alabama. The dominant species collected were Longspine Porgy, Spot, Silver Seatrout, Atlantic Croaker, and Rock Seabass. Seasonal variation was observed in the demersal assemblages at these sand resource areas, which agreed with previous sampling efforts that indicated a community of widespread taxa that migrate inshore seasonally. Variation in fish abundance and diversity was observed among sampled sand resource areas, and was attributed to influences of Mobile Bay outflow on the western sand resource areas relative to the eastern areas.

Western Gulf of Mexico

Brooks et al. (2005) identified 99 fish species (93 non-commercial species, 6 commercial species) that were collected at the Trinity Shoal, Tiger Shoal, Sabine Bank, and Heald Bank areas in the northwest Gulf of Mexico (Table 3-8). Of these species, 5 were frequently caught at one or more shoals, 25 were commonly caught, and 68 were rarely caught. Hardhead Catfish, Sand Seatrout, Silver Seatrout, Spot, Atlantic Croaker, and Least Puffer were frequently or commonly caught at all four areas. Several species exhibited patterns in which they were found commonly only at one area and rarely or absent from the other areas. For instance, Bay Whiff was commonly collected only at Tiger Shoal, while Banded Drum was only commonly caught at Sabine Bank. Dwarf Sand Perch, Silver Jenny, Smooth Puffer, Pinfish, Blackedge Cusk-eel, Lane Snapper, Planehead Filefish, Blackwing Searobin, Shoal Flounder, and Inshore Lizardfish were only commonly collected at Heald Bank. Fringed Flounder, Rock Seabass, and Atlantic Midshipman were found to be absent from only one of the study areas, but present in the other three. Species-specific trends were found between the eastern (Trinity and Tiger Shoals) and western areas (Sabine and Heald Banks). Gafftopsail Catfish was frequently or commonly collected at the eastern sites but was rarely or never collected at western areas; whereas Southern Kingfish, Pigfish, and Bighead Searobin were frequently or commonly caught at the western areas but were rarely or never caught at the eastern sites. Species-specific trends were also found between the northern (Tiger Shoal and Sabine Bank) and southern areas (Trinity Shoal and Heald Bank). Star Drum and Blackcheek Tonguefish were frequently or commonly collected in the northern areas but rarely or never collected in the southern areas; whereas Bigeye Searobin and Longspine Porgy were frequently or commonly caught in the southern areas but rarely or never caught in the northern areas.

Stone et al. (2009) collected generally low numbers of Atlantic Croaker at Ship Shoal in the northwest Gulf of Mexico off the coast of Louisiana. The Atlantic Croaker sizes ranged from 129 to 166 mm suggesting both juvenile and adult lifestages were present. The increase of the size and weight of the individual Atlantic Croaker throughout the year indicated that the population on Ship Shoal may not be transient. Stone et al. (2009) suggested some croaker remain offshore and reside on or around Ship Shoal. Stomach contents of the Atlantic Croaker collected on Ship Shoal in 2005 and 2006 were comprised predominantly by amphipods, burrowing shrimp, unidentified crustaceans, polychaetes and other unidentified material. Stone et al. (2009) suggested that Ship Shoal provides valuable foraging habitat when croaker are present. Hypoxia was rarely observed on Ship Shoal during the summers of 2005 and 2006 indicating that the shoal may serve as a hypoxia refuge.

Wells et al. (2009) collected 41 families and 100 species at Freeport Rocks, a drowned barrier island (sand ridge with shell material) offshore Texas. Eight species (Shoal Flounder, Dwarf Sand Perch, Red Snapper, Least Puffer, Silver Seatrout, Largescale Lizardfish, Silver Jenny, and Sand Seatrout) comprised 69% of the total fish composition at this location. Inshore Lizardfish, Lane Snapper, Bay Whiff, Fringed Flounder, and Offshore Tonguefish were commonly collected, occurring in greater than 50% of the samples. Distinct fish assemblages were observed among inshore mud, shell bank, and offshore mud habitats, although differences in species composition among the areas were minor. Dwarf Sand Perch and Pygmy Sea Bass were important species in the shell bank fish assemblage structure. The highest Dwarf Sand Perch and Least Puffer densities occurred on the ridge compared to the other two areas.

A number of fish species have been found to occur in shoal and ridge/trough complexes over a large geographic range. A review of the fish identified in the literature discussed above shows that 23 fish species occur in shoal and ridge/trough habitats both in the Mid-Atlantic and along the east coast of Florida; 49 species occur in shoal and ridge/trough habitats both along the east coast of Florida and in the Gulf of Mexico; 16 species occurred in each of the Mid-Atlantic, the east coast of Florida and in the Gulf of Mexico; and 18 species occurred in both the Mid-Atlantic and the Gulf of Mexico (Table 3-9).

Seasonal patterns

Temporal patterns of fish occurrence on shoal and ridge/trough complexes have been observed and are generally consistent with region-specific seasonal migratory and recruitment patterns (Cutter and Diaz 2000, Brooks et al. 2005, Gilmore 2008, Slacum et al. 2010). Cutter and Diaz

(2000), Slacum et al. (2006, 2010), and Vasslides and Able (2008a) each found that latitudinal seasonal migrations across depth gradients in the Mid-Atlantic strongly influenced the seasonal patterns in the shoal and ridge/trough complex fish assemblages, where the majority of the species observed were seasonal residents. Species-specific temporal patterns of occurrence of benthic fish on sand banks have also been found in the Gulf of Mexico. Brooks et al. (2005) noted that Banded Drum and Pigfish were commonly to frequently collected in the summer, but were rarely or never collected in the winter, while the Crested Cuskeel was commonly to frequently collected in the winter, but was rarely or never observed in the shoal habitats during the summer. Spot was collected at higher frequencies at Tiger Shoal and Sabine Bank areas during the summer. Smooth Puffer, Planehead Filefish, and Pygmy Sea Bass also occurred at higher frequencies at Heald Bank during the summer. Fringed Flounder, Rock Sea Bass, Southern Kingfish, Atlantic Midshipman, Least Puffer, Inshore Lizardfish, and Shoal Flounder were all collected at higher frequencies in the winter than during the summer at Trinity Shoal, Tiger Shoal, and Sabine Bank. Red Drum was collected at higher frequencies at Trinity Shoal during the winter. Pancake Batfish and Blackedge Cusk-eel were encountered commonly-to-frequently in the winter, but rarely to never in the summer at Heald Bank (off Galveston TX).

Diel patterns

Diel variations in spatial distribution and activity patterns are common among fishes and invertebrates in marine ecosystems and have been well studied. Diel patterns were observed on Fenwick and Weaver Shoals (MD), where fish were found to be more abundant on shoal habitats at night and on biogenic complex trough or flat-bottom habitats during the day (Diaz et al. 2003, Slacum et al. 2006). For example, Smallmouth Flounder and Spotted Hake were eight and six times more likely to occur in complex biogenic habitats during the day than at night (Diaz et al. 2003). Both authors suggested that the amount of available shoal relief (ridge height) may have been a factor in determining fish use of shoals at night. Increased vertical relief or habitat complexity in other marine habitats (e.g., reefs) has been shown to influence the abundance and diversity of fishes (Matthews 1990, Anderson et al. 2005, Walker et al. 2009b). Auster et al. (1995) found that Silver Hake and Little Skate demonstrated diel shifts, from occupying specific microhabitats (0.01 to 0.1 km) during the day to becoming randomly distributed at night, that were associated with foraging behavior. The proximity of both simple and complex habitats on these shoals may provide both refuge from predation and increased resource availability (Diaz et al. 2003). Slacum et al. (2006) also found that nighttime use by fish differed among individual shoals within the same shoal complex; Fenwick and Weaver Shoals had higher fish use at night compared to Shoals B and D. The four shoals exhibited varying degrees of relief; Fenwick and Weaver Shoals had the steepest slopes, while Shoals B and D had the least relief. The influence that small scale bedform relief and microhabitats may have had in this pattern could not be determined (Slacum et al. 2006).

4.2.2 Shoal habitat value

Shoal and ridge/trough complexes appear to differ in their value as habitat due to fluctuations in macroscale environmental factors (e.g., variable salinity related to freshwater input from large river systems, fluctuating oxygen levels due to stratification and nutrient input, depth, and currents; Brooks et al. 2005). Meso- (100 m to 1 km) and microscale (centimeters to meters) factors such as shoal relief, density of biogenic structures, and bedform structure within and adjacent to the complexes can also impact habitat value (Slacum et al. 2006, SAFMC 1998, Zarillo 2009). Individual shoals or ridge/trough systems within a complex may have unique habitat values (Slacum et al. 2006). For example, in the northwest Gulf of Mexico several species exhibited species specific differences in occurrence between eastern (Trinity and Tiger Shoals) and western (Sabine and Heald Banks) areas, and some species demonstrated preference for or absence in individual shoal/bank areas (see Western Gulf of Mexico section above) suggesting that these areas may provide different habitat requirements for these species (Brooks et al. 2005). Mean species richness differed among the study areas; Heald Bank had consistently higher species richness compared to the Trinity Shoal, Tiger Shoal, and Sabine Bank areas. Mean biomass also differed among areas, and was consistently higher at the Trinity Shoal, Sabine Bank, and Heald Bank areas compared to the Tiger Shoal area.

The Trinity and Tiger Shoal areas are located within the Gulf of Mexico hypoxic zone and experience reduced oxygen levels (0-10.7 ppm) from June through August. Trinity Shoal displayed lower species richness and abundance values during the summer that corresponded to the reduced oxygen levels (Brooks et al. 2005). Byrnes et al. (1999) also found that demersal assemblages off the Alabama coast were influenced by fluctuating hydrographic parameters of Mobile Bay in the western areas compared to the more hydrographically stable eastern areas.

Differences in habitat value have also been observed for important finfish species that use shoal and ridge/trough complexes in the northwest Gulf of Mexico. Geary et al. (2007) quantified densities of juvenile red snapper on Freeport Rocks as well as the two banks (Heald and Sabine) surveyed by Brooks et al. (2005), and reported that Freeport Rocks had markedly higher red snapper densities than either Heald Bank or Sabine Bank, suggesting that the value of these banks as nursery areas of red snapper could be distinctly different. However, because the areas were sampled in different years, regional interannual differences can not be completely ruled out.

Reef-associated fish species have been documented in shoal and ridge/trough complexes adjacent to or containing hard bottom substrate (reef patches, oyster or coral reefs, and rock outcroppings) in the South Atlantic, Florida Straits, and the Gulf of Mexico, indicating that the hard bottom features influence the local shoal fish assemblage and increase species diversity in these shoal areas (SAFMC 1998, Zarillo 2009).

Shoal versus non-shoal habitat within a complex

Shoal and non-shoal areas (trough areas) within a shoal complex are distinct habitats that may have different habitat values (Diaz et al. 2003, Brooks et al. 2005, Vasslides and Able 2008a, Slacum et al. 2010). Although these are distinct habitats, the environmental parameters that shape the biological community in the non-shoal areas are influenced by spatial variability in the topography, sediment characteristics, and proximity of the shoal areas (Diaz et al. 2003, Hayes and Nairn 2004).

Vasslides and Able (2008a) and Slacum et al. (2010) both found that the flat-bottom habitats, or troughs, in the large shoal complexes of the Mid-Atlantic Bight had greater fish abundance and diversity than the shoal or ridge habitats. Similarly, species abundance on the ridge tops was significantly lower than areas on either side of the ridge in the southern New Jersey ridge/trough complex (Vasslides 2007). Cutter and Diaz (2000) determined that troughs adjacent to shoals in the Mid-Atlantic Bight contained higher densities of benthic invertebrates than the shoals themselves, which likely provides greater availability of benthic forage and may be the primary reason for increased fish abundance and diversity in these habitats.

Wells et al. (2009) found different fish assemblage structure among the three habitats (inshore mud, offshore mud, shell bank [shoal]) at Freeport Rocks (offshore TX), although the overall diversity in fish assemblages was similar across the northern Gulf of Mexico shelf when compared to other studies investigating fish assemblage structure in similar habitats in the region. The authors suggested that a mosaic of habitats may be important to fish assemblage structure rather than a single habitat type. Geary et al. (2007) assessed the value of shoal (shell bank) and non-shoal (inshore and offshore mud) areas at Freeport Rocks for juvenile red snapper and found no habitat effect. Juveniles were equally abundant in adjacent mud and shoal habitats suggesting that both shoal and non-shoal habitats have the potential to function as red snapper nursery areas.

Use of microhabitats

The interactions of the physical, environmental, and biological processes in shoal and non-shoal areas lead to the formation of characteristic microscale habitats. Microhabitats are known to contribute to variations in fish distribution within regional and local fish assemblages (Auster et al. 1995, Auster et al. 1991, Sullivan et al. 2000). Habitat selection is believed to vary as a function of several factors including physiological constraints, predation pressure, prey availability (Auster et al. 1997), and physical processes (Wells et al. 2009). Positive relationships have been observed between the abundance and diversity of both fish and their prey and increasing structural complexity (Wells et al. 2009). Individuals of most taxa use a variety of habitats both within a single life stage and among different life stages (Auster et al. 1991, Auster et al. 1995, Pierce and Mahmoudi 2001, Mikulas and Rooker 2008, Wells et al. 2009). Juveniles frequently have a strong affinity for complex benthic habitats that can provide shelter from predators and aid in foraging (Lough et al. 1989, Able et al. 1995, Auster et al. 1997, Gregory and Anderson 1997, Thrush et al. 2002). Finfish distributions, especially for juvenile stages, in shoal and ridge/trough complexes have been found to be influenced by sediment grain size, bedform size, the distribution of biogenic structures, the benthic invertebrate community, shoal proximity, and current velocities (Auster et al. 1995, Eggleston 1995, Auster et al. 1997, Szedlmayer and Conti 1999, Cutter and Diaz 2000, Auster et al. 2003, Diaz et al. 2003, Diaz et al. 2004a, Rooker et al. 2004, Szedlmayer and Lee 2004, Patterson et al. 2005, Vasslides and Able 2008a). Spatial and temporal variation in physicochemical conditions (e.g. temperature, salinity, and dissolved oxygen) also structure fish assemblages in these habitats (Sullivan et al. 2000, Vasslides and Able 2008a, Slacum et al. 2010), and the effects of multiple factors can be difficult to disentangle. Microscale vertical relief within shoal and ridge/trough habitats is provided by biogenic structures and small bedform relief, and can be an important component in these areas. Cutter and Diaz (2000) and Diaz et al. (2003) characterized four distinct habitats on Fenwick Shoal and found that the coarser sand-gravel and the *Diopatra* tube habitats had similar fish assemblages, the sand habitat had a fish assemblage similar to other dynamic sandy habitats, and that the *Asabellides* tube habitat was the most dissimilar of the four. Within the two physically-dominated bottom habitats, they observed strong diel patterns in the fish assemblage with four times as many fish present in these habitats at night (See Diel pattern section above). Juvenile fish abundance was significantly greater on large (10 cm height) versus small (5 cm height) bedforms habitats. The highest incidences of fish occurred in habitats with large bedforms and some biogenic structure, which provided additional vertical relief. Similarly, Patterson et al. (2005) concluded that juvenile Red Snapper in the Gulf of Mexico required habitat with microscale complexity, preferring shell ridge habitats compared to low-relief habitats.

4.2.3 Behavior of fishes on or around shoal and ridge/trough complexes

There is limited literature that describes how fish assemblages use specific shoal and ridge/trough complex habitats and the relevance of specific habitat features for whole communities within the continental shelf system (Slacum et al. 2010). Shoals and ridge/trough complexes provide much of the large-scale physical relief and complexity on the inner continental shelf (Diaz et al. 2003) and represent macroscale habitats for finfish on the Atlantic and Gulf of Mexico OCS (Slacum et al. 2010, Vasslides and Able 2008a, Diaz et al. 2003, Brooks et al. 2005). Determining fish-habitat associations at this scale is complicated by variations in other factors known to influence demersal and pelagic fish distribution along the continental shelf, including depth and temperature (Diaz et al. 2003, Gabriel 1992, Overholtz and Tyler 1985, Methratta and Link 2006, Colvocoresses and Musick 1984, Moore et al. 1970). Depth is an inherent characteristic of shoal and ridge/trough complexes and its effects are difficult to separate from those of the physical features of the shoal (Slacum et al. 2010) as the depth gradient varies across a shoal. Depth is associated with temperature variations, prey distribution, and migratory patterns at a macroecological scale (100s kilometers) (Slacum et al. 2010, Grosslein and Azarovitz 1982); these effects may also be occurring on individual shoals within a shoal complex although data on this is currently not available.

Shoals and ridge/trough complexes are considered as ecotones or habitat transition zones that may enhance biological productivity and concentrate organisms at several trophic levels (Gilmore 2008). Fishes documented on shoal and ridge/trough complexes represent a range of trophic guilds from planktivores to tertiary consumers (Garrison and Link 2000, Maranick and Hare 2007). Shoals may provide refuges for pelagic planktivores including Sand Lance, anchovies, Smallmouth Flounder, herrings, Butterfish, sardines, menhadens and scads (Vasslides and Able 2008a, Diaz et al. 2003, Gilmore 2008) that are more vulnerable to predation in deeper waters. These pelagic species are typical prey species for a variety of resident and transient piscivores also documented to use shoal and sand ridge/trough habitats, including Striped Bass, Bluefish, Weakfish, Spiny and Smooth Dogfish, Spanish and King Mackerel, Little Tunny and other various tuna, and sharks (Buckel et al. 1999, Bowman et al. 2000, Garrison and Link 2000, Maranick and Hare 2007, Gilmore 2008). One clear benefit provided by a structurally complex seafloor is an increase in available refuge from predation. Shoal habitats may provide a different type of predation refugia compared to more complex biogenic structured habitats (e.g, sponges, reefs) that exclude predators. Experimental work indicates that complex habitat features can interfere with predator search and pursuit behavior, contributing to lower predation vulnerability for small fishes occupying these habitats (Gotceitas et al. 1995, Bartholomew et al. 2000, Stunz and Minello 2001, Ryer et al. 2004, Scharf et al. 2006). Several field studies have also documented a significant reduction in predation vulnerability for fishes using complex habitats (Beukers and Jones 1997, Heck et al. 2003). The juvenile life stage of many fishes often displays the strongest affinity for complex habitats (Lough et al. 1989, Able et al. 1995, Auster et al. 1997, Gregory and Anderson 1997, Thrush et al. 2002). A disturbance that reduces the vertical relief of a shoal or shoal complex could reduce the overall habitat complexity and value of the feature and the adjacent areas, and therefore contribute to reduced survivorship among juvenile fishes that could have important consequences for population dynamics (Diaz et al. 2004a, Gilmore 2008, Slacum et al. 2010), although these effects are not well understood (Michel et al. 2013).

Shoals and sand ridge complexes may also represent important benthic forage sites for demersal fish assemblages (Gilmore 2008). Stomach content analyses by Diaz et al. (2006), Vasslides and Able (2008b), Zarillo et al. (2008), and Zarillo et al. (2009) each revealed that demersal fishes collected in shoal areas had consumed epifaunal and infaunal invertebrate prey species typical of the benthic communities present in the study areas. Mysid and sand shrimp were important prey items for multiple species (searobins, flounders, and seabass) at all shoal areas. Specifically, polychaetes were a primary prey item for Smallmouth Flounder (Diaz et al. 2006, Zarillo et al. 2008), while fish prey were important for Inshore Lizardfish, Banded Drum, Silver Seatrout, and Summer Flounder (Zarillo et al. 2008, 2009). These studies demonstrate the close link between the invertebrate community and the demersal fishes at these shoal complexes.

Habitat connectivity

Shoals and ridge/trough complexes with their vertical relief and microhabitats provide important nursery and forage habitats on the continental shelf and may enhance early life stage survival and recruitment by functioning as physical and visual barriers between predators and prey species (Nelson and Bonsdorff 1990, Lindholm et al. 1999, Auster et al. 2003, Diaz et al. 2003, Ryer et al. 2004, Scharf et al. 2006, Vasslides and Able 2008a, SAFMC 2009, Wells et al. 2009, Woodland et al. 2012). Interannual settlement patterns for several fish species on the Mid-Atlantic shelf suggest that juveniles utilize discrete nursery habitats consistently from year to year (Sullivan et al. 2000). The transfer of individuals between habitats can result in a substantial movement of biomass, nutrients, and energy from one habitat to another (Deegan 1993). Gillanders et al. (2003) suggested that habitat connectivity depends on the distance between two habitats and the presence of movement corridors or habitat patches that allow fish to freely move among areas. Examination of juvenile settlement in southern New Jersey by Able (2005) suggested connectivity between estuarine and ocean habitats near Beach Haven Ridge. Wells et al. (2009) suggested that along the Texas coast bathymetric features located near estuaries may provide an inshore and offshore movement corridor, for example Freeport and Galveston Bay estuaries and Freeport Rocks Bathymetric High. Shoal and ridge/trough complexes can extend from the beach to several miles offshore, these features may provide a migration corridor linking early life and adult habitats for many fish species (Able 2005, Wells et al. 2009). These features may also be used at a macroscale as guides during spawning or seasonal migrations (CSA International, Inc et al. 2010). Knowledge of the connectivity between juvenile and adult habitats and estuarine and offshore areas has important implications for fisheries management and the effective conservation of marine organisms (Gillanders et al. 2003).

Summary of Main Fish Findings

- Shoals and ridge/trough complexes are among the least studied offshore marine habitats in the Atlantic and Gulf of Mexico OCS (Walsh et al. 2006, Gilmore 2008, Slacum et al. 2010).
- A diverse number of fish species that are common members of the local shallow continental shelf fish assemblage utilize shoal and ridge/trough complex habitats in the Atlantic and Gulf Mexico OCS, including economically and ecologically important species (Tables 3-2 through 3-7).
- Shoals and ridge/trough complexes represent fish habitat that may serve as refuges from predation, forage areas, spawning sites, and nursery areas. These habitats are utilized by multiple life stages (newly settled juveniles, sub-adults, and adults) of marine fishes. A number of fish species (Northern Stargazer, Snakefish, sand lances, and Inshore Lizardfish) have been found to be associated with shoal and ridge top habitats in the Mid-Atlantic. Data on fish species associated only with shoal and ridge top habitats were not found for the South Atlantic, Florida Straits, and Gulf of Mexico regions.
- Shoal areas have been designated as EFH for a number of species and HAPCs for the coastal migratory pelagic species.
- Fish abundance and diversity on shoal and ridge/trough complexes is believed to vary latitudinally and across the continental shelf in reponse to biological and physicochemical factors. Assemblage composition varies temporally; and seasonal changes in fish abundance and community composition appear to be due primarily to spawning, recruitment, and mortality patterns, which appear to be of greater importance than spatial differences between the shoals and adjacent open bottom in structuring shoal and ridge/trough complex fish assemblages.
- Diel patterns of abundance and diversity have been observed in shoal and ridge/trough complexes where fish were more abundant on shoal habitats at night and on biogenic complex trough or flat-bottom habitats during the day.
- Shoal and ridge/trough complexes may have different fish habitat value due to macroscale environmental factors (i.e. variation in salinity, dissolved oxygen, and nutrient inputs) and microscale factors (i.e. shoal relief, bedform structure, and biogenic structures). Individual shoals or ridge/trough systems within a complex may also have different habitat values.
- Shoals and ridge/trough complexes are habitat transition zones that may enhance biological productivity and concentrate organisms at several trophic levels. Stomach content analyses conducted in these areas have demonstrated a close link between the invertebrate community and the demersal fish assemblage.
- Shoal and non-shoal areas (trough areas) in a shoal complex are distinct habitats with different habitat values that are linked together by the topography and its influence on water and sediment dynamics. Non-shoal areas in the Mid-Atlantic Bight appeared to have greater abundance, species richness, and species diversity than the shoal areas (Slacum et al. 2010).

- Shoal and ridge/trough complexes contain a range of microhabitats that influence fish distribution and overall habitat value. Sediment grain size, bedform size, biogenic structures, the forage benthic invertebrate community, shoal proximity to adjacent habitats, and current velocities can each have important influences on juvenile fish microhabitat utilization. Small-scale complexity in shoal and ridge/trough complexes is mainly provided by biogenic structures and small bedform relief.
- Shoal and ridge/trough complexes that extend from the beach to several miles offshore may provide a corridor linking inshore and offshore movements for fish species.

5.0 Outstanding Questions

The literature described in the preceding sections revealed that scientific basis for describing habitat value of shoals is limited. Seveal reports have identified some specific data gaps:

1) Brooks et al. (2005) noted: 1) lack of sampling conducted transversing shoals and banks, and 2) species-specific information including standardized abundance information, individual biomass measurements, and age-length measurements, which is necessary to determine the value of shoals and sand banks as nursery habitat.
2) CSA International, Inc. et al (2010) identified the need for additional information on: 1) species-specific growth rates, reproductive output, feeding habits, and movements to accurately assess habitat quality, 2) direct information on fish predation of shoal invertebrates, 3) spawning locations relative to shoals, 4) burrowing activity of demersal fish species, and 5) species distributions across an entire shelf and structural bottom types.
3) Slacum et al. (2010) identified: 1) the need for targeted, small spatial scale studies in adjacent trough areas to identify the factors that contribute to increased levels of productivity observed in these areas, and 2) more detailed evaluations of microhabitats, environmental parameters, and diel patterns.
4) Michel et al. (2013) identified: 1) the need for more systemic research to understand the ecological roles of sand ridge and swale habitats, their fish abundance, diversity, richness, and the ecological value relative to adjacent habitats, 2) the need to validate the factors and scale of operations that would result in detrimental effects on the blue crab population due to feature size compared to burrow areas in the Gulf of Mexico, 3) the need to understand the importance of sand ridge and swale habitats as spawning, nursery, or foraging areas for benthic and pelagic species, and 4) the need to understand different species' preferential site use and site fidelity. This report provides an expanded overview of the impacts associated with dredging that have been touched upon in this synthesis and can be accessed at: http://www.data.boem.gov/PI/PDFImages/ESPIS/5/5268.pdf.

Summarization of literature related to shoal habitat value for this white paper led to the identification of a number of specific areas of uncertainty that warrant further discussion and analysis to support BOEM's goal of simplifying the review process with resource and regulatory agencies for future proposals for offshore shoal sand mining or structure installation. These outstanding questions are presented in this section to form the basis for discussions during the working group planned for January 2014.

5.1. How does regional/site specific variability between shoals control sediment dynamics and the likelihood that sand removed from a shoal will be replaced through natural processes?

What data are needed (e.g., current measurements, natural sediment transport rates through radioisotope geochronology and other tools)? Which predictive models can be adapted to specific sites?

5.2. What information is needed to predict how much material can be removed from a shoal complex without disrupting the natural physical processes controlling its dimensions?

Does the geologic origin of a shoal affect its ability to reform if disturbed? Is there research related to recovery of shoals from major storm events that would be relevant to evaluating the recovery from human alteration? Are there regional differences in responsiveness of shoals to physical disturbances?

5.3. Are there differences in function and habitat quality between shoals that are actively moving or have a higher sediment flux rate than those that have little or no annual sedimentary disturbances and are generally static?

How quickly does the habitat and ecosystem recover from natural disturbances and can this information be used to predict the ecosystem response to anthropogenic disturbances?

5.4. How can shoal/ridge habitats be effectively sampled to determine their value to fishes at the various scales associated with these habitats?

Traditional sampling gears used to investigate fish-habitat relationships can be biased by features of the habitat that alter catchability. If catchability of a specific gear varies among habitat types, then habitat-specific indices of abundance will not represent unbiased estimates of the number of fish in each habitat. Can greater use of remotely operated vehicles, active acoustics, and gear-mounted or drop cameras alone and in conjunction with other sampling methods help identify and overcome these biases? The utilization of multiple gear types within a habitat and between habitats can help minimize or eliminate sampling biases. Can existing gear types effectively and adequately assess fish-habitat relationships within shoal complexes and adjacent habitats or do new technologies need to be developed? Are there alternate field methods that are better suited to evaluating shoal-dependence?

5.5. Do shoal/ridge habitats represent critical nursery habitats of fishes?

How can we define nursery function of these habitats? Are measures of abundance and species diversity sufficient, or are studies that measure vital rates (e.g., condition, growth, mortality) required? What are the most appropriate methods to investigate the potential implications of sand dredging or placement of wind-generating equipment on the quality and productivity of shoal or ridge habitats?

5.6. How do we determine microhabitats within a shoal/ridge complex that are critically important?

Fine-scale variation in habitat use, especially by juvenile fish, has been documented in shoal and ridge/trough complexes. Spatially-explicit foraging information could potentially inform this question. At what spatial scale can human disturbances be executed? Is it possible to protect microhabitats within a shoal while still utilizing the shoal for sand removal or wind generation? How resilient are microhabitats to disturbances? Do natural or man-made disturbances create or maintain microhabitats and/or microhabitat diversity in shoal complexes? Do recovered or man-made microhabitats have the same habitat quality and function as the initial microhabitat?

The importance of microhabitats related to shoals is a critical question for both fish and benthos. Little information is available to describe the microfaunal and meiofaunal communities in shoal habitats and how these communities vary across microhabitats. Information about these groups might help to answer questions related to microhabitat use by macrofauna and juvenile fishes. The distribution of macrofaunal and megafaunal organisms is known to vary with differences in sediment texture. The causative factors driving this relationship are not fully understood. A better understanding of the relative contributions of physical, chemical, and biological factors that influence benthic community structure would help to inform the question of which microhabitats are most important within shoal/ridge complexes.

5.7. Which shoals and shoal complexes are most valuable and why?

The literature indicates that individual shoals may have different habitat value for mobile macroinvertebrates and demersal and pelagic fish species. Can we identify individual shoals and/or shoal complexes that have higher habitat value compared to others? Can we identify the factor or set of factors that contribute to high shoal habitat value and overall productivity? Can we determine the extent that the valuable shoals are contributing to commercial fishery populations? Can we determine the resiliency to disturbance of the most valuable shoals and/or shoal complexes?

5.8. How do we extrapolate localized disturbance effects to population-level responses at a regional scale?

What are the appropriate parameters? Do presence/absence and/or relative abundance estimates at various spatial scales for both benthic forage communities and fish communities provide sufficient insight? Are these habitats limiting? Can mobile fish simply move to adjacent habitats of similar quality?

Would estimates of vital rates (e.g., condition, growth, and mortality) provide a better assessment of disturbance (reduced habitat quality)? Estimation of vital rates in adjacent habitats would be helpful.

Can novel approaches (otolith chemistry, genetic markers) be used to assess changes in contribution rates of putative nurseries to adult stocks at regional scale?

How does the rate of disturbance to the shoal/ridge habitat affect the recovery time for benthic communities and the subsequent response of the fish community?

5.9. How do species-specific life history traits and/or behavior impact the value and connectivity of shoal/ridge habitats?

What is the influence of life history traits (e.g., planktonic larval duration) on connectivity at a regional scale? Do shoals and large shoal complexes affect local or regional hydrodynamic processes that in turn affect biological processes (e.g. mesocale gyre effects)? Do shoal and shoal complexes influence egg and larval transport and dispersal? Do shoal complexes retain life stages or specific species?

Biologically, habitat and ecosystem connectivity occurs because of species-specific behavior (movement). How can we improve our understanding of shoal and shoal complexes in ecosystem connectivity? Would acoustic telemetry (VPS technology) be useful for obtaining baseline information on movement within and across shoal/ridge systems?

5.10. Do useful indicator species exist?

Identification of potential indicator species would make tracking disturbance impacts more manageable. Can we identify which species are most associated with shoal habitats in the various OCS regions? Can we determine species that would be representative of shoal complexes within a region? There is some understanding of which fishes are associated with shoals in the Mid-Atlantic Bight, but not other regions. Blue crabs have been found to be associated with shoals in the Gulf of Mexico, but not exclusively so. No other invertebrate species has been found exclusively on shoals.

5.11. How do we avoid or minimize disturbances to these habitats? What resource conservation methods are appropriate?

The literature discussing dredging guidelines and impacts (e.g., Michel et al. 2013) have made recommendations to limit the physical and biological impacts of dredging on benthic habitats. These have included:

- Dredging only in actively accreting areas and avoiding erosional or static areas
- Maintenance of shoal geometry
- Following natural contours
- Limiting the depth of removal
- Avoid removal from the crest, or a portion of the crest to maintain nursery habitat
- Remove material in bands with untouched sediment in between to provide a local source of benthic infauna for recolonization of dredged areas
- Avoid removing sediments from along the entire length of a shoal
- Do not remove excessive volume from an individual shoal (generally set at less than 10%)
- Use only shoals with a height to base depth ratio >0.5
- Within a shoal complex, practice rotational dredging on individual shoals to allow recovery
- Dredge only during the winter when biological productivity is lowest

- If hard bottom habitat, corals, or coral reefs occur in the vicinity of the shoal, restrict anchoring, spudding and vessel transits to avoid these features
- Employ best management practices to minimize degradation of water quality
- Place a screen over the cutterhead to minimize entrainment of fishes.

Are these recommendations appropriate for all shoals? Do site-specific conditions differ enough to warrant different conservation measures at different locations? Can we determine time closures during sensitive periods (settlement and spawning) for shoal complexes? Is there evidence that these mitigative actions are effective? Are they feasible to employ?

Literature Cited

Abel, C. E., Tracy, B. A., Vincent, C. L., Jensen, R. E., 1989. Hurricane hindcast methodology and wave statistics for Atlantic and Gulf hurricanes from 1956– 1975. Wave Information Study Report 19, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, Mississippi, 85 pp.

Able, K.W., M.P., Fahay, and G.R. Shepherd, 1995. Early life history of black sea bass, *Centropristis striata*, in the Mid-Atlantic Bight and a New Jersey estuary. Fishery Bulletin 93:429-445.

Able, K.W. 2005. A re-examination of fish estuarine dependence: evidence for connectivity between estuarine and ocean habitats. Estuarine, Coastal and Shelf Science 64:5–17.

Able, K.W., M.P. Fahay, D.A. Witting, R.S. McBride, and S.M. Hagan. 2006. Fish settlement in the ocean vs. estuary: Comparison of pelagic larval and settled juvenile composition and abundance from southern New Jersey, U.S.A. Estuarine, Coastal and Shelf Science 66:280−290.

Adams, D.H., and R. Paperno. 2007. Preliminary assessment of a nearshore nursery ground for the Scalloped Hammerhead off the Atlantic coast of Florida. American Fisheries Society Symposium 50:165-174.

Allison, M., Dellapenna, T. M., Gordon, E. Mitra, S., and Petsch, S., 2010. Impact of Hurricane Katrina (2005) on shelf organic carbon burial and deltaic evolution, Geophys. Res. Lett., 37, L21605, doi:10.1029/2010GL044547.

Anderson, J.T., J.E. Simon, D.C. Gordon, and P.C. Hurley. 2005. Linking fisheries to benthic habitats at multiple scales: Eastern Scotian Shelf haddock. In: P.W. Barnes and J.P. Thomas (eds.), Benthic habitats and the effects of fishing. AFS Symposium 41:251-264.

Aquarone, M.C. and S. Adams. 2009. Northeast US Continental Shelf LME. In: Sherman, K. and Hempel, G. (Editors). The UNEP Large Marine Ecosystem Report: A perspective on changing conditions in LMEs of the world's Regional Seas. United Nations Environment Programme, Nairobi, Kenya. 872 pp.

Ashton, A.D. and A.B. Murray. 2006. High-angle wave instability and emergent shoreline shapes: Wave climate analysis and comparisons to nature. Journal of Geophysical Research, Earth Surface 111: F04012

Aubrey, C.W., and F.F. Snelson. 2007. Early life history of the Spinner Shark in a Florida nursery. American Fisheries Society Symposium 50:175-189.

Auster, P.J., R.J. Malatesta, and C.L.S. Donaldson. 1997. Distributional responses to small-scale habitat variability by early juvenile silver hake, *Merluccius bilinearis*. Environmental Biology of Fishes 50:195-200.

Auster, P.J., R.J. Malatesta, and S.C. LaRosa. 1995. Patterns of microhabitat utilization by mobile megafauna on the southern New England (USA) continental shelf and slope. Marine Ecology Progress Series 127:77–85.

Auster, P.J., J. Lindholm, S. Schaub, G. Funnell, L.S. Kaufman, and P.C. Valentine. 2003. Use of sand wave habitats by silver hake. Journal of Fish Biology 62:143-152.s

Auster, P.J., R.J. Malatesta, S.C. LaRosa, R.A. Cooper, and L.L. Stewart. 1991. Microhabitat utilization by the megafaunal assemblage at a low relief outer continental shelf site: Middle Atlantic Bight, USA. Journal of Northwest Atlantic Fisheries Science 11:59–69.

Bartholomew, A., Diaz, R.J., and Cicchetti, G. 2000. New dimensionless indices of structural habitat complexity: predicted and actual effects on a predator's foraging success. Marine Ecology Progress Series 206:45-58.

Beukers, J.S., and Jones, G.P. 1997. Habitat complexity modifies the impact of piscivores on a coral reef fish population. Oecologia 114:50-59.

BOEM (Bureau of Ocean Energy Management). 2013. Gulf of Mexico OCS G&G Programmatic EIS Area of Interest Map. Available at http://www.boem.gov/GOM-G-G-PEIS/. Accessed on July 5, 2013.

Boesch, D. F. 1979. Benthic ecological studies: Macrobenthos. Chapter 6. Middle Atlantic outer continental shelf environmental studies. Final Report to Bureau of Land Management, Washington, D. C.

Bonzek, C.F., J. Gartland, J.D. Lange, and R.J. Latour. 2008. Northeast Area Monitoring and Assessment Program (NEAMAP) Mid-Atlantic Nearshore Trawl Program Progress Report: Fall 2007 Survey Data Summary. Atlantic States Marine Fisheries Commission, Washington, DC. 156 pp.

Boss, S.K., and C.W. Hoffman. 2001. Geologic Framework Derived from High-Resolution Seismic Reflection, Side-Scan Sonar, and Vibracore Data Offshore Oregon Inlet to Duck, Dare County, North Carolina. 47 pp.

Bowman, R.E., C.E. Stillwill, W.L. Michaels, and M.D. Grosslein. 2000. Food of Northwest Atlantic fishes and two common species of squid. U.S. Department of Commerce. http://www.nefsc.noaa.gov/publications/tm/tm155/tm155.pdf.

Brooks, R.A., S.C. Keitzer, and K.J. Sulak. 2005. Taxonomic Composition and Relative Frequency of the Benthic Fish Community Found on Natural Sand Banks and Shoals in the Northwestern Gulf of Mexico. (A Synthesis of the Southeast Area Monitoring and Assessment Program's Groundfish Survey Database, 1982-2000).

Brooks, R.A., S.S Bell, C.N. Purdy, and K.J. Sulak. 2004. The Benthic Community of Offshore Sand Banks: A Literature Synopsis of the Benthic Fauna Resources in Potential MMS OCS Sand Mining Areas. USGS Outer Continental Shelf Studies Ecosystem Program Report USGS-SIR-2004-5198.

Brooks, R.A, C.N. Purdy, S.S. Bell, and K.J. Sulak. 2006. The benthic community of the eastern US continental shelf: A literature synopsis of benthic faunal resources. Continental Shelf Research 26:804–818.

Buckel, J.A., M.J. Fogarty, and D.O. Conover. 1999. Foraging habits of bluefish, *Pomatomus saltatrix*, on the U.S. east coast continental shelf. Fishery Bulletin 97:758-775.

Burlas, M., Ray, G.L., and Clarke, D. 2001. The New York District's Biological Monitoring Program for the Atlantic Coast of New Jersey, Asbury Park to Manasquan Section Beach Erosion Control Project. Final Report. US Army Engineer District, New York.

Byrnes, M.R., R.M. Hammer, J.L. Kelley, D.B. Baker, T.D. Thibaut, S.A. Zichichi, L.M. Lagera, S.T. Viada, B.A. Vittor, J.S. Ramsey, and J.D. Germano. 2004. Environmental Surveys of Potential Borrow Areas Offshore Northern New Jersey and Southern New York and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. U.S. Dept. of the Interior, Minerals Management Service, Leasing Division, Marine Minerals Branch, Herndon, VA. OCS Report MMS 2004-044. Vol I: 264 pp, Vol II:194 pp.

Byrnes, M.R.. R.M. Hammer, T.D. Thibaut, and D.B. Snyder. 2004a. Potential physical and biological effects of sand mining offshore Alabama, U.S.A. Journal of Coastal Research 20:6–24.

Byrnes, M.R.. R.M. Hammer, T.D. Thibaut, and D.B. Snyder. 2004b. Effects of sand mining on physical processes and biological communities offshore New Jersey, USA. U.S.A. Journal of Coastal Research 20:25-43.

Byrnes, M.R., R.M. Hammer, B.A. Vittor, J.S. Ramsey, D.B. Snyder, K.F. Bosma, J.D. Wood, T.D. Thibaut, and N.W. Phillips. 1999. Environmental Survey of Identified Sand Resource Areas Offshore Alabama: Volume I: Main Text-326 pp. and Volume II: Appendices-132 pp. U.S. Department of Interior, Minerals Management Service, International Activities and Marine Minerals Division (INTERMAR), Herndon, VA. OCS Report MMS 99-0052.

Byrnes, M.R., R.M. Hammer, B.A. Vittor, J.S. Ramsey, D.B. Snyder, J.D. Wood, K.F. Bosma, T.D. Thibaut, and N.W. Phillips. 2000. Environmental Survey of Potential Sand Resource Sites: Offshore New Jersey. U.S. Dept. of the Interior, Minerals Management Service, International Activities and Marine Minerals Division (INTERMAR). Herndon, VA. OCS Report MMS 2000-052. Vol I: 380 pp., Vol II: Appendices 291 pp

Byrnes, M.R., R.M. Hammer, B.A. Vittor, S.W. Kelley, D.B. Snyder, J.M. Cote, J.S. Ramsey, T.D. Thibaut, N.W. Phillips, J.D. Wood, and J.D. Germano. 2003. Collection of Environmental Data within Sand Resource Areas Offshore North Carolina and the Environmental Implications of Sand Removal for Coastal and Beach Restoration. U.S. Dept. of the Interior, Minerals Management Service, Leasing Division, Marine Minerals Branch, Herndon, VA. OCS Report MMS 2000-056. Vol 1: 256 pp, Vol II: Appendices 269 pp.

Carpenter, K.E. (ed.). 2002. The living marine resources of the Western Central Atlantic. Volumes 1 through 3. FAO Species Identification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5. Rome, FAO.

Clark, Peter U.; Dyke, Arthur S.; Shakun, Jeremy D.; Carlson, Anders E.; Clark, Jorie; Wohlfarth, Barbara; Mitrovica, Jerry X.; Hostetler, Steven W. et al., 2009. The Last Glacial Maximum. Science 325: 710–4.

Collette, B.B. and G.K. Klein-MacPhee, Eds. 2002. Bigelow and Schroeder's Fishes of the Gulf Of Maine, 3rd edition. Smithsonian Institution Press, 748 pp.

Colvocoresses, J.A., and J.A. Musick. 1984. Species associations and community composition of Middle Atlantic Bight Continental Shelf demersal fishes. U.S. National Marine Fisheries Service Fishery Bulletin 82:295–313.

Condrey, R.E. and C.G. Gelpi. 2010. Blue crab (Callinectes sapidus) use of the Ship/Trinity/Tiger Shoal Complex as a nationally important spawning/hatching/foraging ground: Discovery, evaluation, and sand mining recommendations based on blue crab, shrimp, and spotted seatrout findings. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2009-043. 42pp.

Conkwright, R.D. and R.A. Gast. 1995. Potential Offshore Sand Resources in Southern Maryland Shoal Fields. Department of Natural Resources Maryland Geological Survey Coastal and Estuarine Geology File Report No. 95-4.

Conkwright, R.D. and C.P. Williams. 1996. Offshore Sand Resources in Central Maryland Shoal Fields. . Department of Natural Resources Maryland Geological Survey Coastal and Estuarine Geology File Report No. 96-3.

Conkwright, R.D., C.P. Williams, and L.B. Christiansen. 2000. Offshore Sand Resources in Northern Maryland Shoal Fields. Department of Natural Resources Maryland Geological Survey Coastal and Estuarine Geology File Report No. 00-2.

Co-ops, 2005. Center for Operational Oceanographic Products and Services, U. S. National Oceanographic and Atmospheric Administration, On-line Data-base, WWW page, http://co-ops.nos.noaa.gov/index.html station, Station 8771341 Galveston Bay Entrance, North Jetty, Texas.

CSA International, Inc., Applied Coastal Research and Enginnering, Inc., Barry A. Vittor & Associates, Inc., C.F. Bean, L.L.C., and Florida Institute of Technology. 2010. Analysis of Potential Biological and Physical Impacts of Dredging on Offshore Ridge and Shoal Features. Prepared by CSA International, Inc. in cooperation with Applied Coastal Research and Engineering, Inc., Barry A. Vittor & Associates, Inc., C.F. Bean, L.L.C., and the Florida Institute of Technology for the U.S. Department of the Interior, Minerals Management Service, Leasing Division, Marine Minerals Branch, Herndon, VA. OCS Study MMS 2010-010. 160 pp. + apps.

Curray, J.R., 1960. Sediments and History of Holocene Transgression, Contiental Shelf, Northwest Gulf of Mexico, in: Shepard, F.P., Phleger, F.B., Van Andel, T.H. (Eds.), Recent Sediments, Northwest Gulf of Mexico: ASymposium Summarizing the Results of Work Carried On in Project 51 of the American Petroleum Institute 1951-1958. The American Association of Petroleum Geologists, Tulsa, Oklahoma, U.S.A., pp. 221-266.

Cutter Jr., G.R., and R.J. Diaz. 2000. Benthic habitat mapping and resource evaluation of potential sand mining areas, 1998–1999. *In*: Hobbs, C. H., III, (Project Manager), Environmental Survey of Potential Sand Resource Sites Offshore Delaware and Maryland, Final Project Report to the Minerals Management Service, OCS Study 2000-055.

Cutter, G.R.J., R.J. Diaz, J.A. Musick, J. Olney, Sr., D.M. Bilkovic, J.P.-Y. Maa, S.C. Kim, C.S. Hardaway, Jr., D.A. Milligan, R. Brindley, and C.H. Hobbs, III. 2000. Environmental Survey of Potential Sand Resource Sites Offshore Delaware and Maryland. U.S. Dept. of the Interior, Minerals Management Service, International Activities and Marine Minerals Division, Herndon, VA. OCS Report MMS 2000-055. 514 pp.

Davis, R. E, and Dolan, R. 1993. Nor'easters. American Scientist, 81: 428-439.

Deegan, L. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. Canadian Journal of Fisheries and Aquatic Sciences. 50:74-79.

Dellapenna, T. M., J. Garrison, A. Cardenas, K. Johnson and J. Flocks. 2010. Report of the Re-Analysis of Sand Resources at Sabine and Heald Banks, East Texas Inner Continental Shelf. Texas General Land Office/U.S. Minerals Management Service. 47 p.

Dellapenna, T.M., S. Hiller, B.R. Fielder, and C.J. Noll. 2006. Sabine Bank Side Scan Sonar Investigation, unpublished report submitted to USGS.

Dellapenna, T. M., J. Pitkewicz, andT. Oertling. 2006A. Report to the Texas Coastal Coordination Council -Report of the Results of Galveston Offshore Sand Source Study Phase 1: Field Investigation-Result for the Jamaica Beach Potential Borrow Site, CEPRA/CMP Final Report. 300 p.

Dellapenna, T. M., J. Pitkewicz and A. Taylor. 2006B. Report of the Results of Galveston Offshore Sand Source Study Phase 1: Field Investigation-Result for the East and West Galveston Island Potential Borrow Sites, CEPRA/CMP Final Report. 300 p.

Dellapenna, T. M., A. Cardenas, K. Johnson and J. Flocks. 2009. Report of the Sand Source Investigation of the Paleo-Sabine-Trinity Marine Features (PSTMF). Texas General Land Office/U.S. Minerals Management Service. 900 p.

Dernie, K.M., M.J. Kaiser, and R.M. Warwick. 2003. Recovery rates of benthic communities following physical disturbance. Journal of Animal Ecology 72:1043-1056.

Diaz, R.J., G.R. Cutter, Jr., and K.W. Able. 2003. The importance of physical and biogenic structure to juvenile fishes on the shallow inner continental shelf. Estuaries 26:12–20.

Diaz, R.J., G.R. Cutter, Jr., and C.H. Hobbs, III. 2004a. Potential impacts of sand mining offshore of Maryland and Delaware, part 2 Biological considerations. Journal of Coastal Research 20:61–69.

Diaz, R. J., M. Solan, and R. M. Valente. 2004b. A review of approaches for classifying benthic habitats and evaluating habitat quality. Journal of Environmental Management 73:165–181.

Diaz, R.J., C.O. Tallent, and J.A. Nestlerode. 2006. Benthic resources and habitats at the Sandbridge Borrow Area: A test of monitoring. Chapter 2. *In:* Hobbs, C.H., III (ed). Field Testing of a Physical/Biological Monitoring Methodology for Offshore Dredging and Mining Operations. U.S. Dept. of the Interior, Minerals Management Service, Leasing Division, Marine Minerals Branch, Herndon, Va. OCS Study MMS 2005-056.

Dibajnia, M., and R.B. Nairn. 2010. Investigation of Dredging Guidelines to Maintain and Protect the Geomorphic Integrity of Offshore Ridge and Shoal Regimes. U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Herndon, VA., OCS Study MMS 2011-025. 150 pp. + appendices.

Diesing, M., A. kubicki, C. winter, and K. Schwarzer. 2006. Decadal scale stability of sorted bedforms, German Bight, southeastern North Sea. Continental Shelf Research, 26: 902-916.

Drucker, B.S., W. Waskes, and M.R. Byrnes. 2004. The U.S. Minerals Management Service outer continental shelf sand and gravel program: environmental studies to assess the potential effects of offshore dredging operations in federal waters. Journal of Coastal Research 20(1):1–5.

Dubois, S., Gelpi, C., Condrey, R., Grippo, M. and Fleeger, J. 2009. Diversity and composition of macrobenthic community associated with sandy shoals of the Louisiana continental shelf. Biodiversity and Conservation, 18: 3759–3784.

Eggleston, D.B. 1995. Recruitment in Nassau grouper *Epinephelus striatus*: post-settlement abundance, microhabitat features, and ontogenetic habitat shifts. Marine Ecology Progress Series 124: 9–22.

Feeney, D., Lassetter Jr., W. L., and Berquist, C. R. 1978. Sand resources evaluation on Virginia's outer continental shelf and digital data access. Virginia Division of Geology and Mineral Resources. Unpublished data 199.79.217[PDF]

Finkl, C.W. and J.L. Andrews. 2008. Shelf geomorphology along the southeast Florida Atlantic continental platform: barrier coral reefs, nearshore bedrock, and morphosedimentary features. Journal of Coastal Research 24(4):823–849.

Finkl, C.W. and C.H. Hobbs III. 2009. Mining sand on the continental shelf of the Atlantic and Gulf Coasts of the U.S. Marine Georesources and Geotechnology 27:230-253.

Finkl, C.W., L. Benedet, J.L. Andrews, B. Suthard, and S.D. Locker. 2007b. Sediment ridges on the west Florida inner continental shelf: sand resources for beach nourishment. Journal of Coastal Research 23(1), 143–159.

Finkl, C.W., J.L. Andrews, B. Suthard, M. Larenas, K. Rodriguez, and L. Benedet. 2007a. Reconnaissance Investigation of Potential Sand Resource Sites Offshore Galveston and Jefferson Counties, Texas: 2006 Offshore Geotechnical Investigations to Identify Sand Sources. Boca Raton, Florida: Coastal Planning & Engineering, Inc., 33p.

Gabriel, W. 1992. Persistence of demersal fish assemblages between Cape Hatteras and Nova Scotia, Northwest Atlantic. Journal of Northwest Atlantic Fisheries Science 14:29-47.

Garrison, L.P., and J.S. Link. 2000. Dietary guild structure of the fish community in the Northeast United States continental shelf ecosystem. Marine Ecology Progress Series 202:231-240.

Gayes, P.T., P. Donovan-Ealy, M.S. Harris, and W. Baldwin. 1998. Assessment of Beach Renourishment Resources on the Inner Shelf off Folly Beach and Edisto Island, South Carolina. Final Report. South Carolina Task Force on Offshore Resources. 43+ pp.

Geary B.W., Mikulas J.J., Rooker J.R., Landry A.M. (2007) Patterns of habitat use by newly settled red snapper in the northwestern Gulf of Mexico. *In* Patterson WF, Cowan, JH, Fitzhugh GR, Nieland DL (eds.). Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society Special Publication 60: 25-38.

Gelpi, C. 2012. Function and diversity of the Ship, Trinity, and Tiger Shoal Complex, with emphasis on macrofauna and spawning blue crabs (Callinectes sapidus). PhD Dissertation. Louisiana State University and Agricultural and Mechanical College. 229 pp.

Gillanders, B.M., K.W. Able, J.A. Brown, D.B. Eggleston, and P.F. Sheridan. 2003. Evidence of connectivity between juvenile and adult habitats for mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247:281-295.

Gilmore, Jr., R.G. 2008. Regional Fishery Resource Survey and Synthesis in Support of Martin County's Comprehensive Beach and Offshore Monitoring Program, Final Report. 32+ pp.

Goff, J.A., L.A. Mayer, P. Traykovski, I. Buynevich, R. Wilkens, R. Raymons, G. Glang, R.L. Evans, H. Olson, and C. Jenkins. 2005. Detailed investigation of sorted bedforms, or 'rippled scor depression,' within Martha's Vineyard coastal observatory, Massachusetts. Continental Shelf Research, 25: 461-484.

Gotceitas, V., S. Fraser, and J.A. Brown. 1995. Habitat use by juvenile Atlantic cod (*Gadus morhua*) in the presence of an actively foraging and non-foraging predator. Marine Biology 123(3): 421-430.

Greene, H.G., M.M. Yoklavich, R.M. Starr, V.M. O'Connell, W.W. Wakefield, D.E. Sullivan, J.E. McRea Jr., and G.M. Cailliet. 1999. A classification scheme for deep seafloor habitats. Oceanologica Acta 22, 663–678.

Gregory, R.S., and Anderson, J.T. 1997. Substrate selection and use of protective cover by juvenile Atlantic cod *Gadus morhua* in inshore waters of Newfoundland. Marine Ecology Progress Series 146: 9-20.

Grippo, M.A., J.W. Flegger, R. Condrey, and K.R. Carman. 2009. High benthic microalgal biomass found on Ship Shoal, north-central Gulf of Mexico. Bulletin of Marine Science 84: 237-256.

Grosslein, M. D., and T. R. Azarovitz. 1982. Fish distribution. New York Sea Grant Institute, MESA New York Bight Atlas Monograph 15, Albany.

Guitierrez, B., T., Voulgaris, G., and Thieler, E. R., 2005. Exploring the persistence of sorted bedforms on the inner-shelf of Wrightsville Beach, North Carolina. Continental Shelf Research, 25: 65-90.

Hayes, M.O., 1967. Hurricanes as Geological Agents: Case studies of Hurricanes Carla, 1961, and Cindy, 1963. The University of Texas at Austin, Bureau of Economic Geology Report on Investigations No. 61, 56 pp.

Hayes, M.O., and R.B. Nairn. 2004. Natural maintenance of sand ridges and linear shoals on the U.S. Gulf and Atlantic continental shelves and the potential impacts of dredging. Journal of Coastal Research 20(1):138–148.

Heck, K.L., Hays, G., and Orth, R.J. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series 253: 123-136.

Henry, W. K. 1979. Some aspects of the fate of cold fronts in the Gulf of Mexico, *Notes and Correspondence, Monthly Weather Review, American Meteorological Society, 107*, 1078-1082.

Heupel, M.R., J.K. Carlson, and C.A. Simpfendorfer. 2007. Shark nusery areas: concepts, definitions, characterization and assumptions. Marine Ecology Progress Series 337:287-297.

Hoenstine,R., H. Freedenberg, A. Dabous, B. Cross, C. Fischler, and M. Lachance. 2002. A Geological Investigation of Sand Resources in the Offshore Area along Florida's Central-East Coast. Florida Geological Survey, Final Summary Report. 14pp.

Hoffman, C.W. 1998. Preliminary Assessment of Potential Sand Resource Areas Offshore of Nags Head, Kitty Hawk, and Kill Devil Hills, North Carolina. U.S. Minerals Management Service/State of North Carolina Sand Resources Task Force. 13pp.

Hummell, R.L, and W.E. Smith. 1996. Geologic Resources Delineation and Hydrographic Characterization of Offshore Sand Resource Site for Use in Beach Nourishment Projects on Dauphin Island, Alabama. Final Report. Geological Survey of Alabama. Economic Geology Division. 169 pp.

Hyland, J.L., L. Balthis, I. Karakassis, P. Magni, A.N. Petrov, and J.P. Shine. 2005. Organic carbon content of sediments as an indicator of stress in the marine benthos. Marine Ecology Progress Series 295:91–103.

Johnson, M.R., C. Boelke, L.A. Chiarella, P.D. Colosi, K. Greene, K. Lellis-Dibble, H. Ludemann, M. Ludwig, S. McDermott, J.. Ortiz, D. Rusanowsky, M. Scott, and J. Smith. 2008. Impacts to Marine Fisheries Habitat from Nonfishing Activities in the Northeastern United States. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Northeast Regional Office. NOAA Technical Memorandum NMFS-NE-209. 322 pp.

Kaplan, B., ed. 2011. Literature Synthesis for the North and Central Atlantic Ocean. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEMRE 2011-012. 447 pp.

Kuehl, S. A., Ketterer, M. E., and Miselis, J. L., 2012. Extension of $^{239+240}$Pu sediment geochronology to coarse-grained marine sediments. Continental Shelf Research, 36: 83-88.

Kimball, S.M., and J.K. Dame. 1989. Geotechnical Evaluation of Sand Resources on the Inner Shelf of Southern Virginia, Volume 1: Report and Appendices A-B, Final Report. Virginia Institute of Marine Science. 44+ pp.

Kulp, M. S. Penland, and K. Ramsey. 2001. Ship Shoal: Sand Resource Synthesis Report. Coastal Research Laboratory, Department of Geology and Geophysics, University of New Orleans. 70+ pp.

Lindholm, J.B., Auster, P.J., and Kaufman, L.S. 1999. Habitat-mediated survivorship of juvenile (0-year) Atlantic cod *Gadus morhua*. Marine Ecology Progress Series 180: 247-255.

Locker, S.D., A.C. Hine, and G.R. Brooks. 2003. Regional stratigraphic framework linking continental shelf and coastal sedimentary deposits of west-central Florida. Marine Geology 200: 351-378.

Lough, R.G., Valentine, P.C., Potter, D.C., Auditore, P.J., Bolz, G.R., Neilson, J.D., and Perry, R.I. 1989. Ecology and distribution of juvenile cod and haddock in relation to sediment type and bottom currents on eastern Georges Bank. Marine Ecology Progress Series 56: 1-12.

Louis Berger Group, Inc. 1999. Environmental report: Use of Federal Offshore Sand Resources for Beach and Coastal Restoration in New Jersey, Maryland, Delaware, and Virginia. OCS Study MMS 99-0036. 305+ pp.

Love, J.W., and P.D. Chase. 2007. Marine fish diversity and composition in the Mid-Atlantic and South Atlantic Bights. Southeastern Naturalist 6:705-714.

Maa, J.P.Y., C.H. Hobbs III, S.C. Kim, and E. Wei. 2004. Potential impacts of sand mining offshore of Maryland and Delaware: Part 1 – Impacts on physical oceanographic processes. Journal of Coastal Research 20:44-60.

Mahon, R., S.K. Brown, K.C.T. Zwanenburg, D.B. Atkinson, K.R. Buja, L. Claflin, G.D. Howell, M.E. Monaco, R.N. O'Boyle, and M. Sinclair. 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. Canadian Journal of Fisheries and Aquatic Science 55:1704.1738.

Maranick, K.E., and J.A. Hare. 2007. Large scale patterns in fish trophodynamics of estuarine and shelf habitats of the southeastern United States. Bulletin of Marine Science 80:67-91.

Martino, E.J., and K.W. Able. 2003. Fish assemblages across the marine to low salinity transition zone of a temperate estuary. Estuarine, Coastal and Shelf Science 56:969–987.

Matthews, K.R. 1990. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. Fishery Bulletin 88:223-239.

Maurer, D., P. Kinner, W. Leathem, and L. Watling. 1976. Benthic faunal assemblages off the Delmarva peninsula. Estuarine and Coastal Mar. Sci., 4: 163-177.

McEachran, J.D. and J.D. Fechhelm. 1998. Fishes of the Gulf of Mexico, Volume 1: *Myxiniformes to Gasterosteiformes*. University of Texas Press, Austin, TX.

McEachran, J.D. and J.D. Fechhelm. 2005. Fishes of the Gulf of Mexico, Volume 2: *Scorpaeniformes to Tetraodontiformes*. University of Texas Press, Austin, TX.

McBride, R. A., & Moslow, T. F. 1991. Origin, evolution, and distribution of shoreface sand ridges, Atlantic inner shelf, USA. Marine Geology, 97(1), 57-85.

McGowen, J., Garner, L., Wilkinson, B.H., 1977. The Gulf shoreline of Texas: processes, characteristics, and factors in use. Bureau of Economic Geology, University of Texas, Austin, Geol. Curc., 77-3. 27 pp.

McKenna, K.K., and K.W. Ramsey. 2002. An Evaluation of Sand Resources, Atlantic Offshore, Delaware. State of Delaware, Delaware Geological Survey, Report of Investigations No. 63. 37pp.

McNinch, J. E., & Luettich Jr, R. A. 2000. Physical processes around a cuspate foreland:: implications to the evolution and long-term maintenance of a cape-associated shoal. Continental Shelf Research, 20(17), 2367-2389.

McNinch, J. E., and Wells, J. T., 1999. Sedimentary processes and depositional history of cape-associated shoal, Cape Lookout, North Carolina. Marine Geology, 158: 233-252.

Methratta, E.T., and J.S. Link. 2006. Seasonal variation in groundfish habitat associations in the Gulf of Maine–Georges Bank region. Marine Ecology Progress Series 326:245–256.

Michel, J., A.C. Bejarano, C.H. Peterson, and C. Voss. 2013. Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand. U.S. Department of the Interior, Bureau of Ocean Energy Management, Herndon, VA. OCS Study BOEM 2013-0119. 258 pp.

Mikulas Jr., J.J. and J.R. Rooker. 2008. Habitat use, growth, and mortality of post-settlement lane snapper (*Lutjanus synagris*) on natural banks in the northwest Gulf of Mexico. Fisheries Research 93:77-84.

MMS. 2004. Environmental Assessment for the Issuance of Non-Competitive Leases for the Use of Outer Continental Shelf Sand Resources from Ship Shoal, Offshore Central Louisiana for

Coastal and Barrier Island Nourishment and Hurricane Levee Construction. United States Department of the Interior, Minerals Management Service (MMS). April 2004. 114 pp.

MMS (Minerals Management Service). 2007. Programmatic environmental impact statement for alternative energy development and production and alternate use of facilities on the Outer Continental Shelf. U.S. Department of the Interior. OCS EIS/EA MMS 2007-046. http://ocsenergy.anl.gov/documents/fpeis.

Moore, D. H.A. Brusher, and L. Trent. 1970. Relative abundance, seasonal distribution, and species composition of demersal fishes off Louisiana and Texas, 1962-1964. Contributions in Marine Science 15:45-70.

Morton, R.A., and J.C. Gibeaut. 1993 Physical and Environmental Assessment of Sand Resources–Texas Continental Shelf. Final Report. Bureau of Economic Geology. The University of Texas. 66 pp.

Morton, R.A., and J.C. Gibeaut. 1995. Physical and Environmental Assessment of Sand Resources: Sabine and Heald Banks, Second Phase 1994-1995. Final Report. Bureau of Economic Geology. The University of Texas. 62+ pp.

Murray, A.B. and E.R. Thieler. 2004. A new hypothesis and exploratory model for the formation of large-scale inner-shelf sediment sorting and "rippled scour depressions." Continental Shelf Research 24: 295-315.

Musick, J.A., J.A. Colvocoresses, E.J. Foell 1986. Seasonality and distribution, availability and composition of fish assemblages in Chesapeake Bight. Chapter 21. *In:* Yanez-Arancibia, A (ed.), Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration. University of Mexico Press, Mexico City.

NMFS. 2013a. NOAA Fisheries Service: Office of Protected Resources: Species Under the Endangered Species Act (ESA).National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NMFS). Internet website: http://www.nmfs.noaa.gov/pr/species/esa/. Accessed: June 2013.

NMFS (National Marine Fisheries Service). 2013b. Summary of Essential Fish Habitat (EFH) and General Habitat Parameters for Federally Managed Species. Available at http://www.nero.noaa.gov/hcd/list.htm. Accessed on June 25, 2013.

NMFS (National Marine Fisheries Service). 2009. Final Amendment 1 to the 2006 Consolidated Atlantic Highly Migratory Species Fishery Management Plan, Essential Fish Habitat. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Office of Sustainable Fisheries, Highly Migratory Species Management Division, Silver Spring, MD. Public Document. 395 pp.

Nelson, W.G., and Bonsdorff, E. 1990. Fish predation and habitat complexity: are complexity thresholds real? Journal of Experimental Marine Biology and Ecology 141: 183-194.

Nittrouer, C. A., & Wright, L. D. (1994). Transport of particles across continental shelves. Reviews of Geophysics, 32(1), 85-113.

Nowlin Jr, W.D., Jochens, A.E., DiMarco, S.F., Reid, R.O., Howard, M.K., 2005. Low-Frequency Circulation Over the Texas-Louisiana Continental Shelf, in: Sturges, W., Lugo-Fernández, A. (Eds.), Circulation in the Gulf of Mexico: observations and models:

Geophysical monograph series. American Geophysical Union, Washington D.C., pp. 219-240.

Overholtz, W.J., and A.V. Tyler. 1985. Long-term responses of the demersal fish assemblages of Georges Bank. Fishery Bulletin 83:507–520.

Osman, R.W. and R.B. Whitlatch. 1998. Local control of recruitment in an epifaunal community and the consequences to colonization processes. Hydrobiologia 375-376:113-123.

Patterson, W.F., C.A. Wilson, S.J. Bentley, J.H. Cowan, T. Henwood, Y.C. Allen, and T.A. Dufrene. 2005. Delineating juvenile Red Snapper habitat on the Northern Gulf of Mexico continental shelf. American Fisheries Society Symposium 41:277-288.

Parker, S.J, D.J. Davies, and W.E. Smith. 1993. Geological, Economic, and Environmental Characterization of Selected Near-Term Leasable Offshore Sand Deposits and Competing Onshore Sources for Beach Nourishment. Final Report. Geological Survey of Alabama. Energy and Coastal Geology Division. 223 pp.

Petersen, C.G.J. 1913. Valuation of the sea. II. The animal communities of the sea-bottom and their importance for marine zoogeography. Report of the Danish Biological Station to the Board of Agriculture. 21: 1-44.

Phelps, D.C., and G.W. Holem. 2005. Sand Source Availability Investigations; The Search for Sand for Duval County, Florida Beach Renourishment.

Pierce, D.J. and B. Mahmoudi. 2001. Nearshore fish assemblage along the central west coast of Florida. Bulletin of Marine Science 68:243–270.

Ramsey, K.E., and S. Penland. 1992. Stratigraphic Assessment of Sand Resources Offshore Holly and Peveto Beaches, Louisiana. Louisiana Geological Survey. Center for Coastal, energy, and Environmental Resources. 26+ pp.

Reyier, E.A., D.H. Adams, and R.H. Lowers. 2008. First evidence of a high density nursery grounds for the Lemon Shark, *Negaprion brevirostris,* near Cape Canaveral, Florida. Florida Scientist 71(2):134-148.

Rindsberg, A.K. and D.C. Kopaska-Merkel. 2006. Sand-Quality Characteristics of Alabama Beach Sediment, Environmental Conditions, and Comparison to Offshore Sand Resources: Annual Report 2. Geological Survey of Alabama. Geologic Investigations Program. Open-File Report 0607. 128pp.

Robin, C.R. 1999. A field guide to Atlantic coast fishes of North America. New York: Houghton Mifflin Company.

Rodriguez, A.B., J.B. Anderson, F.P. Siringan, and M. Taviani. 1999. Sedimentary facies and genesis of Holocene sand banks on the east Texas inner continental shelf. In: Isolated Shallow Marine Sand Bodies: Sequence Stratigraphic Analysis and Sedimntologic Interpretation (Eds. J. Snedden and K. Bergman), SEPM Spec. Publ. 64: 165-178.

Rodriguez, A. B., J.B. Anderson, F.P. Siringan, and M. Taviani. 2004. Holocene evolution of the East Texas coast and inner continental shelf: along-strike variability in coastal retreat rates. Journal of Sedimentary Research, 74: 405-421.

Rodriguez, A.B., M.L. Fassell, and J.B. Anderson. 2001. Variations in shoreface progradation and ravinement along the Texas coast, Gulf of Mexico. Sedimentology 48: 837-853.

Rodriguez, A.B., Hamilton, M.D., Anderson, J.B., 2000. Facies and Evolution of the Modern Brazos Delta, Texas: Wave vs Flood Influence. Journal of Sedimentary Research 70, 283-295.

Rogers, B. E., Kulp, M. A., and Miner, M. D., 2009. Late Holocene chronology, origin, and evolution of the St. Bernard Shoals, northern Gulf of Mexico. Geo-Marine Letters, 29: 379-394.

Rooker, J.R., A.M. Landry, B.W. Geary, and J.A. Harper. 2004. Assessment of a shell bank and associated substrates as nursery habitat of postsettlement red snapper. Estuarine, Coastal and Shelf Science 59:653–661.

Ryer, C.H., Stoner, A.W., and Titgen, R.H. 2004. Behavioral mechanisms underlying the refuge value of benthic habitat structure for two flatfishes with differing anti-predator strategies. Marine Ecology Progress Series 268: 231-243.

SAFMC (South Atlantic Fishery Management Council). 1998. Final Habitat Plan for the South Atlantic region: Essential Fish Habitat Requirements for Fishery Management Plans of the South Atlantic Fishery Management Council the Shrimp Fishery Management Plan, the Red Drum Fishery Management Plan, the Snapper Grouper Fishery Management Plan, the Coastal Migratory Pelagics Fishery Management Plan, the Golden Crab Fishery Management Plan, the Spiny Lobster Fishery Management Plan, the Coral, Coral Reefs, and Live/Hard Bottom Habitat Fishery Management Plan, the Sargassum Habitat Fishery Management Plan, and the Calico Scallop Fishery Management Plan.

SAFMC (South Atlantic Fishery Management Council). 2009. Comprehensive Ecosystem-Based Amendment 1 for the South Atlantic Region

SAFMC (South Atlantic Fishery Management Council). 2010. Briefing Book, March 1-5, 2010, Comprehensive Ecosystem-Based Management Committee, Attachment 1B – EFH and HAPCs. 29pp.

Sanders, H.L. 1958 Benthic studies in Buzzards Bay. I. Animal-sediment relationships. Limnology and Oceanography. 3:245-258.

Scharf, F.S., J.P. Manderson, and M.P. Fabrizio. 2006. The effects of seafloor habitat complexity on survival of juvenile fishes: Species-specific interactions with structural refuge. Journal of Experimental Marine Biology and Ecology 335:167-176.

Seelig, W.N., Sorensen, R.M., 1973. Investigation of Shoreline Changes at Sargent Beach, Texas, TAMU-SG-73-212 ed. Texas A&M University Sea Grant p. 153.

Sherman, K., P. Celone, S. Adams. 2004. NOAA Fisheries Service's large marine ecosystems program: status report. U.S. Dept. of Commerce, NOAA, NMFS. 21 pp.

Slacum, H.W. Jr., W.H. Burton, E.T. Methratta, E.D. Weber, R. Llansó, and J. Dew-Baxter. 2010. Assemblage structure in shoal and flat-bottom habitats on the Inner Continental Shelf of the Middle Atlantic Bight, USA. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:277-298.

Slacum, H.W. Jr., W.H. Burton, J.H. Vølstad, J. Dew, E. Weber, R. Llansó, and D.Wong. 2006. Comparisons Between Marine Communities Residing on Sand Shoals and Uniform-bottom Substrate in the Mid-Atlantic Bight. Final Report to the U.S. Department of the Interior, Minerals Management Service, International Activities and Marine Minerals Division, Herndon, VA. OCS Report MMS 2005-042, 149 pp. + app.

Smith, P.C. 1996. Nearshore Ridges and Underlying Pleistocene Sediments on the Inner Continential Shelf of New Jersey. MSc. Thesis. Geological Sciences, Rutgers University. 157pp.

Snelgrove, P.V.R. and C.A. Butman. 1994. Animal sediment relationships revisited—Cause versus effect. Oceanography and Marine Biology 32:111-177.

Snelgrove, P.V.R., J.F. Grassle, J.P. Grassle, R.F. Petrecca, and K.I. Stocks. 2001. The role of colonization in establishing patterns of community composition and diversity in shallow water sedimentary communities. Journal of Marine Research 59:813-830.

Steves, B.P., R.K. Cowen, and M.H. Malchoff. 1999. Settlement and nursery habitats for demersal fishes on the continental shelf of the New York Bight. Fishery Bulletin 98:167–188.

Stone, G.W., R.E. Condrey, J.W. Fleeger, S.M. Khalil, D. Kobashi, F. Jose, E. Evers, S. Dubois, B. Liu, S. Arndt, C. Gelpi, M.A. Grippo, Y. Luo, S.M. SiadatMousavi, Y. Chen, M. Alavillamo, and F. Reynal. 2009. Environmental investigation of long-term use of Ship Shoal sand resources for large scale beach and coastal restoration in Louisiana. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2009-024. 278 pp.

Stunz, G.W., and T.J. Minello 2001. Habitat-related predation on juvenile wild-caught and hatchery-reared red drum *Sciaenops ocellatus* (Linnaeus). Journal of Experimental Marine Biology and Ecology 260: 13-25.

Sullivan, M.C., R.K. Cowen, K.W. Able, and M.P. Fahay, 2000. Spatial scaling of recruitment in four continental shelf fishes. Marine Ecology Progress Series 207:141–154.

Swift, D.J.P. and M.E. Fields. 1981. Evolution of a classic sand ridge field: Maryland secor, North American inner shelf. Sedimentology 28:461-482.

Swift, D.J.P., P.C. Sears, B. Bohlke and R. Hunt, 1978. Evolution of a shoal retreat massif, North Carolina shelf: inferences from areal geology. Marine Geology, 27: 19-42.

Szedlmayer, S.T., and J. Conti. 1999. Nursery habitats, growth rates, and seasonality of age-0 red snapper, *Lutjanus campechanus*, in the northeast Gulf of Mexico. Fishery Bulletin 97(3):626-635.

Szedlmayer, S.T., and J.D. Lee. 2004. Diet shifts of juvenile red snapper (*Lutjanus campechanus*) with changes in habitat and fish size. Fishery Bulletin 102(2):366-375.

Theroux, R.B. and R.L. Wigley. 1998. Quantitative composition and distribution of the macrobenthic invertebrate fauna of the continental shelf ecosystems of the northeastern United States. U.S. Dept. Commerce, NOAA Tech. Rep. NMFS 140. 240 pp.

Thieler, E. R., Foster, D. S., Himmelstoss, E. A., 2014. Geological framework of the northern North Carolina, USA inner continental shelf and its influence on coastal evolution. Marine Geology, 348: 113-130.

Thieler, E. R., Ashton, A. D., 2011. ‘Cape capture’: geologic data and modeling results suggest the Holocene loss of a Carolina Cape. Geology 39: 339-342.

Thorson, G. 1957. Bottom communities (sublittoral or shallow shelf). Geological Society of America/Memoir. 67:461-534.

Thrush, S.F., Schultz, D., Hewitt, J.E., and Talley, D. 2002. Habitat structure in soft-sediment environments and abundance of juvenile snapper *Pagrus auratus*. Marine Ecology Progress Series 245: 273-280.

Turbeville, D.B., Marsh, G.A., 1982. Benthic Fauna of an Offshore Borrow Area in Broward County, Florida. U.S. Army, Corps of Engineers Coastal Engineering Research Center, Miscellaneous Report No. 82-1.

Uptegrove, J., J.S. Waldner, D.W. Hall, P.C. Smith, G.M. Ashley, R.E. Sheridan, Z. Allen-Lafayette, M.C. Goss, F.L. Muller, and E. Keller. 2006. Characterization of Sediments in Federal Waters Offshore of New Jersey as Potential Sources of Beach Replenishment Sand. Phase II, Year 2 Final Report, Minerals Management Service Cooperative Agreement # 14-35-0001-30751.

Van Oyen, T., H. de Swart, and P. Blondeaux. 2011. Formation of rhythmic sorted bed forms on the continental shelf: an idealistic model. J. Fluid Mechanics, 684: 475-508.

Vasslides, J. M. 2007. Fish assemblages and habitat use across a shoreface sand ridge in southern New Jersey. MS Thesis. New Brunswick Rutgers, The State University of New Jersey. 106 pp.

Vasslides, J. M., and K. W. Able. 2008a. Importance of shoreface sand ridges as habitat for fishes off the northeast coast of the United States. Fishery Bulletin 106:93–107.

Vasslides, J. M., and K. W. Able. 2008b. Abundance and diet of three sciaenid fishes in southern New Jersey: an assessment of habitat value for shoreface for sand ridges. Bulletin of the New Jersey Academy of Science.

Walker, B.K., L.K.B. Jordan, and R.E. Spieler. 2009b. Relationship of reef fish assemblages and topographic complexity on southeastern Florida coral reef habitats. Journal of Coastal Research 53:39-48.

Walker, M., S. Johnson, S.O. Rasmussen, T. Popp, J.P. Steffensen, P. Gibbard, W. Hoek, J. Lowe, S. Bjorck, L.C. Cwynar, K. Hughen, P. Kershaw, B. Kromer, T. Litt, D.J. Lowe, T. Nagagawa, R. Newnham, and J. Schwander. 2009a. Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. Journal of Quartenary Science, 24: 3-17.

Wallace, D.J., J.B. Anderson, and R.A. Fernandez. 2010. Transgressive ravinement versus depth of closure: a geological perspective from the upper Texas coast. Journal of Coastal Research, 26: 1057-1067.

Walsh, H.J., K.E. Marancik, and J.A. Hare. 2006. Juvenile fish assemblages collected on unconsolidated sediments of the southeast United States continental shelf. Fishery Bulletin 104:256-277.

Wells, R.J.D., J.O. Harper, J.R. Rooker, A.M. Landry Jr., and T.M. Dellapenna. 2009. Fish assemblage structure on a drowned barrier island in the northwestern Gulf of Mexico. Hydrobiologia 625:207-221.

Wigley, R.L. and R.B. Theroux. 1981. Atlantic continental shelf and slope of the United States - macrobenthic invertebrate fauna of the Middle Atlantic Bight region-faunal composition and quantitative distribution. U.S. Dept. of the Interior, Geological Survey. USGS Prof. Pap. 529-N. 198 pp.

Williams, S.J. 1988. Geologic Framework and Sand Resources of Quaternary Deposits Offshore Virginia, Cape Henry to Virginia Beach. Department of the Interior. U.S. Geological Survey. Open-File Report 87-667.

Woodland, R.J., D.H. Secor, M.C. Fabrizio, and M.J. Wilberg. 2012. Comparing the nursery role of inner continental shelf and estuarine habitats for temperate marine fishes. Estuarine, Coastal and Shelf Science 99:61-73.

Wright, D. L., 1995. Morphodynamics of inner continental shelves. CRC Press, 241 pp.

Wright, E., P. Gayes, P. Ealy, and W. Baldwin. 1998. Assessment of Beach Renourishment Resource on the Inner Shelf of Hilton Head Island, SC. Final Report. South Carolina Task Force on Offshore Resources. 23+ pp.

Wright, E., P. Gayes, P. Ealy, W. Baldwin, and M.S. Harris. 1999. Assessment of Beach Renourishment Resources on the Inner Shelf Seaward of Pawleys Island, South Carolina. Final Report. South Carolina Task Force on Offshore Resources. 26+ pp.

Zajac, R.N, 2008. Challenges in marine, soft-sediment benthoscape ecology. Landscape Ecology 23: 7-18.

Zale, A.V., D.L. Parrish, and T.M. Sutton (eds). 2013. Fisheries Techniques 3rd Edition. American Fisheries Society, Bethesda, Maryland. 1,009 pp.

Zarillo, G.A., J.A. Reidenauer, K.A. Zarillo, T. Shinskey, E.A. Reyier, M.J. Barkaszi, J.M. Shenker, M. Verdugo, and N. Hodges. 2008. Biological Characterization/Numerical Wave Model Analysis within Borrow Sites Offshore West Florida Coast Final Report. Offshore Sand and Gravel Program and Alternative Energy Branch Herndon, VA. OCS Study MMS 2008-055. Volume I: Main Text 224 pp. + Volume II: Appendices 300 pp.

Zarillo, G.A., K.A. Zarillo, J.A. Reidenauer, E.A. Reyier, T. Shinskey, M.J. Barkaszi, J.M. Shenker, M. Verdugo, and N. Hodges. 2009. Final Biological Characterization and Numerical Wave Model Analysis within Borrow Sites Offshore of Florida’s Northeast Coast Report-Volume I: Main Text 286 pp. + Volume II: Appendices A-D 448 pp. Contract No. 1435-01-05-CT-39075-M05PC00005. MMS Study 2008-060.

Figures

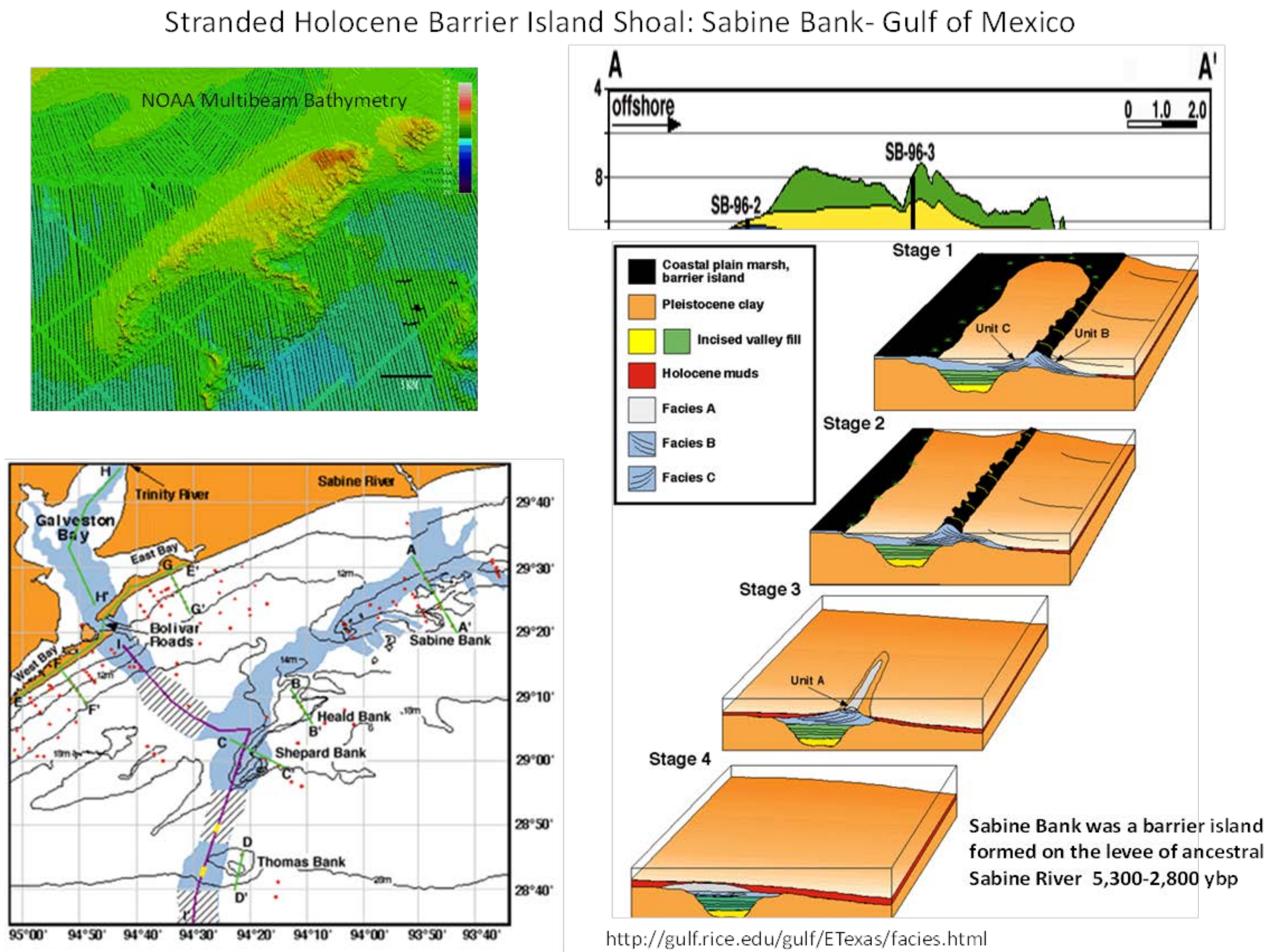


Figure 2-1. Characteristics of Sabine Bank, a stranded Holocene barrier island shoal. Source: http://gulf.rice.edu/gulf/ETexas/facies.html.

Stranded Bayhead Delta-Paleo-valley deposit Shoal: Heald Bank- Northern Gulf of Mexico

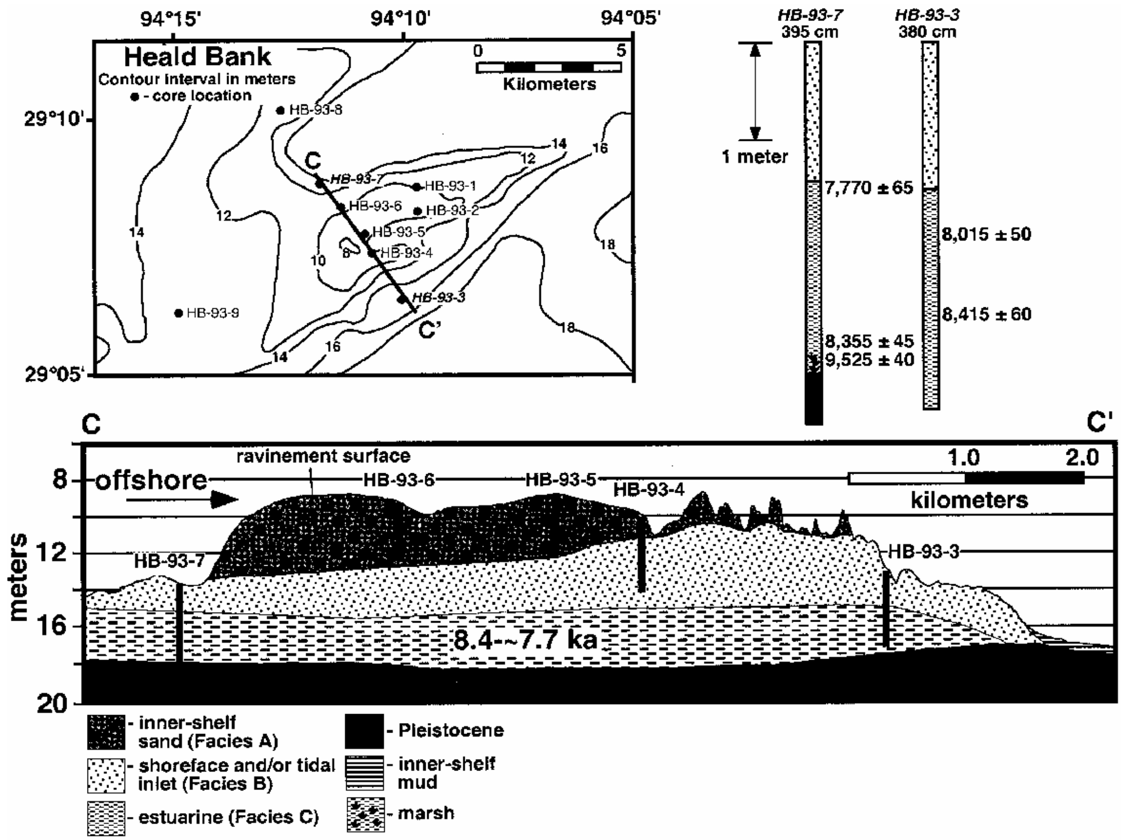


Fig. 14. Bathymetric map of the Heald Bank area showing the locations of sediment cores and cross section C-C'. Cores highlighted on the map in italic bold type were sampled for dating and are shown in detail. Cross section C-C' is modified after Rodriguez et al. (1999) and was created from analysis of cores, precision depth recorder profiles, and seismic data. Location of cross section C-C' is also shown in Figure 1. Additional information is summarized in Table 1.

Figure 2-2. Characteristics of Heald Bank, a stranded Bayhead delta shoal. Source: Rodriguez et al. 2004.

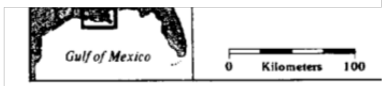


Fig. 1. Location map of the Holocene Mississipi River delta plain showing distribution of transgressive barriers and shoals. Over the last 7,000 years, the Mississippi River has built a delta plain consisting of six complexes; four are abandoned (Maringoin, Teche, St. Bernard, and Lafourche), and two are active (Modern and Atchafalaya). More than 75 percent of the Mississippi River delta plain is abandoned and is in various stages of transgression due to submergence (modified from Frazier 1967, 1974).

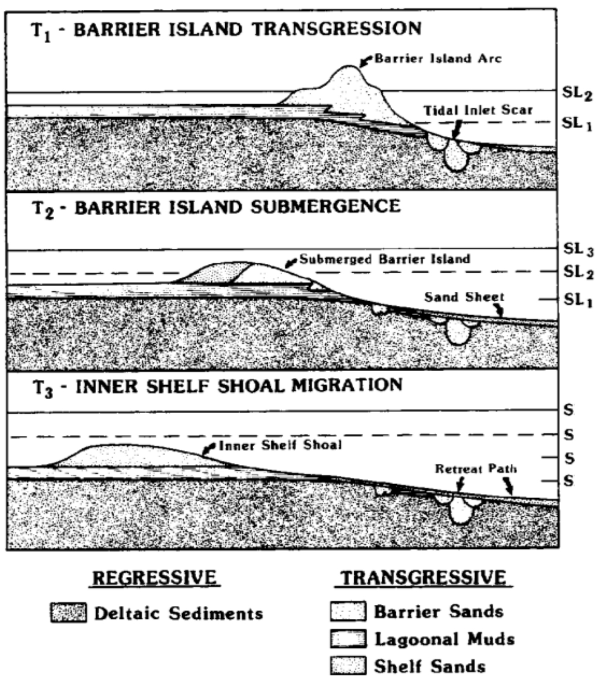
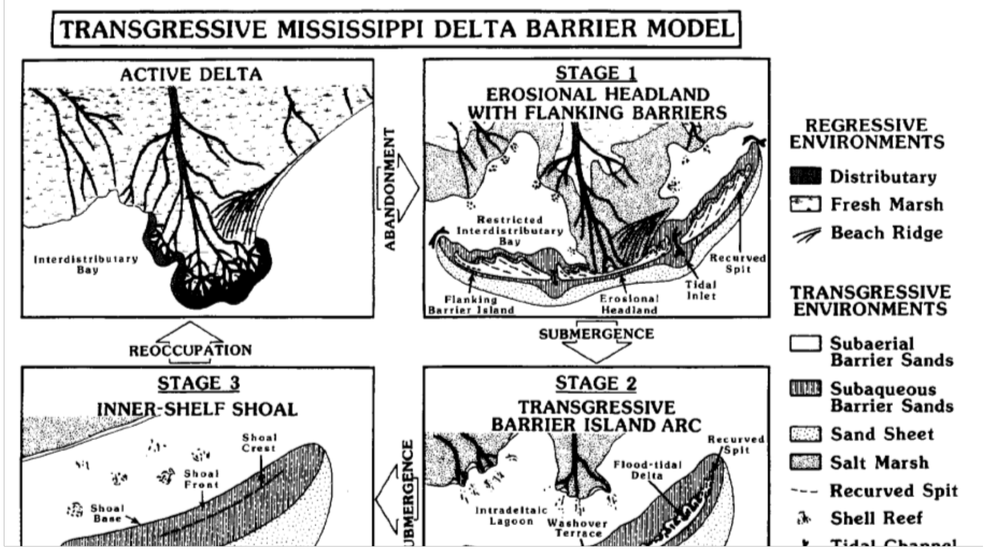
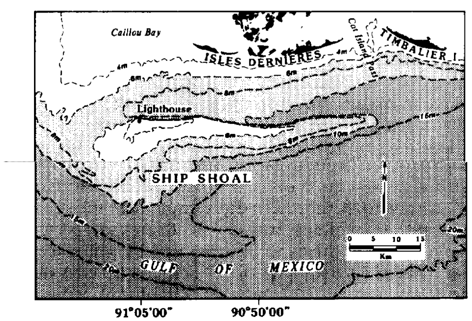


Fig. 16. This stratigraphic model illustrates the *transgressive submergence* process in which a marine inner-shelf sand shoal is generated by the reworking of a submerged barrier island arc sand body associated with an abandoned delta complex.

MISSISSIPPI DELTA TRANSGRESSIVE BARRIERS 943





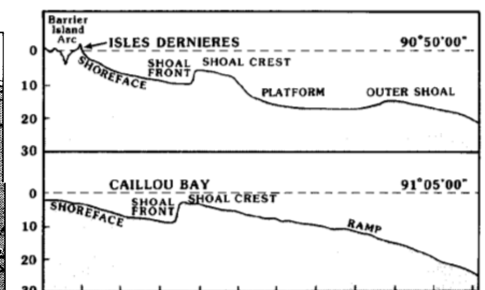


Figure 2-3. Development of inner shelf sand shoal in the Gulf of Mexico. Source: Penland et al., 1988.

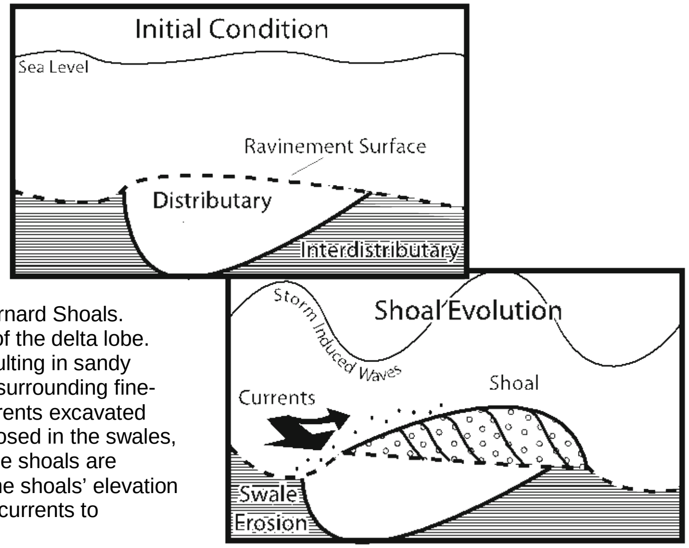


Fig. 14. Model depicting the evolution of the St. Bernard Shoals. Initially, transgression truncates the upper portion of the delta lobe. The ravinement produced an irregular seafloor resulting in sandy distributary channel bases slightly elevated above surrounding fine-grained deposits. Subsequently, strong marine currents excavated sandy sediment from the distributary channels exposed in the swales, and deposited the sediment as shoals. Note that the shoals are oriented subparallel to the main current, and that the shoals' elevation above the surrounding seafloor causes secondary currents to transport the entrained sediment over the shoals.

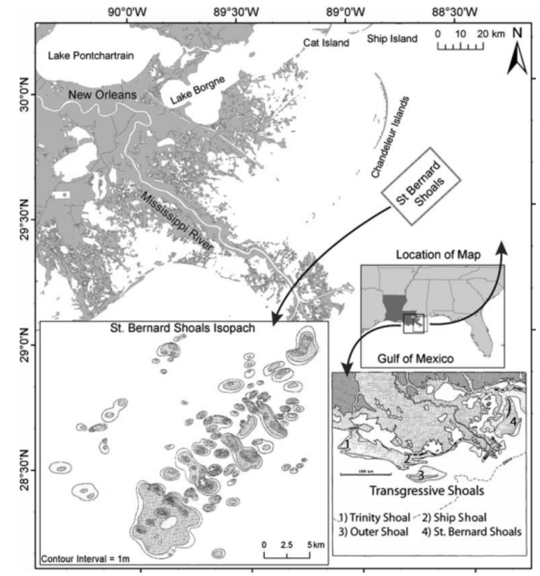


Fig. 7. CI-87 seismic cross-section showing the characteristics of the distributary channel facies, and the stratigraphic relationship between the shoals and the underlying progradational facies. The larger of the two distributary channels shown here is the main channel of the La Loutre distributary network underlying the shoals. Note the asymmetrical morphology of the individual shoals, and how the present-day seafloor is at a lower elevation than the ravinement surface underlying the shoals.

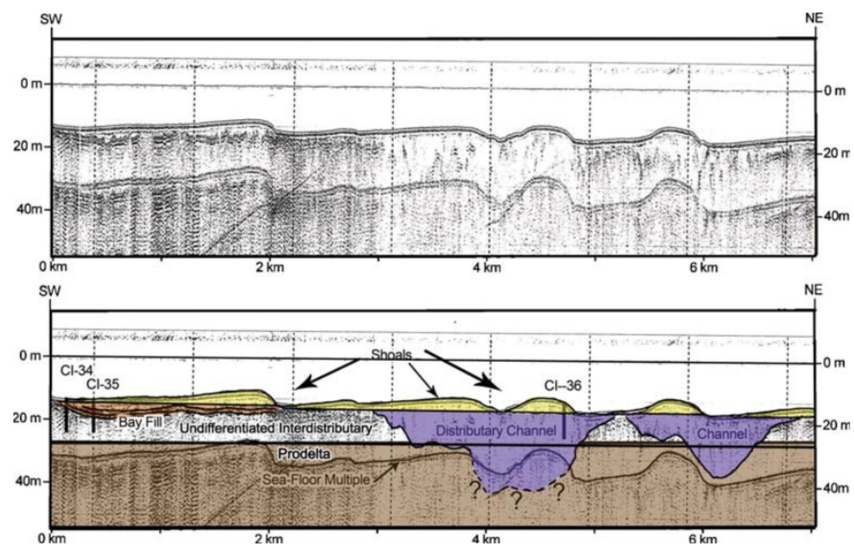


Figure 2-4. Evolution and current characteristics of St. Bernard Shoals. Source: Rogers et al., 2009.

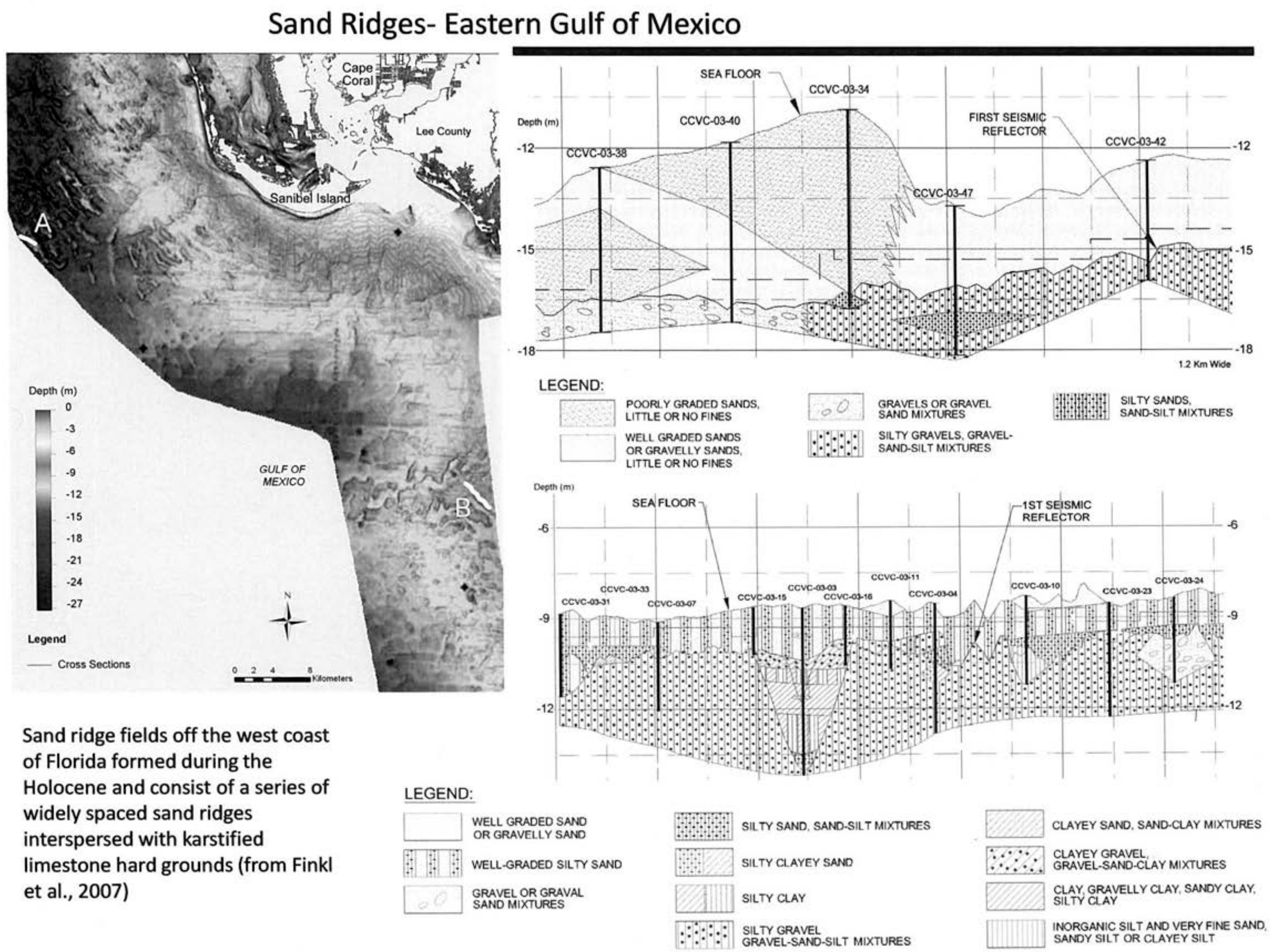


Figure 2-5. Characteristics Holocene produced shoal fields in eastern Gulf of Mexico. Source: Finkl et al. 2007b.

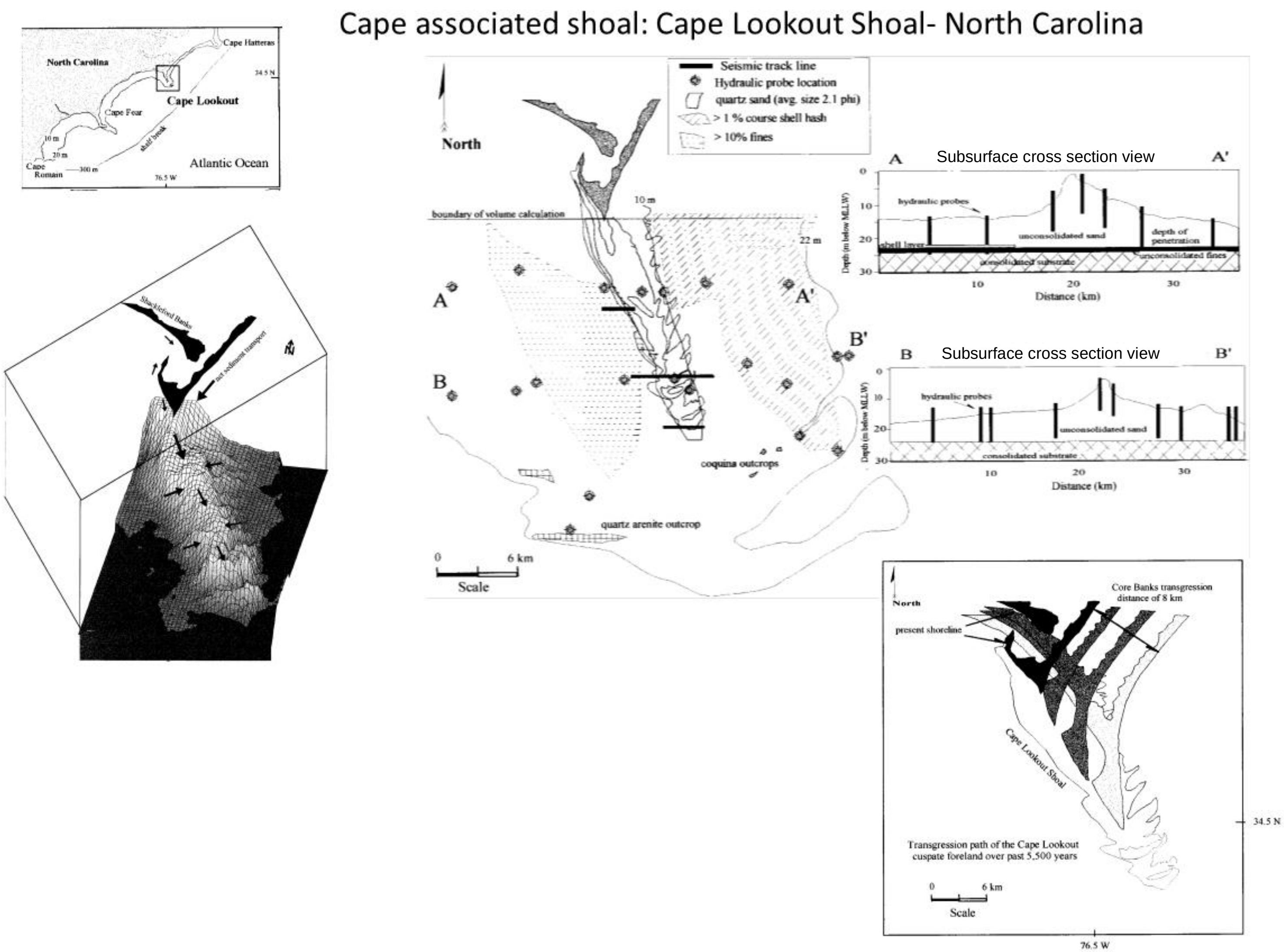
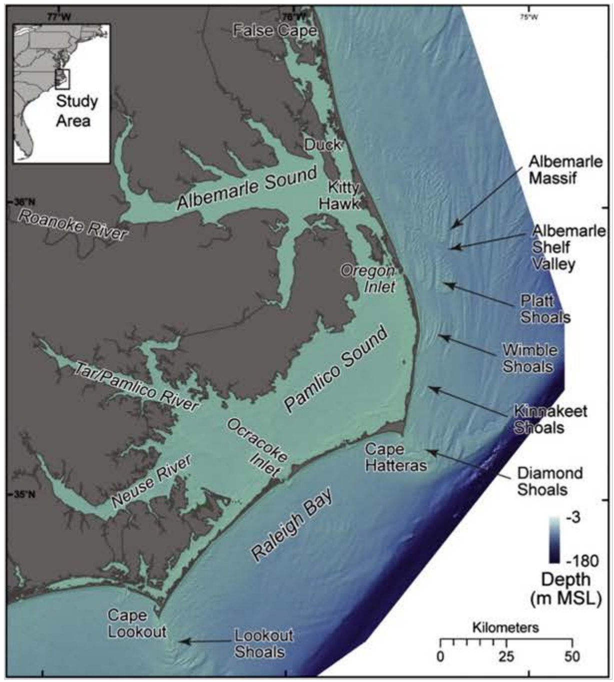


Fig. 10. Proposed transgression path of Cape Lookout Point over past 5500 years.

Figure 2-6. Characteristics of Cape Lookout Shoal, a cape-associated shoal. Source: McNinch and Wells 1999.



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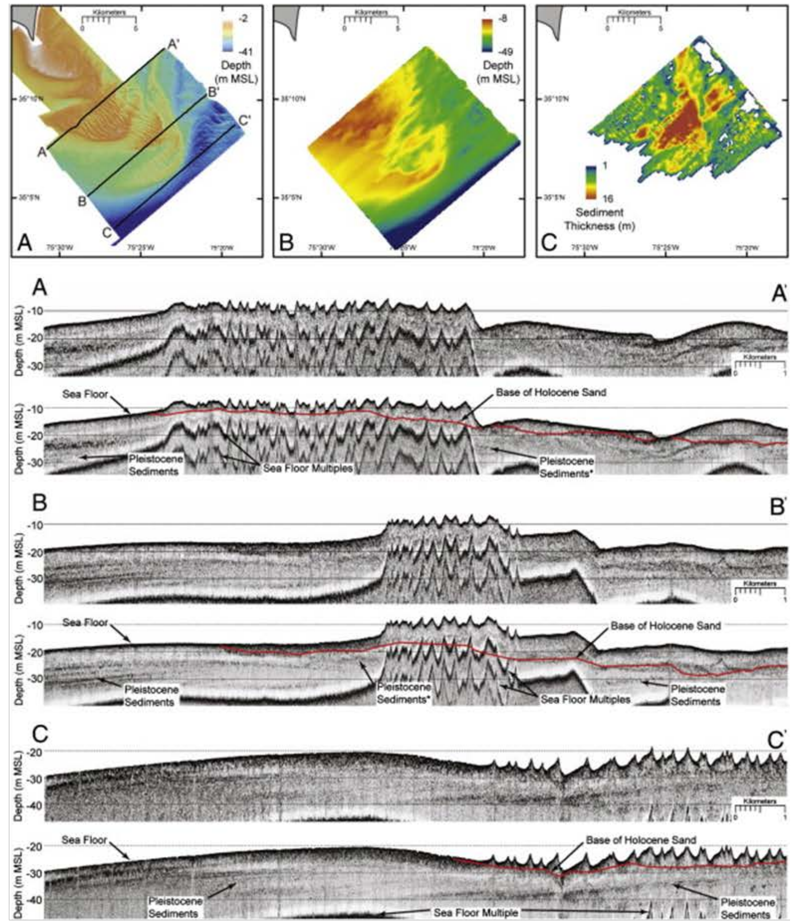

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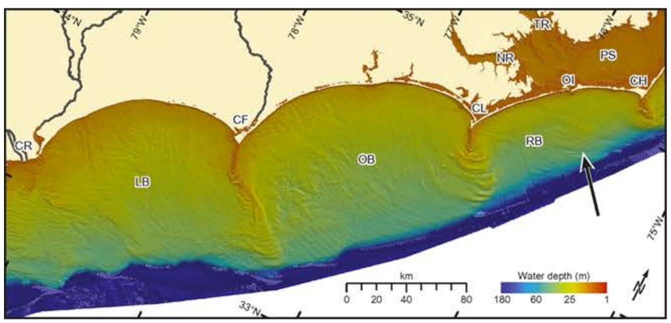


(Theiler and Ashton, 2014)

Figure 2-7. Cape Associated shoals and Massifs. Sources: Theiler et al., 2014 and Theiler and Ashton, 2011.

Retreat Massif Shoals: Albemarle Shelf, North Carolina

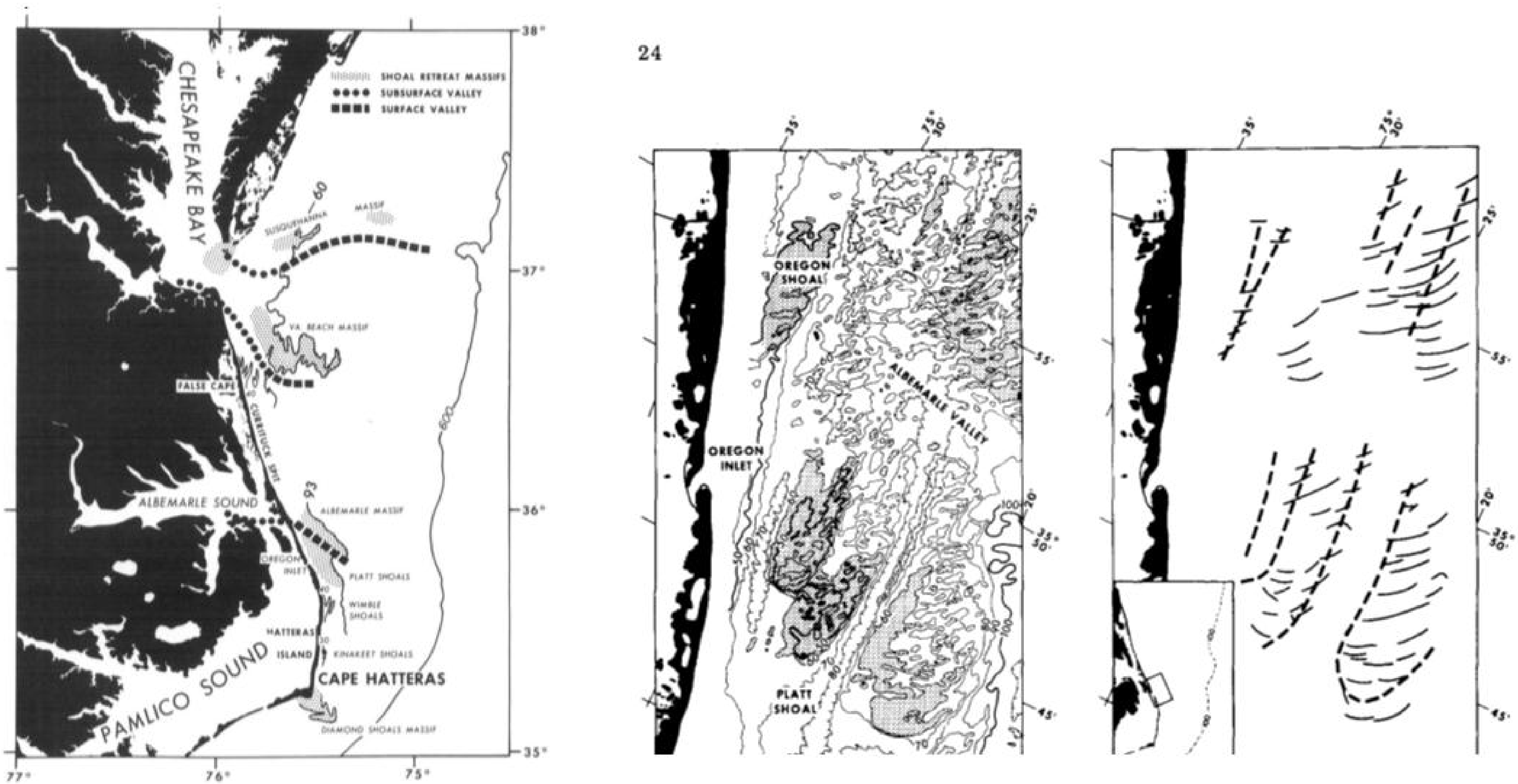


Fig. 1. Morphologic framework of the Virginia and northern North Carolina Shelf.

Figure 2-8. Characteristics of Albermarle Shelf retreat massif shoals. Source: Swift et al. 1978.

Sorted Bedform Shoals: Wrightsville Beach, North Carolina

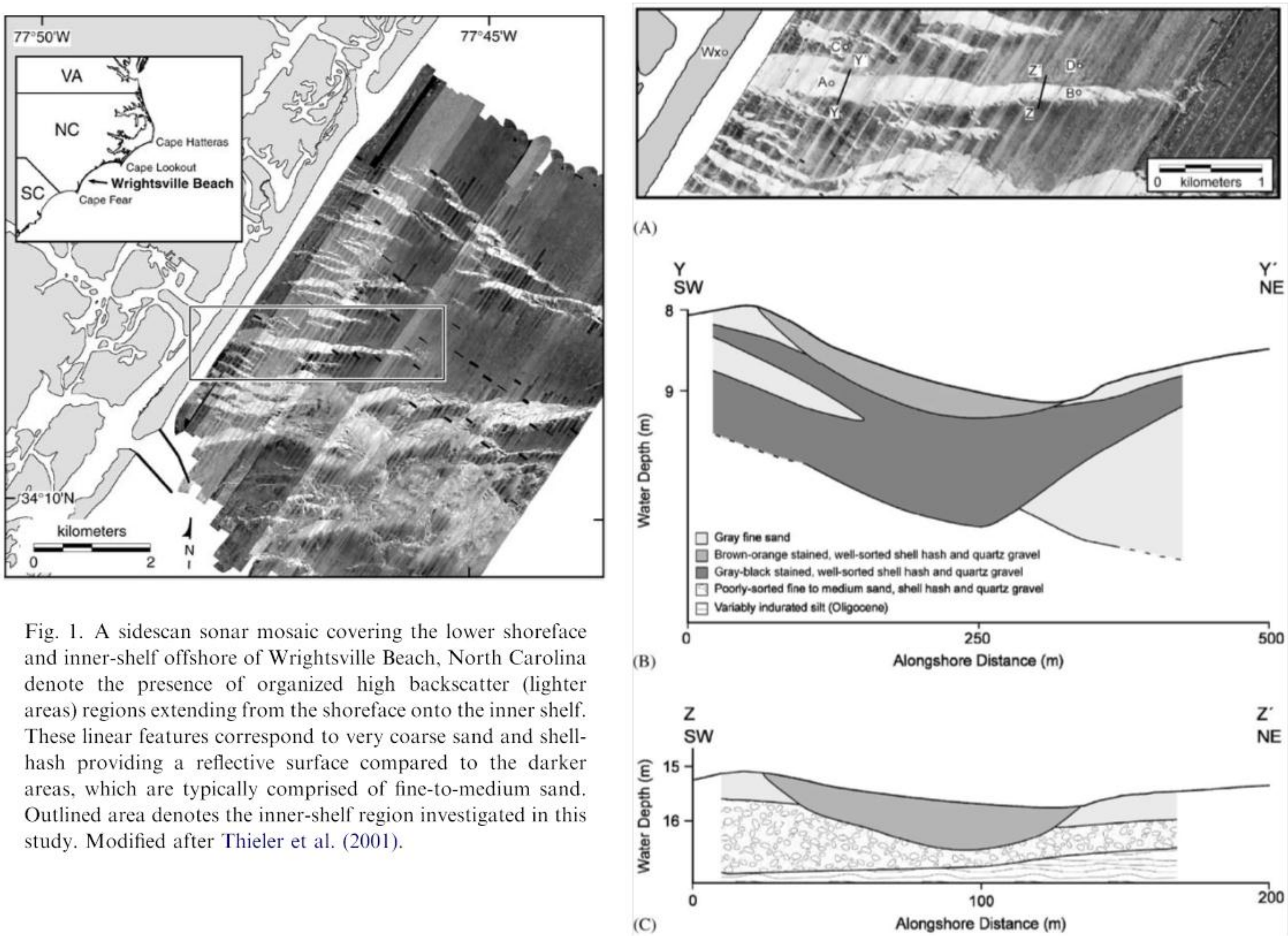
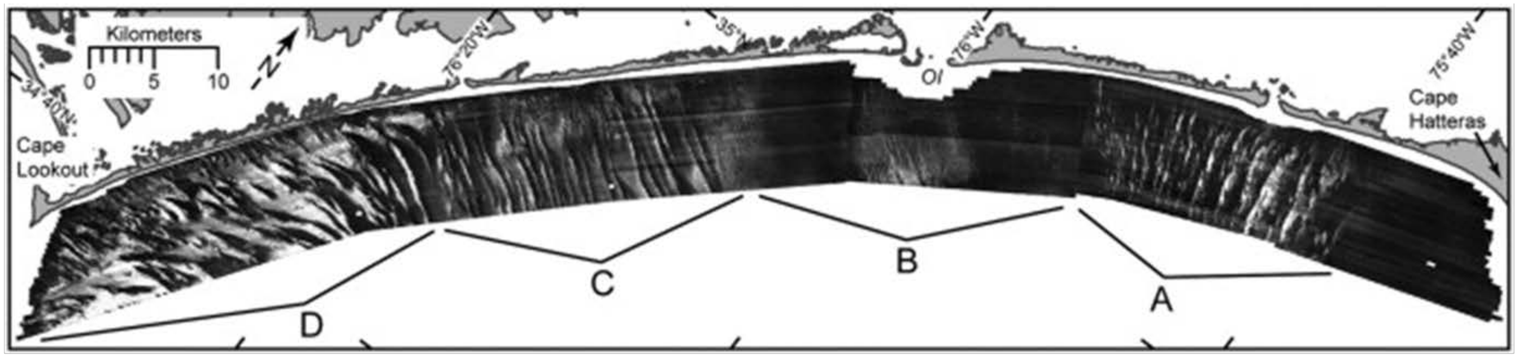
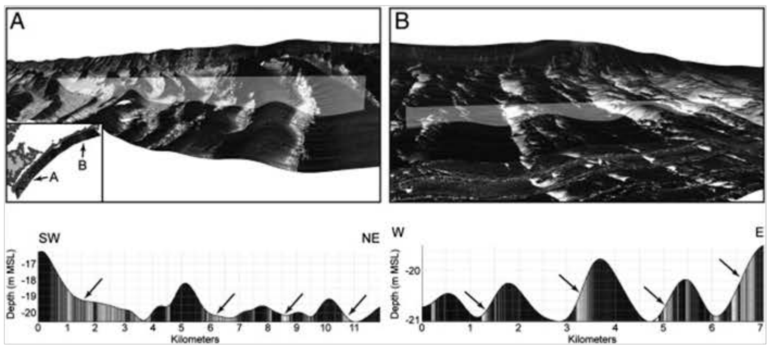
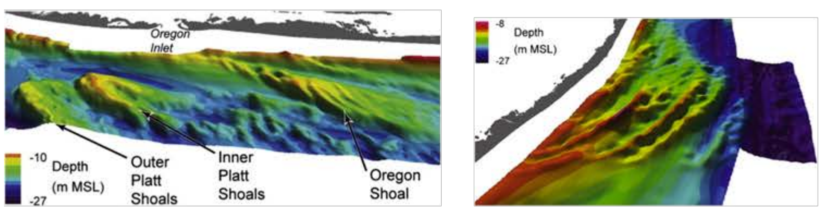


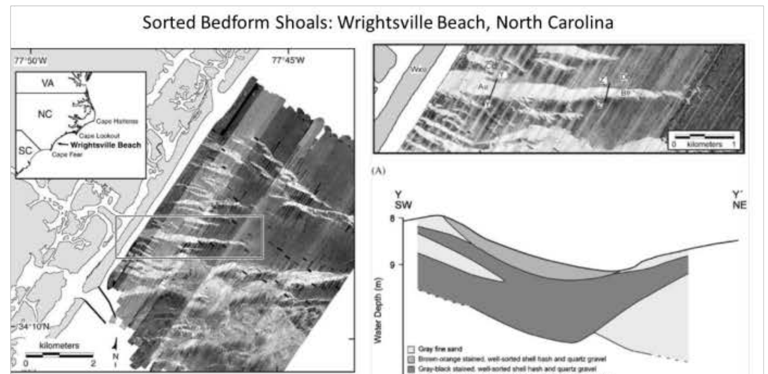
Figure 2-9. Characteristics of sorted bedform shoals off Wrightsville, NC. Source: Guitierrez et al. 2005.







(Theiler et al., 2014)



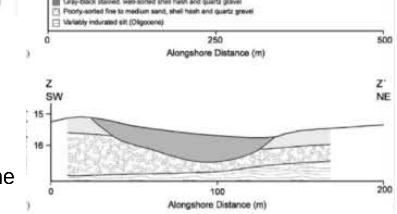


Fig. 1. A sidescan sonar mosaic covering the lower shoreface and inner-shelf offshore of Wrightsville Beach, North Carolina denote the presence of organized high backscatter (lighter areas) regions extending from the shoreface onto the inner shelf. These linear features correspond to very coarse sand and shell-hash providing a reflective surface compared to the darker areas, which are typically comprised of fine-to-medium sand,. Outlined area denotes the inner-shelf region investigated in this study. Modified after Thieler et al. 2001).

Guitierrez et al., 2005

Figure 2-10. Characteristics of sorted bedforms along the North Carolina coast. Sources: Theiler et al. 2014 and Guitierrez et al. 2005.

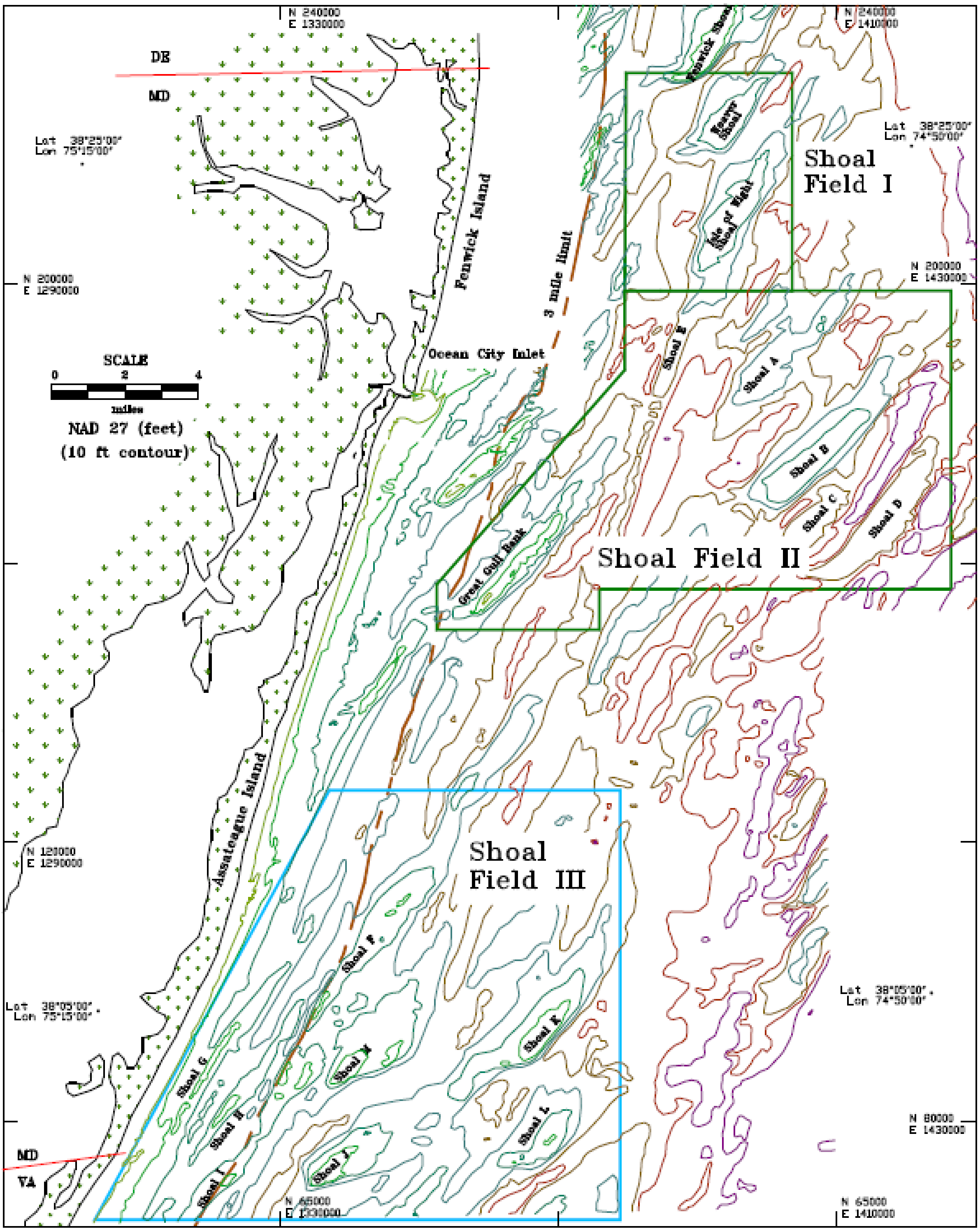


Figure 2-11. An example of offshore ridge/trough system (also known as a shoal field) off the Delaware-Maryland coast identified as potential sand resources. Source: Conkwright and Gast, 1995.

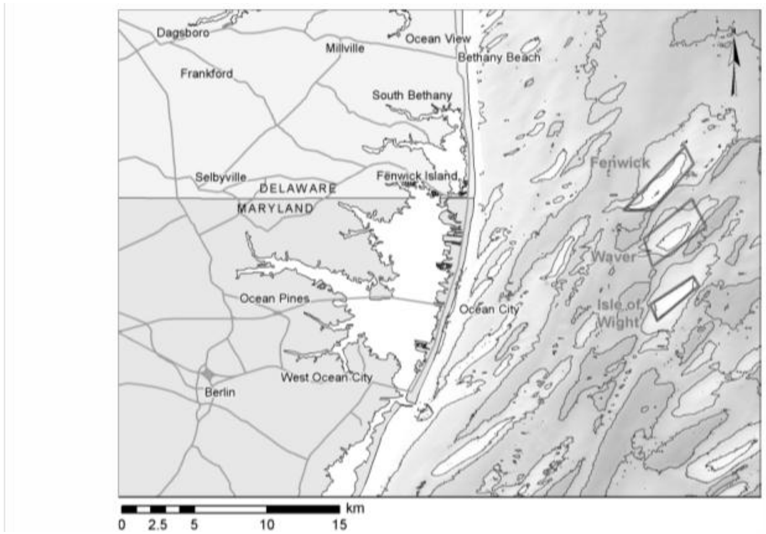


Fig. 1 Example of ridge and swale topography typical of the Mid-Atlantic Bight region. Note detailed bathymetry (VIMS, 2000).

Ridge and Swale Shoals: Maryland-Delaware shelf

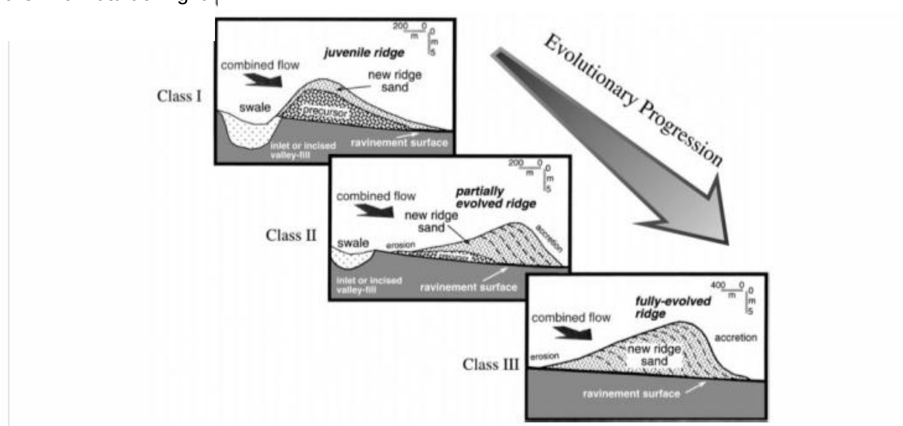


Fig. 6. Schematic diagram of ridge classes. From Smeddem amd Dalymple (1999). The precursor in the case of Class I and II ridges is a pre-existing bathymetric feature, sometimes associated with a shoreline or inlet, which provides the nucleation point for the ridge via the Huthnance process. Subsequently, this precursor may be removed or reduced in size through current erosion and ridge migration. Accretion on the landward side of the juvenile ridge (Class I) is largly induced by fair-weather wave transport from the ridge crest and is not expected to occur in ridges developed in deepr water, as with Classes II and III. New ridge sand is primarily deposited in shelf waters by combined flows associated with storm passage.

Figure 2-12. Evolution of ridge and swale shoals off Maryland and Delaware. Source: Haynes and Nairn 2004.

Shoal and Ridge Complexes: Sandbridge Shoal, Virginia

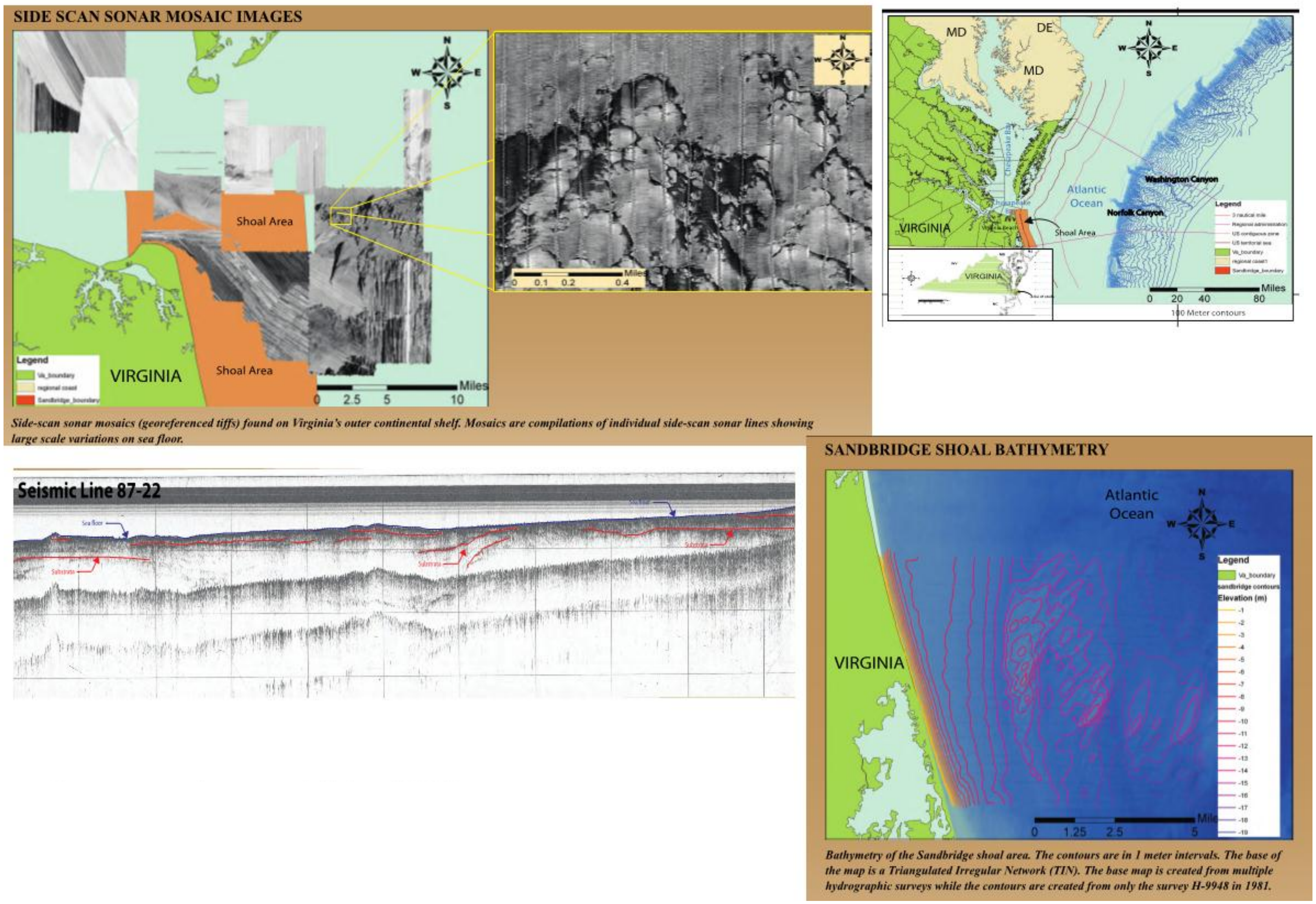


Figure 2-13. Characteristics of Sandbridge Shoal, a shoal and ridge complex. Source: Shoals. Feeney et al. 1978.

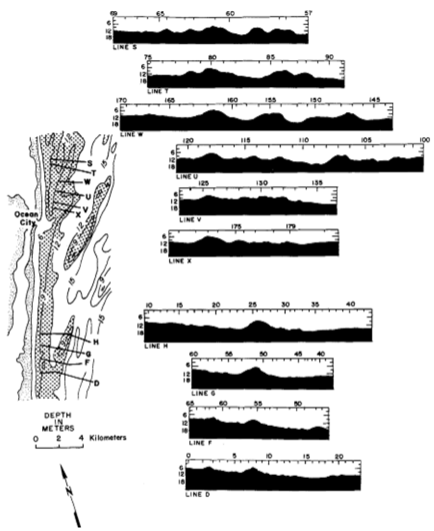
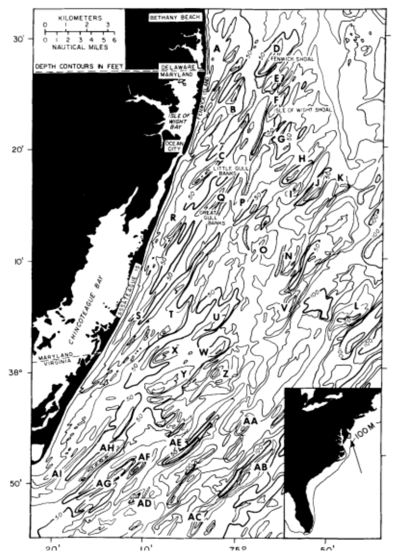
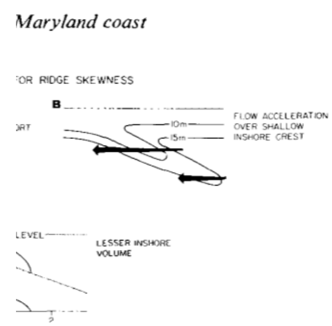


Fig. 3. Fathometer profiles of shoreface ridges. Profiles S-X are for OceanCity Shoal, D-H for San Antonio Shoal.





Maryland coast

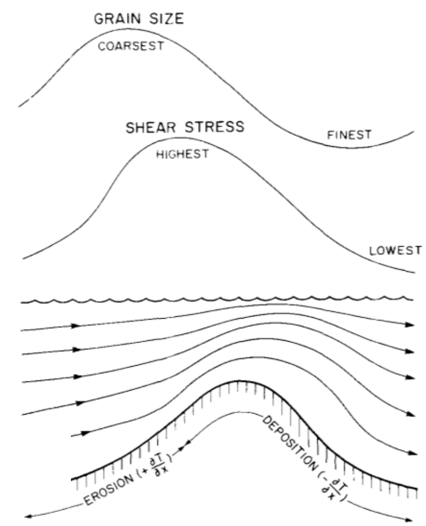


Fig. 15. Schematic illustration of model for ridge generation.

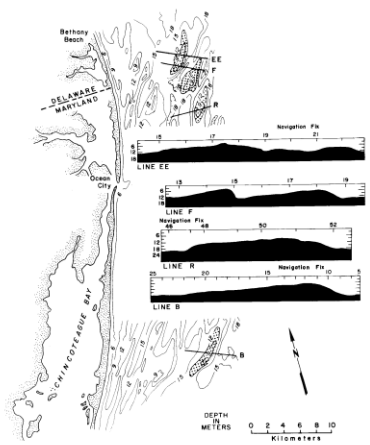


Fig. 5. Fathometer profiles from transects across offshore ridges.

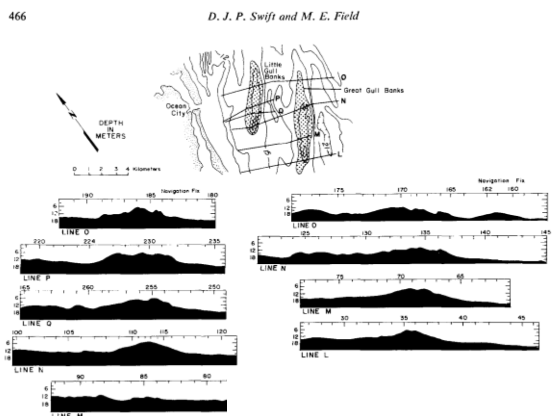


Fig. 4. Fathometer profiles for nearshore ridges (Little Gull Banks and Great Gull Banks)

Figure 2-14. Bathymetric conditions of Mid-Atlantic Bight shoals. Source: Swift and Field 1981.

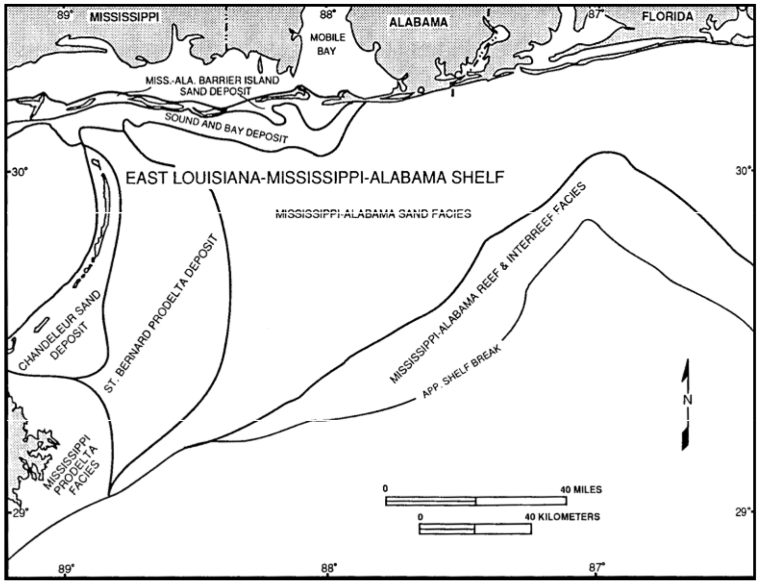


Fig. 2-2. Sedimentary facies on east Lousiana-Mississippi-Alabama Shelf.

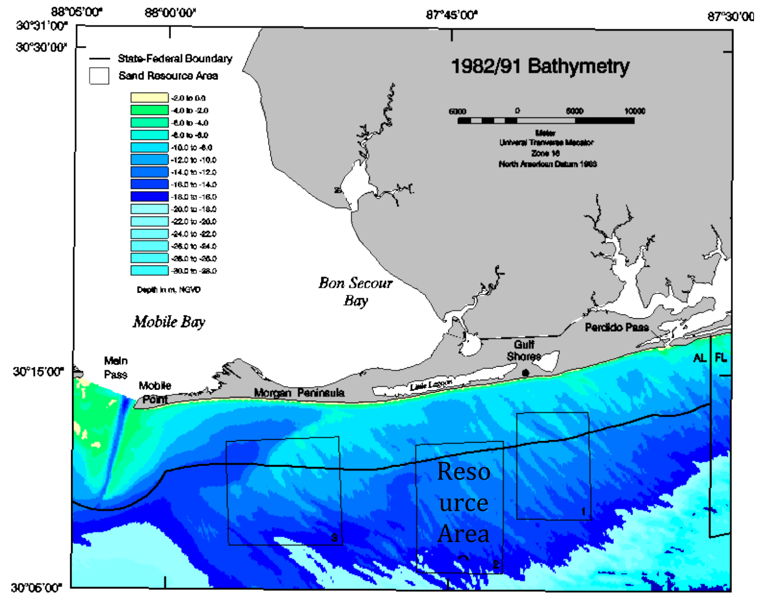


Fig. 3-11. Nearshore baythmetry (1982-85) for the northeastern Alabama coastal zone.

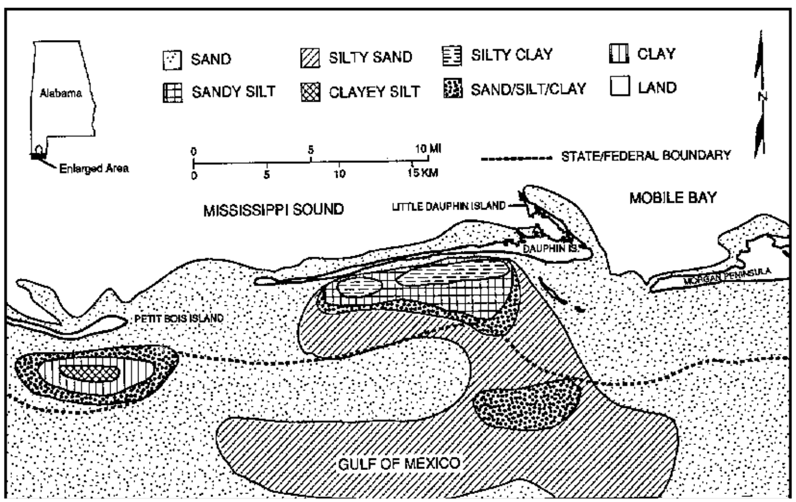


Fig 2-8. Surface sediment distribution in the west Alabama inner continental shelf.

Figure 2-15. Characteristics of Resource Area 2 shoals off the coast of Alabama. Source: Byrnes et al. 1999.

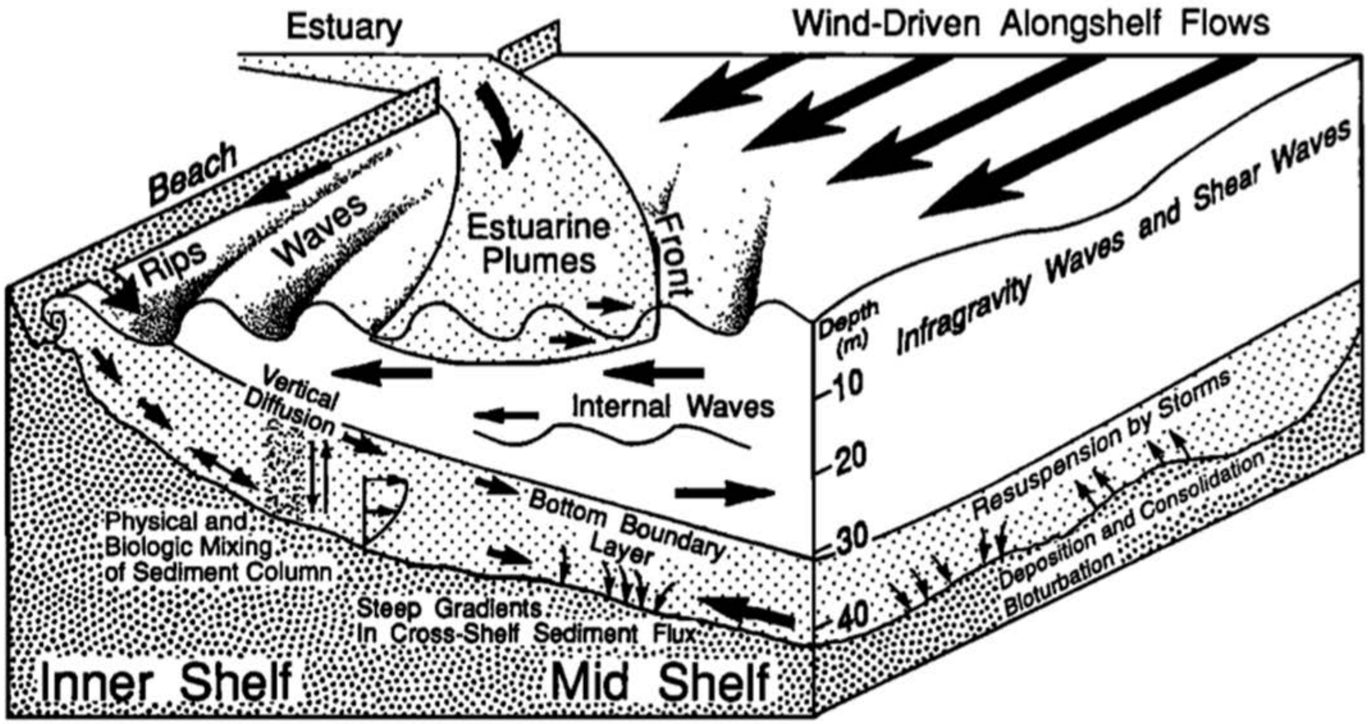


Figure 2-16. Conceptual diagram illustrating the major physical processes responsible for across-shelf particulate transport. Source: Nittrouer and Wright 1994.

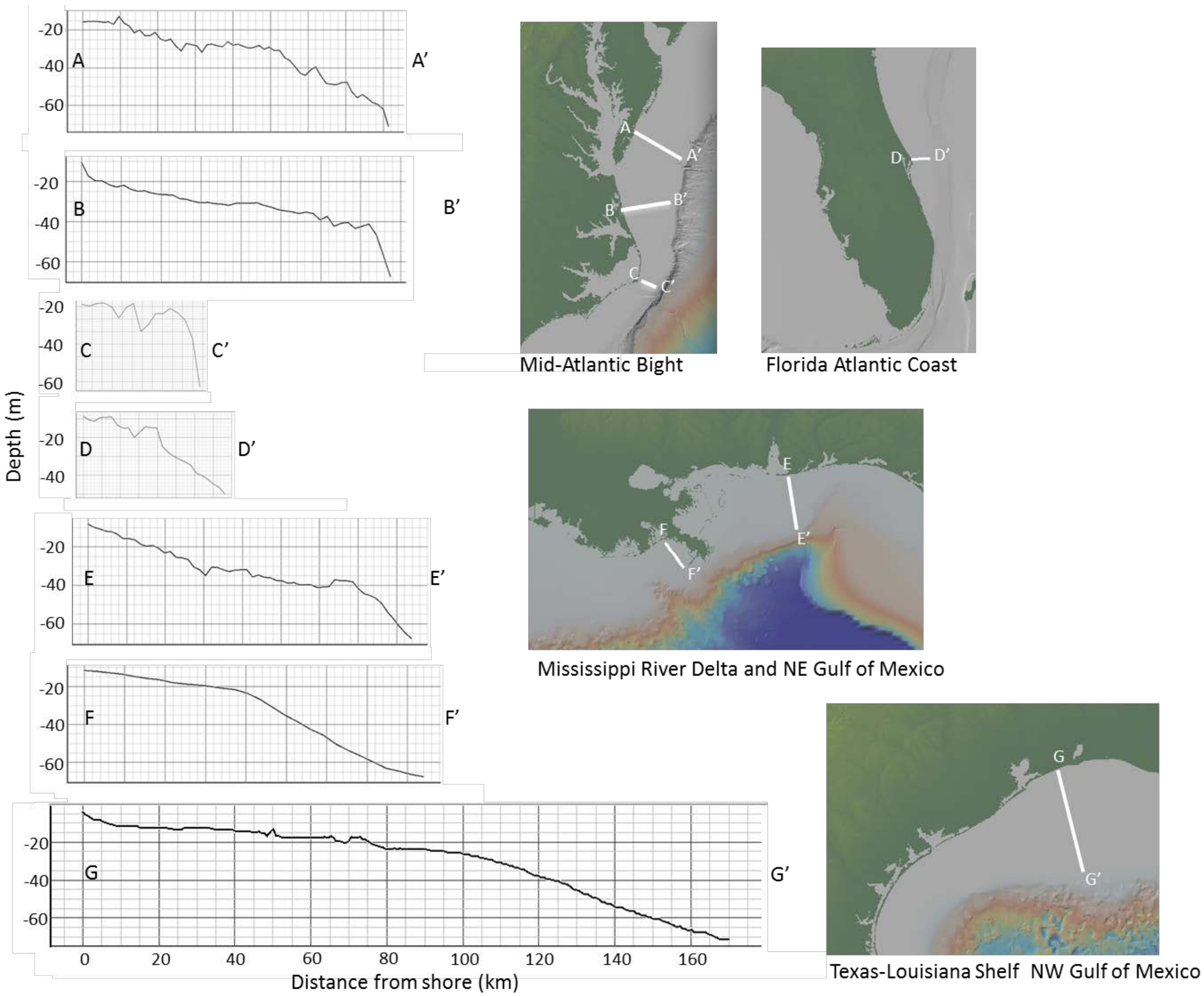


Figure 2-17. Cross-shelf bathymetric profiles in the US Atlantic and Gulf of Mexico OCS. Source: Wright 1995.

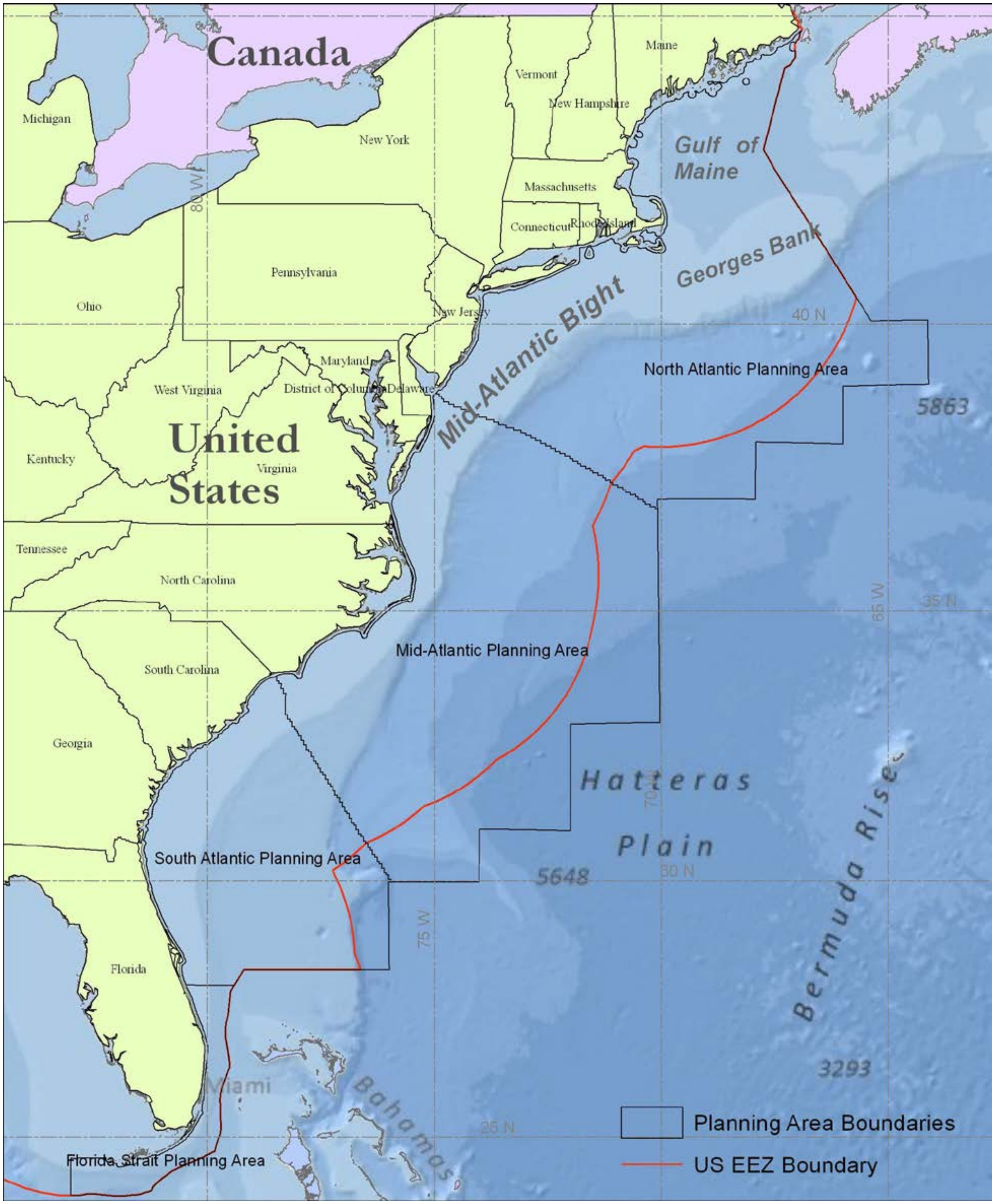


Figure 2–18. U.S. Atlantic Outer Continental Shelf region showing the Bureau of Ocean Energy Management Planning Area boundaries and the U.S. Exclusive Economic Zone (EEZ) boundary.

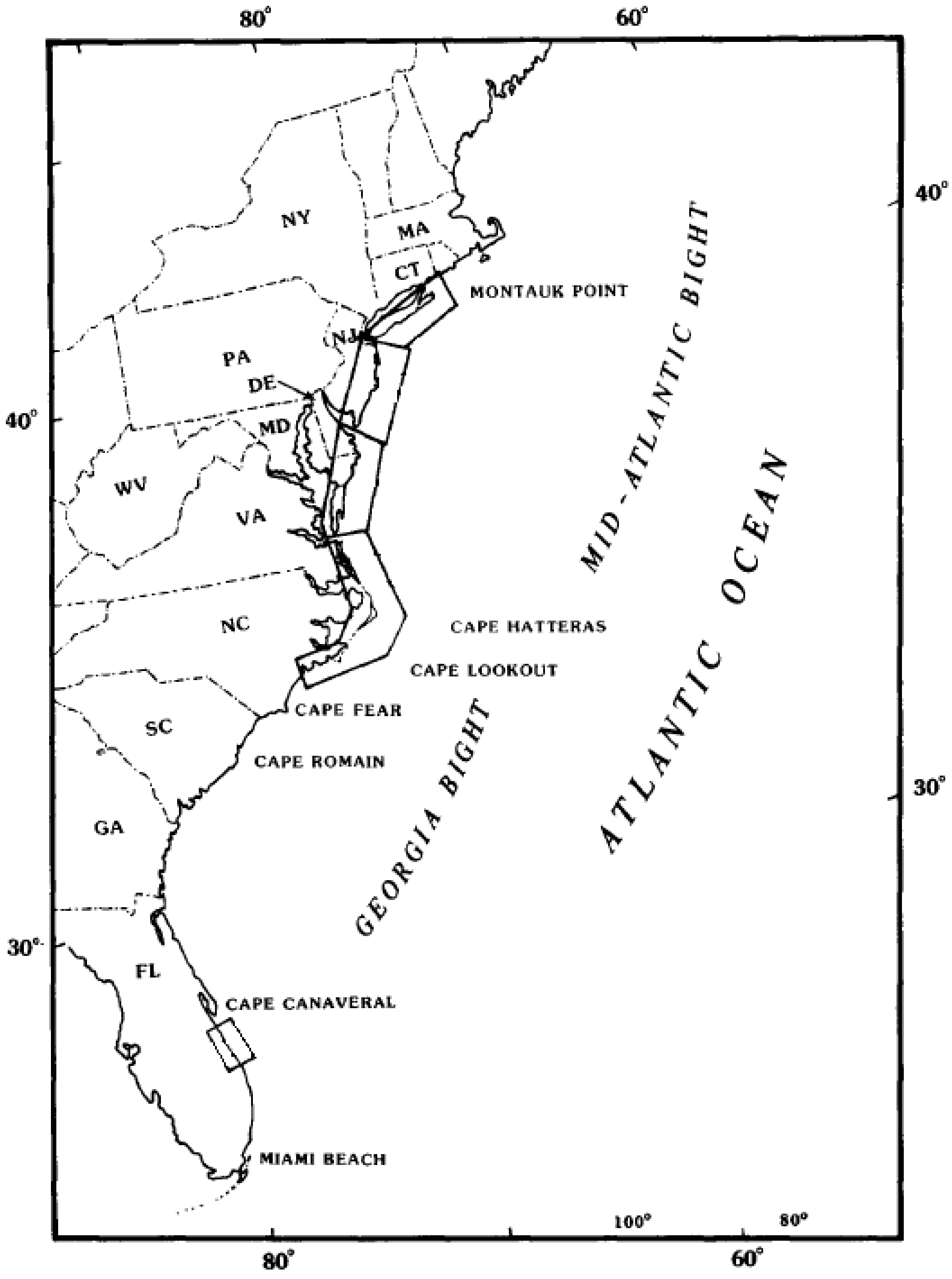


Figure 2-19. Shoreface-attached and detached sand ridge areas along the U.S. Atlantic coast and inner shelf from Montauk Point, New York to Miami Beach, Florida (modified from McBride and Moslow 1991).

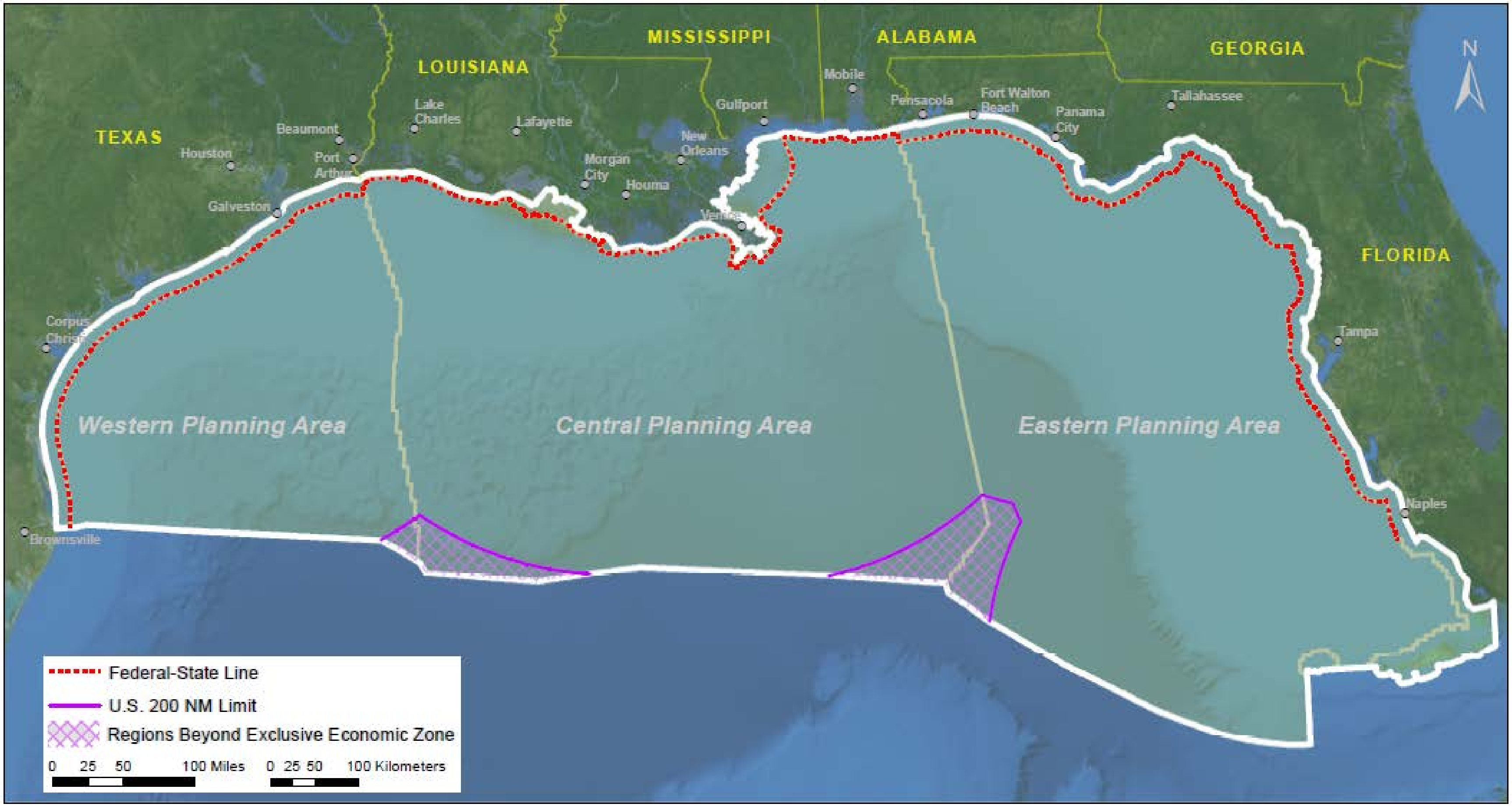


Figure 2-20. U.S. Gulf of Mexico Outer Continental Shelf region showing the Bureau of Ocean Energy Management Planning Area boundaries and the U.S. Exclusive Economic Zone (EEZ) boundary (modified from BOEM 2013).

Tables

Table 3-1. Studies investigating shoal and ridge/trough complexes in the Atlantic and Gulf of Mexico Outer Continental Shelf regions.

Study	Study Area	Sampling Approach
Brooks et al. 2005	Heald and Sabine Banks off the coast of Texas, Tiger and Trinity Shoals off the coast of Louisiana, and two control areas one near each of the shoal areas. No benthic sediment or habitat information was provided for the control areas except that they did not contain exploitable sand resources.	SEAMAP groundfish survey and associated environmental data from 1982-2000 for study areas. Summer and fall trawls using a 12.2-m net used from Alabama, Mississippi, and Louisiana, and a 6.1-m net from Texas were towed from a minimum of 10 minutes to a maximum of 60 minutes. The study was interested in only species that utilized the benthos for habitat or feeding during part of their life history as a result pelagic fish were removed from the data set prior to analysis. A total of 434 trawls were conducted in the bank/shoals areas with 6% of the trawls conducted on-bank.
Byrnes et al. 1999	Five sand resource areas (Resource Area 1, 2, 3, 4, and 5) along the Alabama coast	Sampling at each area was conducted in May and December 1997 by 10-minute 25-ft mongoose trawl along a pre-plotted transect. Two trawls were conducted at each area.
Diaz et al. 2003	Fenwick and Weaver Shoals, off the coast of Maryland and Delaware	Sampling was conducted in May 1999 using a combination of video sled transects and a 2-m metered beam trawls on and immediately adjacent to Fenwick and Weaver Shoals. Eight 2-minute trawls were collected, four during the day and four at night. Sampling was conducted in May 1999.
Diaz et al. 2006	Sandbridge Shoal, off the coast of Virginia	Data was collected over a four year period; June 2002 six months prior to initial dredging, August 2003 four months post initial dredging, June 2004 two months post second dredging, and June 2005 fourteen months post all dredging. Sampling was conducted by 10-minute 4.9 m (16-foot) otter trawl on and immediately adjacent to the shoal.

Study	Study Area	Sampling Approach
Slacum et al. 2006	Linear shoal complex (Fenwick Shoal, Weaver Shoal, Shoal B, Shoal D, and nonadjacent flat-bottom sites), off the coast of Maryland and Delaware.	Sampling was conducted using a 30.5 m commercial trawl, a 7.6 m research trawl, varying mesh size gillnets, and a 120-kHz split-beam bioacoustic system (night). Trawls were towed for 10 minutes. Gillnets were set for an average of 4 hours. Sampling was conducted seasonally for two consecutive years beginning in the fall of 2002. Seasonal bioacoustic surveys were not conducted during the two winter seasons.
Slacum et al. 2010	Linear shoal complex (Fenwick Shoal, Weaver Shoal, Shoal B, Shoal D, and nonadjacent flat-bottom sites), off the coast of Maryland and Delaware.	Sampling was conducted at the tops of the shoals and the center of the nonadjacent flat-bottom areas by small experimental demersal trawl, large commercial trawl, and experimental gillnet. Sampling was conducted seasonally for two consecutive years beginning in the fall of 2002. Trawls were towed for 10 minutes. Gillnets were set for an average of 4 hours.
Stone et al. 2009	Ship Shoal off the coast of Louisiana	Nighttime trawl sampling was conducted during the spring, summer, and fall of 2005 and 2006 using a 25-ft otter trawl towed for 30-minutes at nine stations (three each on the eastern flank, western flank, and middle of the shoal) to investigate distribution and abundance of the commercially important Atlantic Croaker and penaeid shrimp species on Ship Shoal. Only Atlantic Croaker, shrimp, and blue crab numbers were reported, total fish catch and a list of fish taxa were not provided. Stomach content analysis for the Atlantic Croaker and penaeid shrimp were also conducted.

Study	Study Area	Sampling Approach
Vasslides 2007	Ship Bottom Ridge, Beach Haven Ridge, and Brigantine Ridge off southern New Jersey	A 2-m beam-trawl was towed for 1 minute at eight stations along a transect from Little Egg Inlet across Beach Haven Ridge in midsummer and late summer from 1991-1995. Two-minute 4.9-m otter trawl sampling was conducted at eight stations on and within the vicinity of Beach Haven Ridge in July and September from 1997-2006 and six station transects across both Ship Bottom Ridge and Brigantine Ridge in July and September 2006. Trawl durations were short in an attempt to sample discrete habitat types.
Vasslides & Able 2008	Beach Haven Ridge, off the coast of southern New Jersey	A 1-minute 2-m beam trawl was towed at eight stations along a transect from Little Egg Inlet across Beach Haven Ridge in July and September from 1991-1995. A 2-minute otter trawl was towed at eight stations on and within the vicinity of Beach Haven Ridge in July and September from 1997-2006. Trawl durations were short in an attempt to sample discrete habitat types.
Walsh et al. 2006	Continental shelf off the Georgia coast. The cross-shelf transect included the Gray's Reef National Marine Sanctuary (NMS) area.	A ten station cross-shelf transect was sampled quarterly from April 2000 through February 2002 using a 2-m beam trawl. Sampling avoided the Gray's Reef NMS by placing four stations adjacent to the four sides of the sanctuary. Three 5-minute tows were made at each station. In April 2000, a remotely operated vehicle was used conducting two 15-minute drifts at eight of the ten stations.
Wells et al. 2009	Freeport Rocks Bathymetric High (drowned barrier island) and adjacent mud-bottom substrates, continental shelf off the Texas coast.	Two replicate 10-minute trawls were conducted from May to December 2000 with a 6-m otter trawl at three habitat areas (inshore mud, shell hash/sand bank, and offshore mud).

Study	Study Area	Sampling Approach
Zarillo 2008	Toms' Hills (T1 and T2 shoal system) and Siesta Shoal off the west Florida coast along Sarasota, Charlotte, Lee, and Collier Counties.	Ten-minute otter trawls were conducted within and adjacent to each proposed borrow site during fall 2005 and spring 2006 surveys. Hard bottom substrates encountered at each shoal limited sampling to a total of 29 successful tows.
Zarillo 2009	Five shoals (designated as B11, A9, A8, A6, and A4) off the east Florida coast along Duval, St. Johns, Flagler and Volusia Counties	At each shoal three nocturnal 10-minute otter trawls were conducted within the footprint of the proposed borrow site and the area immediately adjacent to the site during November 2005 and June 2006 surveys.

Table 3-2. Atlantic highly migratory species that have defined Essential Fish Habitat that contain shoals areas in the Mid-Atlantic, South Atlantic, Straits of Florida, and/or Gulf of Mexico (data from NMFS 2009).

Scientific Name	Common Name
Alopias vulpinus	Thresher Shark
Carcharhinus acronotus	Blacknose Shark
Carcharhinus altimus	Bignose Shark
Carcharhinus brevipinna	Silky Shark
Carcharhinus brevipinna	Spinner Shark
Carcharhinus isodon	Finetooth Shark
Carcharhinus leucas	Bull Shark
Carcharhinus limbatus	Blacktip Shark
Carcharhinus obscurus	Dusky Shark
Carcharhinus perezi	Caribbean Reef Shark
Carcharhinus plumbeus	Sandbar Shark
Carcharhinus signatus	Night Shark
Carcharodon carcharias	White Shark
Cetorhinus maximus	Basking Shark
Galeocerdo cuvieri	Tiger Shark
Ginglymostoma cirratum	Nurse Shark
Istiophorus platypterus	Sailfish
Isurus oxyrinchus	Shortfin Mako Shark
Katsuwonus pelamis	Atlantic Skipjack Tuna
Makaira nigricans	Blue Marlin
Negaprion brevirostris	Lemon Shark
Odontaspis taurus	Sand Tiger Shark
Prionace glauca	Blue Shark
Rhincodon typus	Whale Shark
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark
Sphyrna lewini	Scalloped Hammerhead Shark
Sphyrna mokarran	Great Hammerhead Shark
Sphyrna tiburo	Bonnethead Shark
Squatina dumeril	Atlantic Angel Shark
Tetrapturus albidus	White Marlin
Tetrapturus pfluegeri	Longbill Spearfish
Thunnus alalunga	Atlantic Albacore Tuna
Thunnus albacres	Atlantic Yellowfin Tuna
Thunnus obesus	Atlantic Bigeye Tuna
Thunnus thynnus	Atlantic Bluefin Tuna
Xiphias gladius	Swordfish

Table 3-3. Managed fish and invertebrate species that may utilize offshore shoals in the Mid-Atlantic (data from CSA International, Inc. et al. 2010 Tables 4.7. and 4.8.). Management agencies include: Atlantic State Marine Fishery Commision (ASMFC), National Marine Fishery Service (NMFS) Highly Migratory Species (HMS), Mid-Atlantic Fishery Management Council (MAFMC), and New England Fishery Management Council (NEFMC).

Managed Fishes		**Management Agencies**
Scientific Name	**Common Name**	
Carcharhinus brevipinna	Silky Shark	ASMFC; NMFS HMS
Carcharhinus limbatus	Blacktip Shark	ASMFC; NMFS HMS
Carcharhinus obscurus	Dusky Shark	ASMFC; NMFS HMS
Carcharhinus plumbeus	Sandbar Shark	ASMFC; NMFS HMS
Carcharhinus signatus	Night Shark	ASMFC; NMFS HMS
Centropristis striatus	Black Sea Bass	ASMFC; MAFMC
Cetorhinus maximus	Basking Shark	ASMFC; NMFS HMS
Clupea harengus	Atlantic Herring	ASMFC
Galeocerdo cuvieri	Tiger Shark	ASMFC; NMFS HMS
Leiostomus xanthurus	Spot	ASMFC
Lophius americanus	Goosefish	NEFMC
Lopholatilus chamaeleonticeps	Tilefish	MAFMC
Micropogonias undulatus	Atlantic Croaker	ASMFC
Morone saxatilis	Striped Bass	ASMFC
Odontaspis taurus	Sand Tiger Shark	ASMFC; NMFS HMS
Paralichthys dentatus	Summer Flounder	ASMFC; MAFMC
Peprilus triacanthus	Butterfish	MAFMC
Pomatomus saltatrix	Bluefish	ASMFC; MAFMC
Pseudopleuronectes americanus	Winter Flounder	ASMFC; NEFMC
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark	ASMFC; NMFS HMS
Scomber scombrus	Atlantic Mackerel	MAFMC
Scophthalmus aquosos	Windowpane	NEFMC
Sphyrna lewini	Scalloped Hammerhead	ASMFC; NMFS HMS
Squalus acanthias	Spiny Dogfish	ASMFC; MAFMC; NEFMC
Stenotomus chrysops	Scup	ASMFC; MAFMC
Urophycis chuss	Red Hake	NEFMC

Managed Invertebrates		**Management Agencies**
Scientific Name	**Common Name**	
Arctica islandica	Ocean Quahog	MAFMC
Illix illecebrosus	Short-finned Squid	MAFMC
Limulus polyphemus	Horseshoe crab	ASMFC
Loligo pealei	Long-finned Squid	MAFMC
Spisula solidissima	Surf Clam	MAFMC

Table 3-4. Scientific and common names of the fish species documented on shoal and ridge/trough complexes in the North and Mid-Atlantic (data from Diaz et al. 2003, Martino and Able 2003, Able et al. 2006, Diaz et al. 2006, Vasslides 2007, Vasslides and Able 2008a, CSA International Inc. et al. 2010, Slacum et al. 2010).

Scientific Name	Common Name	Scientific Name	Common Name
Abudefduf saxatilis	Sergeant Major	*Gadus morhua*	Atlantic Cod
Acipenser oxyrhynchus	Atlantic Sturgeon	*Gasterosteus aculeatus*	Threespine Stickleback
Alopias vulpinus	Thresher Shark	*Glyptocephalus cynoglossus*	Witch Flounder
Alosa aestivalis	Blueback Herring	*Gobiosoma bosc*	Naked Goby
Alosa mediocris	Hickory Shad	*Gobiosoma ginsburgi*	Seaboard Goby
Alosa pseudoharengus	Alewife	*Gymnura altavela*	Spiny Butterfly Ray
Alosa sapidissima	American Shad	*Gymnura micrura*	Smooth Butterfly Ray
Ammodytes spp.	Sand Lance species	*Hemitripterus americanus*	Sea Raven
Anchoa hepsetus	Striped Anchovy	*Hippocampus erectus*	Lined Seahorse
Anchoa mitchilli	Bay Anchovy	*Hypsoblennius hentz*	Feather Blenny
Apeltes quadracus	Fourspine Stickleback	*Lagodon rhomboides*	Pinfish
Astroscopus guttatus	Northern Stargazer	*Larimus fasciatus*	Banded Drum
Bairdiella chrysoura	Silver Perch	*Leiostomus xanthurus*	Spot
Brevoortia tyrannus	Atlantic Menhaden	*Leucoraja ocellata*	Winter Skate
Caranx crysos	Blue Runner	*Limanda ferruginea*	Yellowtail Flounder
Carcharhinus obscurus	Dusky Shark	*Liparis inquilinus*	Inquiline Snailfish
Carcharhinus plumbeus	Sandbar Shark	*Lophius americanus*	Goosefish
Centropristis striatus	Black Sea Bass	*Lumpenus lampretaeformis*	Snakeblenny
Chilomycterus schoepfi	Striped Burrfish	*Melanogrammus aeglefinus*	Haddock
Citharichthys spilopterus	Bay Whiff	*Menidia beryllina*	Inland Silverside
Clupea harengus	Atlantic Herring	*Menidia menidia*	Atlantic Silverside
Conger oceanicus	Conger Eel	*Menticirrhus saxatilis*	Northern Kingfish
Cynoscion regalis	Weakfish	*Merluccius bilinearis*	Silver Hake
Dasyatis centroura	Roughtail Stingray	*Micropogonias undulatus*	Atlantic Croaker
Dasyatis say	Bluntnose Stingray	*Monacanthus hispidus*	Planehead Filefish
Decapterus punctatus	Round Scad	*Morone americana*	White Bass
Dipturus laevis	Barndoor Skate	*Morone saxatilis*	Striped Bass
Enchelyopus cimbrius	Fourbeard Rockling	*Mugil curema*	White Mullet
Engraulis eurystole	Silver Anchovy	*Mustelus canis*	Smooth Dogfish
Etropus microstomus	Smallmouth Flounder	*Mycteroperca microlepis*	Gag
Etrumeus teres	Round Herring	*Myliobatis freminvillei*	Bullnose Ray
Fistularia tabacaria	Bluespotted Cornetfish	*Myoxocephalus aenaeus*	Grubby

Scientific Name	Common Name	Scientific Name	Common Name
Myoxocephalus octodecemspinosus	Longhorn Sculpin	*Scomber scombrus*	Atlantic Mackerel
Ophidion marginatum	Striped Cusk-eel	*Scomberomorus maculatus*	Spanish Mackerel
Opsanus tau	Oyster Toadfish	*Scophthalmus aquosos*	Windowpane
Paralichthys dentatus	Summer Flounder	*Selene setapinnis*	Atlantic Moonfish
Paralichthys oblongus	Fourspot Flounder	*Seriola zonata*	Banded Rudderfish
Peprilus paru	Harvestfish	*Sphoeroides maculatus*	Northern Puffer
Peprilus triacanthus	Butterfish	*Sphyraena borealis*	Northern Sennet
Pholis gunnellus	Rock Gunnel	*Squalus acanthias*	Spiny Dogfish
Pogonias cromis	Black Drum	*Squatina dumeril*	Atlantic Angel Shark
Pollachius virens	Pollock	*Stenotomus chrysops*	Scup
Pomatomus saltatrix	Bluefish	*Syngnathus fuscus*	Northern Pipefish
Prionotus carolinus	Northern Searobin	*Synodus foetens*	Inshore Lizardfish
Prionotus evolans	Striped Searobin	*Tautoga onitis*	Tautog
Pristigenys alta	Short Bigeye	*Tautolabrus adspersus*	Cunner
Pseudopleuronectes americanus	Winter Flounder	*Trachinocephalus myops*	Snakefish
Pseudupeneus maculatus	Spotted Goatfish	*Trichiurus lepturus*	Atlantic Cutlassfish
Rachycentron canadum	Cobia	*Trinectes maculatus*	Hogchoker
Raja eglanteria	Clearnose Skate	*Urophycis chuss*	Red Hake
Raja erinacea	Little Skate	*Urophycis regia*	Spotted Hake
Rhinoptera bonasus	Cownose Ray	*Urophycis tenuis*	White Hake
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark	*Zoarces americanus*	Ocean Pout
Sarda sarda	Atlantic Bonito		

Table 3-5. Scientific and common names of the fish species documented on shoal and ridge/trough complexes in the South Atlantic and Florida Straits (data from Zarillo et al. 2009 and Gilmore 2008).

Scientific Name	Common Name	Scientific Name	Common Name
Ablennes hians	Flat Needlefish	*Canthidermis maculatus*	Rough Triggerfish
Acanthocybium solanderi	Wahoo	*Canthidermis sufflamen*	Ocean Triggerfish
Achirus lineatus	Lined Sole	*Canthigaster rostrata*	Sharpnose Puffer
Ahlia egmontis	Key Worm Eel	*Caranx bartholomaei*	Yellow Jack
Aluterus heudeloti	Dotterel Filefish	*Caranx crysos*	Blue Runner
Aluterus monoceros	Unicorn Filefish	*Caranx hippos*	Crevalle Jack
Aluterus schoepfi	Orange Filefish	*Caranx latus*	Horse-Eye Jack
Aluterus scriptus	Scrawled Filefish	*Caranx ruber*	Bar Jack
Anchoa cubana	Cuban Anchovy	*Carcharhinus acronotus*	Blacknose Shark
Anchoa hepsetus	Striped Anchovy	*Carcharhinus altimus*	Bignose Shark
Anchoa lamprotaenia	Bigeye Anchovy	*Carcharhinus brevipinna*	Spinner Shark
Anchoa lyolepis	Dusky Anchovy	*Carcharhinus isodon*	Finetooth Shark
Anchoa mitchilli	Bay Anchovy	*Carcharhinus leucas*	Bull Shark
Anchoviella perfasciata	Flat Anchovy	*Carcharhinus limbatus*	Blacktip Shark
Anclopsetta dilecta	Three-eye Flounder	*Carcharhinus obscurus*	Dusky Shark
Anclopsetta quadrocellata	Ocellated Flounder	*Carcharhinus plumbeus*	Sandbar Shark
Astroscopus y-graecum	Southern Stargazer	*Centropristis ocyurus*	Bank Sea Bass
Balistes capriscus	Gray Triggerfish	*Centropristis philadelphica*	Rock Sea Bass
Balistes vetula	Queen Triggerfish	*Chaetodipterus faber*	Atlantic Spadefish
Bellator brachychir	Shortfin Searobin	*Chilomycterus antennatus*	Bridled Burrfish
Bellator egreta	Streamer Searobin	*Chilomycterusatinga*	Spotted Burrfish
Bellator militaris	Horned Searobin	*Chilomycterusschoepfi*	Striped Burrfish
Bembrops anatirostris	Duckbill Flathead	*Chloroscombrus chrysurus*	Atlantic Bumper
Bembrops gobioides	Goby Flathead	*Citharichthys arctifrons*	Gulf Stream Flounder
Bothus ocellatus	Eyed Flounder	*Citharichthys arenaceus*	Sand Whiff
Bothus robinsi	Robins Flounder	*Citharichthys cornutus*	Horned Whiff
Bregmaceros houdei	Stellate Codlet	*Citharichthys gymnorhinus*	Unicorn Whiff
Brevoortia smithi	Yellowfin Menhaden	*Citharichthys macrops*	Spotted Whiff
Brevoortia tyrannus	Atlantic Menhaden	*Citharichthys spilopterus*	Bay Whiff
Calamus spp.	Porgy (juvenile)	*Coryphaena hippurus*	Dolphin
Cantherhines macrocerus	Whitespotted Filefish	*Cyclopsetta chittendeni*	Mexican Flounder
Cantherhines pullus	Orangespotted Filefish	*Cyclopsetta fimbriata*	Spotfin Flounder

Scientific Name	Common Name	Scientific Name	Common Name
Cynoscion nothus	Silver Seatrout	*Hemiramphus balao*	Balao
Dactyloscopus tridigitatus	Sand Stargazer	*Hemiramphus basiliensis*	Ballyhoo
Dasyatis americana	Southern Stingray	*Hippocampus erectus*	Lined Seahorse
Dasyatis centroura	Roughtail Stingray	*Hyporhamphus meeki*	Halfbeak
Dasyatis sayi	Bluntnose Stingray	*Hyporhamphus unifasciatus*	Silverstripe Halfbeak
Decapterus macarellus	Mackeral Scad	*Ioglossus calliurus*	Blue Goby
Decapterus punctatus	Round Scad	*Istiophorus platypterus*	Sailfish
Decapterus tabl	Redtail Scad	*Jenkinsia lamprotaenia*	Dwarf Herring
Diodon histrix	Porcupinefish	*Kathetostoma albigutta*	Lancer Stargazer
Diodon holacanthus	Balloonfish	*Lactophrys polygonia*	Honeycomb Cowfish
Diplectrum bivittatum	Dwarf Sand Perch	*Lactophrys quadricornis*	Scrawled Cowfish
Diplectrum formosum	Sand Perch	*Lactophrys trigonus*	Trunkfish
Elagatis bipinnulatus	Rainbow Runner	*Lactophrys triqueter*	Smooth Trunkfish
Elops saurus	Ladyfish	*Lagocephalus laevigatus*	Smooth Puffer
Engraulis eurystole	Silver Anchovy	*Lagodon rhomboides*	Pinfish
Engyophrys senta	Spiny Flounder	*Larimus fasciatus*	Banded Drum
Equetus lanceolatus	Jack-Knifefish	*Leiostomus xanthurus*	Spot
Etropus crossotus	Fringed Flounder	*Lepophidium brevibarbe*	Shortbeard Cusk-eel
Etropuscyclosquamus	Shelf Flounder	*Letharchus velifer*	American Sailfin Eel
Etropusmicrostomus	Smallmouth Flounder	*Menticirrhus americanus*	Southern Kingfish
Etropusrimosus	Gray Flounder	*Microdesmidae*	Wormfish
Etrumeus teres	Round Herring	*Microgobius carri*	Seminole Goby
Euleptorhamphus velox	Flying Halfbeak	*Micropogonias undulatus*	Atlantic Croaker
Euleptorhamphus viridis	Ribbon Halfbeak	*Mobula hypostoma*	Devil Ray
Euthynnus alletteratus	Little Tunny	*Mola lanceolata*	Sharptail Sunfish
Gastropsetta frontalis	Shrimp Flounder	*Mola mola*	Oceanfish Sunfish
Gerreidae	Mojarra	*Monacanthus ciliatus*	Fringed Filefish
Gnatholepis egregius	Freckled Stargazer	*Monacanthushispidus*	Planehead Filefish
Gymnachirus melas	Naked Sole	*Monacanthussetifer*	Pygmy Filefish
Gymnothorax saxicola	Honeycomb Moray	*Monacanthustuckeri*	Slender Filefish
Gymnura micrura	Smooth Butterfly Ray	*Monolene antillarum*	Slim Flounder
Haemulon spp.	Grunt (juvenile)	*Monolene sessilicauda*	Deepwater Flounder
Harengula clupeola	False Pilchard	*Morone saxatilis*	Striped Bass
Harengula humeralis	Redear Sardine	*Mustelus canis*	Smooth Dogfish
Harengula jaguana	Scaled Sardine	*Mustelus norrisi*	Florida Smoothhound
Hemicaranx amblyrhynchus	Bluntnose Jack	*Nes longus*	Orangespotted Goby

Scientific Name	Common Name	Scientific Name	Common Name
Oligoplites saurus	Leather Jacket	*Scomberomorus regalis*	Cero
Ophidion grayi	Blotched Cusk-eel	*Scophthalmus aquosus*	Windowpane
Ophidion holbrookii	Band Cusk-eel	*Selar crumenopthalmus*	Bigeye Scad
Ophidion marginatum	Striped Cusk-eel	*Selene setapinnis*	Atlantic Moonfish
Ophidion selenops	Mooneye Cusk-eel	*Sphoeroides maculatus*	Northern Puffer
Opisthonema oglinum	Atlantic Thread Herring	*Sphoeroides nephelus*	Southern Puffer
Oxyurichthys stigmalophius	Spotfin Goby	*Sphoeroides pachygaster*	Blunthead Puffer
Parablennius marmoreus	Seaweed Blenny	*Sphoeroides spengleri*	Bandtail Puffer
Paralichthys albigutta	Gulf Flounder	*Sphoeroides testudineus*	Checkered Puffer
Paralichthysdentatus	Summer Flounder	*Sphreaena picudilla*	Southern Sennet
Paralichthyslethostigma	Southern Flounder	*Sphyrn mokarran*	Great Hammerhead
Paralichthysoblongus	Fourspot Flounder	*Sphyrn tiburo*	Bonnethead
Paralichthyssquamilentus	Broad Flounder	*Sphyrna lewini*	Scalloped Hammerhead
Peprilus paru	American Harvestfish	*Squatina dumerili*	Atlantic angel Shark
Platybelone argalus	Keeltail Needlefish	*Stephanolepis hispidus*	Planehead Filefish
Poecilopsetta beani	Stripedfin Flounder	*Strongylura timucu*	Timucu
Pomatomus saltatrix	Bluefish	*Syacium gunteri*	Shoal Flounder
Pontinus longispinis	Longspine Scorpionfish	*Syacium micrurum*	Channel Flounder
Pontinus rathbuni	Highfin Scorpionfish	*Syacium papillosum*	Dusky Flounder
Prionace glauca	Blue Shark	*Symphurus civitatus*	Offshore Tonguefish
Prionotus alatus	Spiny Searobin	*Symphurusdiomedianus*	Spottedfin Tonguefish
Prionotus carolinus	Northern Searobin	*Symphurusminor*	Largescale Tonguefish
Prionotus evolans	Striped Searobin	*Symphurusnebulosus*	Freckled Tonguefish
Prionotus martis	Barred Searobin	*Symphurusparvus*	Pygmy Tonguefish
Prionotus ophryas	Bandtail Searobin	*Symphurusplagiusa*	Blackcheek Tonguefish
Prionotus roseus	Bluespotted Searobin	*Symphurus urospilus*	Spottail Tonguefish
Prionotus rubio	Blackwing Searobin	*Syngnathus springeri*	Bull Pipefish
Prionotus scitulus	Leopard Searobin	*Synodus foetens*	Inshore Lizardfish
Prionotus stearnsi	Shortwing Searobin	*Tarpon atlanticus*	Tarpon
Prionotus tribulus	Bighead Searobin	*Trachinotus carolinus*	Florida Pompano
Pristis pectinata	Smalltooth Sawfish	*Trachinotus falcatus*	Permit
Rachycentron canadum	Cobia	*Trachinotus goodei*	Palometa
Raja eglanteria	Clearnose Skate	*Trachurus lathami*	Rough Scad
Raja garmani	Rosette Skate	*Trichiurus lepturus*	Atlantic Cutlassfish
Raja texana	Roundel Skate	*Tylosurus acus*	Agujon
Rhinobatos lentiginosus	Atlantic Guitarfish	*Tylosurus crocodilus*	Houndfish
Rhizoprinodon terraenovae	Atlantic sharpnose Shark	*Uraspis secunda*	Cottonmouth Jack
Sardinella aurita	Spanish Sardine	*Varicus marilynae*	Orangebelly Goby
Scomberomorus cavalla	King Mackerel	*Xanthichthys ringens*	Sargassum Triggerfish
Scomberomorus maculatus	Spanish Mackerel		

Table 3-6. Scientific names, common names and relative abundance of the fish species documented on shoal and ridge/trough complex habitats along the east Florida continental shelf. Relative abundance is denoted by: A = Abundant, C = Common, O= Occasional, R = Rare, and X = documented but the relative abundance is unknown (data from Gilmore 2008).

Scientific Name	Common Name	Relative Abundance
Ablennes hians	Flat Needlefish	C
Acanthocybium solanderi	Wahoo	O
Achirus lineatus	Lined Sole	X
Aluterus heudeloti	Dotterel Filefish	R
Aluterus monoceros	Unicorn Filefish	O
Aluterus schoepfi	Orange Filefish	O
Aluterus scriptus	Scrawled Filefish	O
Anchoa cubana	Cuban Anchovy	A
Anchoa hepsetus	Striped Anchovy	O
Anchoa lamprotaenia	Bigeye Anchovy	O
Anchoa lyolepis	Dusky Anchovy	A
Anchoa mitchilli	Bay Anchovy	A
Anchoviella perfasciata	Flat Anchovy	O
Anclopsetta dilecta	Three-eye Flounder	X
Anclopsetta quadrocellata	Ocellated Flounder	X
Astroscopus y-graecum	Southern Stargazer	X
Balistes capriscus	Gray Triggerfish	C
Balistes vetula	Queen Triggerfish	R
Bellator brachychir	Shortfin Searobin	X
Bellator egreta	Streamer Searobin	X
Bellator militaris	Horned Searobin	X
Bembrops anatirostris	Duckbill Flathead	X
Bembrops gobioides	Goby Flathead	X
Bothus ocellatus	Eyed Flounder	X
Bothus robinsi	Robins Flounder	X

Scientific Name	Common Name	Relative Abundance
Brevoortia smithi	Yellowfin Menhaden	A
Brevoortia tyrannus	Atlantic Menhaden	A
Cantherhines pullus	Orangespotted Filefish	O
Canthidermis maculatus	Rough Triggerfish	R
Canthidermis sufflamen	Ocean Triggerfish	C
Canthigaster rostrata	Sharpnose Puffer	O
Caranx bartholomaei	Yellow Jack	O
Caranx crysos	Blue Runner	O
Caranx hippos	Crevalle Jack	C
Caranx latus	Horse-eye Jack	C
Caranx ruber	Bar Jack	C
Carcharhinus acronotus	Blacknose Shark	C
Carcharhinus altimus	Bignose Shark	O
Carcharhinus brevipinna	Spinner Shark	A
Carcharhinus isodon	Finetooth Shark	C
Carcharhinus leucas	Bull Shark	C
Carcharhinus limbatus	Blacktip Shark	A
Carcharhinus obscurus	Dusky Shark	O
Carcharhinus plumbeus	Sandbar Shark	A
Centropristis ocyurus	Bank Sea Bass	X
Centropristis philadelphica	Rock Sea Bass	X
Chilomycterus antennatus	Bridled Burrfish	R
Chilomycterus atinga	Spotted Burrfish	R
Chilomycterus schoepfi	Striped Burrfish	O
Chloroscombrus chrysurus	Atlantic Bumper	A

Scientific Name	Common Name	Relative Abundance
Citharichthys arctifrons	Gulf Stream Flounder	X
Citharichthys arenaceus	Sand	X
Citharichthys cornutus	Horned Whiff	X
Citharichthys gymnorhinus	Unicorn Whiff	X
Citharichthys macrops	Spotted Whiff	X
Citharichthys spilopterus	Bay Whiff	X
Coryphaena hippurus	Dolphin	C
Cyclopsetta chittendeni	Mexican Flounder	X
Cyclopsetta fimbriata	Spotfin Flounder	X
Dasyatis americana	Southern Stingray	C
Dasyatis centroura	Roughtail Stingray	C
Dasyatis sayi	Bluntnose Stingray	C
Decapterus macarellus	Mackeral Scad	A
Decapterus punctatus	Round Scad	A
Decapterus tabl	Redtail Scad	X
Diodon histrix	Porcupinefish	O
Diodon holacanthus	Balloonfish	O
Diplectrum bivittatum	Dwarf Sand Perch	A
Diplectrum formosum	Sand Perch	A
Elagatis bipinnulatus	Rainbow Runner	R
Elops saurus	Ladyfish	O
Engraulis eurystole	Silver Anchovy	O
Engyophrys senta	Spiny Flounder	X
Etropus crossotus	Fringed Flounder	X
Etropus cyclosquamus	Shelf Flounder	X
Etropus microstomus	Smallmouth Flounder	X
Etropus rimosus	Gray Flounder	X
Etrumeus teres	Round Herring	R

Scientific Name	Common Name	Relative Abundance
Euleptorhamphus velox	Flying Halfbeak	C
Euleptorhamphus viridis	Ribbon Halfbeak	X
Euthynnus alletteratus	Little Tunny	C
Gastropsetta frontalis	Shrimp Flounder	X
Gnatholepis egregius	Freckled Stargazer	X
Gymnachirus melas	Naked Sole	X
Gymnothorax saxicola	Honeycomb Moray	A
Gymnura micrura	Smooth Butterfly Ray	C
Harengula clupeola	False pilchard	R
Harengula humeralis	Redear Sardine	A
Harengula jaguana	Scaled Sardine	A
Hemicaranx amblyrhynchus	Bluntnose Jack	R
Hemiramphus balao	Balao	A
Hemiramphus basiliensis	Ballyhoo	A
Hyporhamphus meeki	Halfbeak	A
Hyporhamphus unifasciatus	Silverstripe Halfbeak	R
Ioglossus calliurus	Blue Goby	X
Istiophorus platypterus	Sailfish	O
Jenkinsia sp	Dwarf Herring	R
Kathetostoma albigutta	Lancer Stargazer	X
Lactophrys polygonia	Honeycomb Cowfish	O
Lactophrys quadricornis	Scrawled Cowfish	O
Lactophrys trigonus	Trunkfish	O
Lactophrys triqueter	Smooth Trunkfish	O
Lagocephalus laevigatus	Smooth Puffer	R
Microgobius carri	Seminole Goby	C
Mobula hypostoma	Devil Ray	C

Scientific Name	Common Name	Relative Abundance
Mola lanceolata	Sharptail Sunfish	R
Mola mola	Oceanfish Sunfish	O
Monacanthus ciliatus	Fringed Filefish	O
Monacanthus hispidus	Planehead Filefish	C
Monacanthus setifer	Pygmy Filefish	O
Monacanthus tuckeri	Slender Filefish	O
Monolene antillarum	Slim Flounder	X
Monolene sessilicauda	Deepwater Flounder	X
Morone saxatilis	Striped Bass	R
Mustelus canis	Smooth Dogfish	R
Mustelus norrisi	Florida Smoothhound	R
Nes longus	Orangespotted Goby	X
Oligoplites saurus	Leather Jacket	X
Opisthonema oglinum	Atlantic Thread Herring	A
Oxyurichthys stigmalophius	Spotfin Goby	X
Paralichthys albigutta	Gulf Flounder	X
Paralichthys dentatus	Summer Flounder	X
Paralichthys lethostigma	Southern Flounder	X
Paralichthys oblongus	Fourspot Flounder	X
Paralichthys squamilentus	Broad Flounder	X
Platybelone argalus	Keeltail Needlefish	C
Poecilopsetta beani	Stripedfin Flounder	X
Pomatomus saltatrix	Bluefish	C
Pontinus longispinis	Longspine Scorpionfish	X
Pontinus rathbuni	Highfin Scorpionfish	X
Prionace glauca	Blue Shark	X
Prionotus alatus	Spiny Searobin	X

Scientific Name	Common Name	Relative Abundance
Prionotus carolinus	Northern Searobin	X
Prionotus evolans	Striped Searobin	X
Prionotus martis	Barred Searobin	X
Prionotus ophryas	Bandtail Searobin	X
Prionotus roseus	Bluespotted Searobin	X
Prionotus rubio	Blackwing Searobin	X
Prionotus scitulus	Leopard Searobin	X
Prionotus stearnsi	Shortwing Searobin	X
Prionotus tribulus	Bighead Searobin	X
Pristis pectinata	Smalltooth Sawfish	R
Rachycentron canadum	Cobia	C
Raja eglanteria	Clearnose Skate	C
Raja garmani	Rosette Skate	O
Raja texana	Roundel Skate	O
Rhinobatos lentiginosus	Atlantic Guitarfish	C
Rhizoprinodon terraenovae	Atlantic Sharpnose Shark	A
Sardinella aurita	Spanish Sardine	A
Scomberomorus cavalla	King Mackerel	A
Scomberomorus maculatus	Spanish Mackerel	A
Scomberomorus regalis	Cero	O
Scophthalmus aquosus	Windowpane	X
Selar crumenopthalmus	Bigeye Scad	X
Sphoeroides maculatus	Northern Puffer	R
Sphoeroides nephelus	Southern Puffer	O
Sphoeroides pachygaster	Blunthead Puffer	R
Sphoeroides spengleri	Bandtail Puffer	C
Sphoeroides testudineus	Checkered Puffer	C

Scientific Name	Common Name	Relative Abundance
Sphyrn mokarran	Great Hammerhead	O
Sphyrn tiburo	Bonnethead	O
Sphyrna lewini	Scalloped Hammerhead	C
Squatina dumerili	Atlantic angel Shark	C
Strongylura timucu	Timucu	O
Syacium gunteri	Shoal Flounder	X
Syacium micrurum	Channel Flounder	X
Syacium papillosum	Dusky Flounder	X
Symphurus civitatus	Offshore Tonguefish	X
Symphurus diomedianus	Spottedfin Tonguefish	X
Symphurus minor	Largescale Tonguefish	X
Symphurus nebulosus	Freckled Tonguefish	X
Symphurus parvus	Pygmy Tonguefish	X

Scientific Name	Common Name	Relative Abundance
Symphurus plagiusa	Blackcheek Tonguefish	X
Symphurus urospilus	Spottail Tonguefish	X
Tarpon atlanticus	Tarpon	C
Trachinotus carolinus	Florida Pompano	C
Trachinotus falcatus	Permit	C
Trachinotus goodei	Palometa	C
Trachurus lathami	Rough Scad	X
Trichiurus lepturus	Atlantic Cutlassfish	C
Tylosurus acus	Agujon	C
Tylosurus crocodilus	Houndfish	C
Uraspis secunda	Cottonmouth Jack	R
Varicus marilynae	Orangebelly Goby	X
Xanthichthys ringens	Sargassum Triggerfish	O

Table 3-7. Scientific and common names of the fish species documented on shoal and ridge/trough complexes in the Gulf of Mexico (data from Zarillo et al. 2008, Byrnes et al. 1999, Brooks et al. 2005, Wells et al. 2009).

Scientific Name	Common Name	Scientific Name	Common Name
Acanthostracion polygonius	Honeycomb Cowfish	*Decapterus spp.*	Scad
Acanthostracion quadricornis	Scawled Cowfish	*Diodon spp.*	Porcupinefish
Achirus lineatus	Lined Sole	*Diplectrum bivittatum*	Dwarf Sand Perch
Aluterus monoceros	Unicorn Filefish	*Diplectrum formosum*	Sand Perch
Aluterus schoepfi	Orange Filefish	*Engraulis eurystole*	Silver Anchovy
Aluterus scriptus	Scrawled Filefish	*Engyophrys senta*	Spiny Flounder
Anchoa hepsetus	Striped Anchovy	*Epinephelus morio*	Red Grouper
Anchoa lyolepis	Dusky Anchovy	*Etropus crossotus*	Fringed Flounder
Ancylopsetta dilecta	Three-eye Flounder	*Etropus cyclosquamus*	Shelf Flounder
Ancylopsetta ommata	Gulf of Mexico Ocellated Flounder	*Etropus microstomus*	Smallmouth Flounder
Ancylopsetta quadrocellata	Ocellated Flounder	*Eucinostomus gula*	Silver Jenny
Antennarius radiosus	Singlespot Frogfish	*Eucinostomus harengulus*	Tidewater Mojarra
Archosargus probatocephalus	Sheepshead	*Gobionellus hastatus*	Sharptail Goby
Arius felis	Hardhead Catfish	*Gymnachirus texae*	Fringed Sole
Astroscopus y-graecum	Southern Stargazer	*Haemulon aurolineatum*	Tomtate
Bagre marinus	Gafftopsail Catfish	*Haemulon plumierii*	White Grunt
Bairdiella chrysoura	Silver Perch	*Halieutichthys aculeatus*	Pancake Batfish
Bothus robinsi	Twospot Flounder	*Hildebrandia flava*	Yellow Conger
Brotula barbata	Bearded Brotula	*Hippocampus erectus*	Lined Seahorse
Calamus proridens	Littlehead Porgy	*Hoplunnis macrurus*	Freckled Pike-conger
Centropristis philadelphica	Rock Seabass	*Hyporhamphus spp.*	Halfbeak
Chilomycterus schoepfi	Striped Burrfish	*Jenkinsia majua*	Little-eye Round Herring
Chloroscombrus chrysurus	Atlantic Bumper	*Lactophrys quadricornis*	Scrawled Cowfish
Citharichthys macrops	Spotted Whiff	*Lactophrys triqueter*	Smooth Trunkfish
Citharichthys spilopterus	Bay Whiff	*Lagocephalus laevigatus*	Smooth Puffer
Cyclopsetta chittendeni	Mexican Flounder	*Lagodon rhomboides*	Pinfish
Cynoscion arenarius	Sand Seatrout	*Larimus fasciatus*	Banded Drum
Cynoscion nothus	Silver Seatrout	*Leiostomus xanthurus*	Spot
Dasyatis americana	Southern Stingray	*Lepophidium brevibarbe*	Blackedge Cusk-eel
Dasyatis sayi	Bluntnose Stingray	*Lutjanus campechanus*	Red Snapper

Scientific Name	Common Name	Scientific Name	Common Name
Lutjanus griseus	Gray Snapper	*Prionotus rubio*	Blackwing Searobin
Lutjanus synagris	Lane Snapper	*Prionotus scitulus*	Leopard Searobin
Menticirrhus americanus	Southern Kingfish	*Prionotus tribulus*	Bighead Searobin
Menticirrhus littoralis	Gulf Kingfish	*Raja texana*	Roundel Skate
Menticirrhus saxatilis	Northern Kingfish	*Rhinoptera bonasus*	Cownose Ray
Micropogonias undulatus	Atlantic Croaker	*Rhizoprionodon terraenovae*	Atlantic Sharpnose Shark
Monacanthus ciliatus	Fringed Filefish	*Rypticus maculatus*	Whitespotted Soapfish
Monacanthus hispidus	Planehead Filefish	*Sardinella aurita*	Spanish Sardine
Mustelus canis	Smooth Dogfish	*Saurida brasiliensis*	Largescale Lizardfish
Mustelus norris	Florida Smoothound	*Sciaenops ocellata*	Red Drum
Nicholsina usta	Emerald Parrotfish	*Scorpaena brasiliensis*	Barbfish
Ogcocephalus corniger	Longnose Batfish	*Scorpaena calcarata*	Smoothead Scorpionfish
Ogcocephalus declivirostris	Slantbrow Batfish	*Scorpaena grandicornis*	Plumed Scorpionfish
Ogcocephalus nasutus	Shortnose Batfish	*Serraniculus pumilio*	Pygmy Seabass
Ogcocephalus pantostictus	Spotted Batfish	*Serranus atrobranchus*	Blackbear Seabass
Ogcocephalus parvus	Roughback Batfish	*Serranus phoebe*	Tattler
Ophichthus gomesii	Shrimp Eel	*Serranus subligarius*	Belted Sandfish
Ophidion antipholus	Longnose Cusk-eel	*Sphoeroides dorsalis*	Marbled Puffer
Ophidion grayi	Blotched Cusk-eel	*Sphoeroides nephelus*	Southern Puffer
Ophidion holbrooki	Bank Cusk-eel	*Sphoeroides parvus*	Least Puffer
Ophidion marginatum	Striped Cusk-eel	*Sphoeroides spengleri*	Bandtail Puffer
Ophidion selenops	Mooneye Cusk-eel	*Sphyrna tiburo*	Bonnethead
Ophidion welshi	Crested Cusk-eel	*Stellifer lanceolatus*	Star Drum
Opisthonema oglinum	Atlantic Thread Herring	*Stenotomus caprinus*	Longspine Porgy
Orthopristis chrysoptera	Pigfish	*Stephanolepis hispidus*	Planehead Filefish
ParaConger caudilimbatus	Margintail Conger	*Syacium gunteri*	Shoal Flounder
Paralichthys albigutta	Gulf Flounder	*Syacium papillosum*	Dusky Flounder
Paralichthys lethostigma	Southern Flounder	*Symphurus civitatus*	Offshore Tonguefish
Pareques acuminatus	High-hat	*Symphurus diomedianus*	Spotted Tonguefish
Pareques umbrosus	Cubbyu	*Symphurus plagiusa*	Blackcheek Tonguefish
Peprilus burti	Gulf Butterfish	*Syngnathus louisianae*	Chain Pipefish
Phaeoptyx pigmentaria	Dusky Carinalfish	*Synodus foetens*	Inshore Lizardfish
Pogonias cromis	Black Drum	*Synodus poeyi*	Offshore Lizardfish
Porichthys plectrodon	Atlantic Midshipman	*Trachurus lathami*	Rough Scad
Prionotus longispinosus	Bigeye Searobin	*Trichopsetta ventralis*	Sash Flounder
Prionotus martis	Gulf of Mexico Barred Searobin	*Trinectes maculatus*	Hogchoker
Prionotus ophryas	Bandtail Searobin	*Upeneus parvus*	Dwarf Goatfish
Prionotus roseus	Bluespotted Searobin	*Urophycis floridana*	Southern Hake

Table 3-8. Scientific names, common names and catch frequency of the fish species documented on Heald Bank, Sabine Bank, Trinity Shoal, and Tiger Shoal ("*" denotes commercial species). Catch frequency is denoted by: F = Frequently caught, C = Commonly caught, R = Rarely caught, "—" = Never caught (data from Brook et al. 2005).

Scientific Name	Common Name	Heald Bank	Sabine Bank	Trinity Shoal	Tiger Shoal
Achirus lineatus	Lined Sole	—	—	R	R
Aluterus monoceros	Unicorn Filefish	R	—	—	—
Aluterus schoepfi	Orange Filefish	—	R	—	—
Aluterus scriptus	Scrawled Filefish	—	R	R	—
Ancylopsetta dilecta	Three-eye Flounder	R	—	—	—
Ancylopsetta quadrocellata	Ocellated Flounder	R	R	R	—
Arius felis	Hardhead Catfish	F	C	C	C
Astroscopus y-graecum	Southern Stargazer	—	R	R	R
Bagre marinus	Gafftopsail catfish	—	—	C	C
Bairdiella chrysoura	Silver Perch	—	R	—	—
Brotula barbata	Bearded Brotula	R	—	R	—
Centropristis philadelphica	Rock Seabass	C	C	C	R
Chilomycterus schoepfi	Striped Burrfish	R	R	R	R
Citharichthys macrops	Spotted Whiff	R	—	R	—
Citharichthys spilopterus	Bay Whiff	R	R	R	C
Cyclopsetta chittendeni	Mexican Flounder	—	R	R	—
Cynoscion arenarius	Sand Seatrout	C	C	C	F
Cynoscion nothus	Silver Seatrout	C	C	C	C
Dasyatis americana	Southern Stingray	—	R	R	—
Dasyatis sayi	Bluntnose Stingray	—	—	R	—
Diplectrum bivittatum *	Dwarf Sand Perch	C	R	R	—
Diplectrum formosum *	Sand Perch	R	R	—	—
Engyophrys senta	Spiny Flounder	R	R	—	—
Etropus crossotus	Fringed Flounder	C	C	—	C
Etropus cyclosquamus	Shelf Flounder	—	—	R	—
Etropus microstomus	Smallmouth Flounder	R	R	—	—
Eucinostomus gula	Silver Jenny	C	R	R	—
Gobionellus hastatus	Sharptail Goby	—	—	R	R
Gymnachirus texae	Fringed Sole	R	—	—	—
Halieutichthys aculeatus	Pancake Batfish	R	R	R	—
Hildebrandia flava	Yellow Conger	—	—	R	—
Hoplunnis macrurus	Freckled Pike-conger	R	—	—	—
Lactophrys quadricornis	Scrawled Cowfish	R	R	—	—
Lactophrys triqueter	Smooth Trunkfish	R	—	—	—
Lagocephalus laevigatus	Smooth Puffer	C	R	R	R

Scientific Name	Common Name	Heald Bank	Sabine Bank	Trinity Shoal	Tiger Shoal
Lagodon rhomboides	Pinfish	C	R	R	R
Larimus fasciatus	Banded Drum	R	C	R	R
Leiostomus xanthurus	Spot	C	C	C	C
Lepophidium brevibarbe	Blackedge Cusk-eel	C	R	R	R
Lutjanus campechanus *	Red Snapper	F	C	R	—
Lutjanus synagris *	Lane Snapper	C	R	R	R
Menticirrhus americanus	Southern Kingfish	C	R	C	R
Menticirrhus littoralis	Gulf Kingfish	—	R	R	—
Menticirrhus saxatilis	Northern Kingfish	—	R	—	—
Micropogonias undulatus	Atlantic Croaker	F	C	F	F
Monacanthus hispidus	Planehead Filefish	C	R	R	R
Mustelus canis	Smooth Dogfish	—	—	R	—
Mustelus norris	Florida Smoothound	R	—	—	—
Ogcocephalus corniger	Longnose Batfish	R	—	—	—
Ogcocephalus declivirostris	Slantbrow Batfish	R	—	—	—
Ogcocephalus nasutus	Shortnose Batfish	R	R	—	—
Ogcocephalus pantostictus	Spotted Batfish	R	—	—	—
Ogcocephalus parvus	Roughback Batfish	R	—	R	—
Ophichthus gomesii	Shrimp Eel	—	—	—	R
Ophidion grayi	Blotched Cusk-eel	R	R	R	—
Ophidion holbrooki	Bank Cusk-eel	—	R	R	—
Ophidion welshi	Crested Cusk-eel	R	R	R	R
Orthopristis chrysoptera	Pigfish	C	C	R	—
Paraconger caudilimbatus	Margintail Conger	—	—	R	—
Paralichthys albigutta	Gulf Flounder	—	R	—	—
Paralichthys lethostigma	Southern Flounder	R	R	R	R
Pogonias cromis	Black Drum	—	R	R	R
Porichthys plectrodon	Atlantic Midshipman	C	R	C	C
Prionotus longispinosus	Bigeye Searobin	C	R	C	R
Prionotus ophryas	Bandtail Searobin	R	R	R	—
Prionotus roseus	Bluespotted Searobin	R	—	—	—
Prionotus rubio	Blackwing Searobin	C	R	R	R
Prionotus scitulus	Leopard Searobin	R	R	R	—
Prionotus tribulus	Bighead Searobin	C	C	R	R
Raja texana	Roundel Skate	—	R	R	—
Rhinoptera bonasus	Cownose Ray	R	R	R	—
Rhizoprionodon terraenovae	Atlantic Sharpnose Shark	R	R	R	R
Rypticus maculatus	Whitespotted Soapfish	R	—	—	—
Saurida brasiliensis	Largescale Lizardfish	R	R	R	R

Scientific Name	**Common Name**	**Heald Bank**	**Sabine Bank**	**Trinity Shoal**	**Tiger Shoal**
Sciaenops ocellata *	Red Drum	—	R	R	—
Scorpaena brasiliensis	Barbfish	—	R	—	—
Scorpaena calcarata	Smoothead Scorpionfish	R	R	R	—
Serraniculus pumilio	Pygmy Sea Bass	R	R	—	—
Serranus atrobranchus	Blackbear Sea Bass	R	—	—	—
Serranus phoebe	Tattler	—	R	—	—
Sphoeroides dorsalis	Marbled Puffer	—	—	R	—
Sphoeroides nephelus	Southern Puffer	—	—	R	R
Sphoeroides parvus	Least Puffer	C	C	C	C
Sphoeroides spengleri	Bandtail Puffer	—	—	R	—
Sphyrna tiburo *	Bonnethead	R	R	R	—
Stellifer lanceolatus	Star Drum	R	C	R	C
Stenotomus caprinus	Longspine Porgy	F	R	C	—
Syacium gunteri	Shoal Flounder	C	R	R	R
Syacium papillosum	Dusky Flounder	R	R	R	—
Symphurus civitatus	Offshore Tonguefish	—	R	R	R
Symphurus diomedianus	Spotted Tonguefish	R	—	—	—
Symphurus plagiusa	Blackcheek Tonguefish	R	C	R	C
Synodus foetens	Inshore Lizardfish	C	R	R	R
Synodus poeyi	Offshore Lizardfish	—	R	—	—
Trichopsetta ventralis	Sash Flounder	—	—	R	—
Trinectes maculatus	Hogchoker	—	R	R	R
Upeneus parvus	Dwarf Goatfish	R	—	R	—

Table 3-9. Scientific names of the fish species documented in shoal and ridge/trough complexes over large geographic ranges. "X" denotes present in that region.

Species	Mid-Atlantic	Eastern coast of Florida	Gulf of Mexico
Achirus lineatus		X	X
Aluterus monoceros		X	X
Aluterus schoepfi		X	X
Aluterus scriptus		X	X
Anchoa hepsetus	X	X	X
Anchoa lyolepis		X	X
Anchoa mitchilli	X	X	
Anclopsetta dilecta		X	X
Anclopsetta quadrocellata		X	X
Astroscopus y-graecum		X	X
Bairdiella chrysoura	X		X
Bothus robinsi		X	X
Brevoortia tyrannus	X	X	
Caranx crysos	X	X	
Carcharhinus obscurus	X	X	
Carcharhinus plumbeus	X	X	
Centropristis philadelphica		X	X
Chilomycterus schoepfi	X	X	X
Chloroscombrus chrysurus		X	X
Citharichthys macrops		X	X
Citharichthys spilopterus	X	X	X
Cyclopsetta chittendeni		X	X
Cynoscion nothus		X	X
Dasyatis americana		X	X
Dasyatis centroura	X	X	
Dasyatis sayi	X	X	X
Decapterus punctatus	X	X	
Diplectrum bivittatum		X	X
Diplectrum formosum		X	X
Engraulis eurystole	X	X	X
Engyophrys senta		X	X
Etropus crossotus		X	X
Etropus cyclosquamus		X	X
Etropus microstomus	X	X	X
Etrumeus teres	X	X	
Gymnura micrura	X	X	
Hippocampus erectus	X	X	X
Lactophrys quadricornis		X	X
Lactophrys triqueter		X	X
Lagocephalus laevigatus		X	X

Species	**Mid-Atlantic**	**Eastern coast of Florida**	**Gulf of Mexico**
Lagodon rhomboides	X	X	X
Larimus fasciatus	X	X	X
Leiostomus xanthurus	X	X	X
Lepophidium brevibarbe		X	X
Menticirrhus americanus		X	X
Menticirrhus saxatilis	X		X
Micropogonias undulatus	X	X	X
Monacanthus ciliatus		X	X
Monacanthus hispidus	X	X	X
Morone saxatilis	X	X	
Mustelus canis	X	X	X
Mustelus norrisi		X	X
Ophidion grayi		X	X
Ophidion holbrookii		X	X
Ophidion marginatum	X	X	X
Ophidion selenops		X	X
Opisthonema oglinum		X	X
Paralichthys albigutta		X	X
Paralichthys dentatus	X	X	
Paralichthys lethostigma		X	X
Paralichthys oblongus	X	X	
Peprilus paru	X	X	
Pomatomus saltatrix	X	X	
Prionotus carolinus	X	X	
Prionotus evolans	X	X	
Prionotus martis		X	X
Prionotus ophryas		X	X
Prionotus roseus		X	X
Prionotus rubio		X	X
Prionotus scitulus		X	X
Prionotus tribulus		X	X
Rachycentron canadum	X	X	
Raja eglanteria	X	X	
Raja texana		X	X
Rhinoptera bonasus	X		X
Rhizoprinodon terraenovae	X	X	X
Scomberomorus maculatus	X	X	
Scophthalmus aquosus	X	X	
Sphoeroides maculatus	X	X	
Sphoeroides nephelus		X	X
Sphoeroides spengleri		X	X
Squatina dumerili	X	X	
Stephanolepis hispidus		X	X

Species	Mid-Atlantic	Eastern coast of Florida	Gulf of Mexico
Syacium gunteri		X	X
Syacium papillosum		X	X
Symphurus civitatus		X	X
Symphurus diomedianus		X	X
Symphurus plagiusa		X	X
Synodus foetens	X	X	X
Trachurus lathami		X	X
Trichiurus lepturus	X	X	

Appendix A: Glossary

Bank –A submerged mound-like or ridge-like deposit of sand, gravel, or other sediment forming an elevated area on the sea floor of modest to substantial extent.

Bar – Various elongated offshore ridge, bank, or mound of sand, gravel, or other unconsolidated material submerged at least at high tide, and built up by the action of waves and currents on the water bottom, especially at the mouth of a river or estuary, or at a short distance from the beach.

Barrier island – A long, narrow, sandy coastal island, representing a broadened barrier beach that is above high tide and parallel to the shore, and that commonly has dunes and marshy terranes extending landward from the beach.

Bedform – A surface feature that is an individual element of the morphology of a mobile granular or cohesive bed that develops due to local deposition and/or erosion caused by interactions with the water current. Bedforms range from flat, near featureless surfaces to complex forms covering a wide range of sizes that are characterized by topographic highs and lows of varying form and structure.

Biogenic structures – A term used to describe the structures produced by living organisms including tubes, burrows, shell beds, or depressions.

Connectivity – The degree the seascape facilitates or impedes movement among resource patches.

Continental margin – The ocean floor that is between the shoreline and the abyssal ocean floor.

Continental shelf – Part of the continental margin between the shoreline and the continental slope (or a depth of 200 m if there is no noticeable continental slope); characterized by its gentle slope of 0.1°.

Delta – The low, nearly flat, alluvial tract of land at or near the mouth of a river, forming a triangular or fan-shaped plain, crossed by many distributaries of the main river, extending beyond the general trend of the coast, and resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, and currents.

Demersal fish – A term used for species of fish that live on or near the sea bottom for at least part of their life cycle, as known as groundfish.

Essential Fish Habitat (EFH) – The waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity. Where ‘‘waters’’ include aquatic areas and their associated physical, chemical, and biological properties that are used by fish; and ‘‘substrate’’ includes sediment, hard bottom, structures underlying the waters, and associated biological communities.

Facies – The aspect, appearance, and characteristics of a sediment unit, usually reflecting the conditions of its origin, especially as differentiating the unit from adjacent or associated units.

Fish assemblage – The fish species that occur together in a single area, such that they have the reasonable opportunity for daily interaction with each other.

Gravel – a) An unconsolidated, natural accumulation of rock fragments resulting from erosion, consisting predominantly of particles larger than sand such as pebbles (10-25 mm), cobbles (25-500 mm), boulders (>500 mm), or any combination of these. b) Fragments having a diameter in the range of 2-75 mm (1/6 to 3 in.).

Habitat Areas of Particular Concern (HAPC) – Essential Fish Habitat that is judged to be particularly important to the long-term productivity of populations of one or more managed species, or to be particularly vulnerable to degradation.

Microhabitat – A small specialized habitat that supports a distinct flora and fauna. The area scale is approximately 0.01 to 0.1 km.

Nearshore – The area extending seaward generally a short distance from the shoreline to depths generally less than 5 fathoms (10 m).

Paleochannel – A remnant of a stream or river channel cut in older sediment or rock and filled by the younger overlying sediment; a buried river channel.

Pelagic fish – A term used for species of fish that live within the water column.

Piscivores – A carnivorous animal which eats primarily fish.

Planktivore –An aquatic organism that feeds on zooplankton, phytoplankton or other planktonic food.

Relief – The vertical difference in elevation between the top of a sand ridge and the trough or flat-bottom habitat of a given area.

Ridge and trough system – Long subparallel ridges and troughs aligned obliquely across the regional trend of the contours, also known as ridge and swale complexes or ridge and swale topography.

Sand – Loose particles of rock or mineral (sediment) that range in size from 0.05-2.0 mm in diameter.

Sand ridge – A term for a low, long, and narrow elevation of sand formed at some distance from the shore, and either submerged or emergent.

Sand wave – A term to describe a large and asymmetrical subaqueous bedform in sand.

Shoal – A natural, underwater ridge, bank, or bar consisting of, or covered by, sand or other unconsolidated material, rising from the bed of a body of water to near the surface.

Shoal complex – Two or more shoals (and adjacent morphologies, such as troughs) that are interconnected by past and/or present sedimentary and hydrographic processes.

Shoreface – The zone between the seaward limit of the shore and the more nearly horizontal surface of the offshore zone; typically extends seaward to storm wave depth or approximately 10 m.

Stratigraphic facies – Facies distinguished primarily on the basis of form, nature of boundaries, and mutual relations, to which appearance and composition are subordinated.

Swale – A long, narrow, generally shallow, trough-like depression between two sand ridges

Tidal delta – A delta formed at the mouth of a tidal inlet on either the lagoon or the seaward side of a barrier island or baymouth bar by changing tidal currents that sweep sand in and out of the inlet.

Veneer – A thin, widespread layer of sediment covering an older thicker strata or bed.

Appendix B: Summary of Ecological Conditions in BOEM Planning Areas

Atlantic Planning Areas

The Atlantic OCS region provides habitat that supports a wealth of species including commercially and recreationally important fish and shellfish, and several endangered and threatened species. Appendix Table B–1 lists the many primary species of commercial importance in the Atlantic OCS and their scientific names. Appendix Table B-2 gives all fish species identified by the NMFS Office of Protected Resources as endangered, threatened, or species of concern in the Atlantic OCS region. The New England Fishery Management Council (NEFMC), the Mid-Atlantic Fishery Management Council (MAFMC), and the South Atlantic Fishery Management Council (SAFMC) manage a majority of the fisheries in the Atlantic OCS federal waters. Other stocks and species are managed by states, multi-state commissions, international fishery organizations, or a combination of bodies. The regional fishery management councils have designated Essential Fish Habitat (EFH) as defined in the Magnuson-Stevens Act for 28 species in the New England region, 14 species in the Mid-Atlantic region, 73 species in the South Atlantic, and 23 highly migratory species (sharks, tunas, and billfish). The life histories of the economically and ecologically important species have been described in detail by Gabriel (1992) for demersal fishes between Cape Hatteras and Nova Scotia, Robin (1999) for fishes of US Atlantic waters, Bowman et al. (2000) for diets of northwest Atlantic fishes and squid, Collette and Klein-MacPhee (2002) for fishes in the Gulf of Maine, and Love and Chase (2007) for marine diversity of Mid- and South Atlantic bights. Life history and habitat information of EFH-managed species in the North Atlantic and Mid-Atlantic regions are provided in EFH source documents and the EFH Mapper.

Gulf of Mexico Planning Areas

The Gulf of Mexico OCS region also provides habitat that supports a variety of species including commercially and recreationally important species, and several threatened and endangered species. Appendix Table B–3 lists the many primary species of commercial importance in the Gulf of Mexico OCS and their scientific names. Appendix Table B-2 gives all fish species in the Gulf of Mexico OCS identified by the NMFS Office of Protected Resources as endangered, threatened, or species of concern. The Gulf of Mexico Fishery Management Council (GMFMC) has designated EFH for 46 species of fish and invertebrates in the Gulf of Mexico accounting for approximately one-third of the managed species and are considered ecological representatives of the remaining species. General descriptions of fish species inhabiting the Gulf of Mexico, and the life histories of the economically and ecologically important species have been described by McEachran and Fechhelm (1998, 2005), and Carpenter (2002). Life history and habitat information of EFH-managed species in the Gulf of Mexico regions are provided in GMFMC (1998) and the EFH Mapper.

Supplemental Tables

Appendix Table B–1. Common and scientific names of major commercial species of fish and invertebrates in the Atlantic Outer Continental Shelf region.

Common Name	Scientific Name	Common Name	Scientific Name
Alewife	*Alosa pseudoharengus*	Pollock	*Pollachius virens*
AmberJack	*Seriola* spp.	Pompano, African	*Alectis ciliaris*
AmberJack, greater	*Seriola dumerili*	Pompano, Florida	*Trachinotus carolinus*
AmberJack, lesser	*Seriola fasciata*	Porgy, jolthead	*Calamus bajonado*
Bass, striped	*Morone saxatilis*	Porgy, knobbed	*Calamus nodosus*
Bluefish	*Pomatomus saltatrix*	Porgy, red	*Pagrus pagrus*
Butterfish	*Peprilus triacanthus*	Pout, ocean	*Zoarces americanus*
Clam, arc, blood	*Anadara olivaris*	Redfish, Acadian	*Sebastes fasciatus*
Clam, Atlantic Jackknife	*Ensis directus*	Salmon, Atlantic	*Salmo salar*
Clam, Atlantic surf	*Spisula solidissima*	Scallop, bay	*Argopecten irradians*
Clam, northern quahog	*Mercenaria mercenaria*	Scallop, sea	*Placopecten magellanicus*
Clam, ocean quahog	*Arctica islandica*	Scamp	*Mycteroperca phenax*
Clam, quahog	*Mercenaria campechiensis*	Scup	*Stenotomus chrysops*
Clam, softshell	*Mya arenaria*	Scups or porgies	Sparidae spp.
Clams or bivalves	*Bivalvia* spp.	Sea bass, black	*Centropristis striata*
Cobia	*Rachycentron canadum*	Sea bass, rock	*Centropristis philadelphica*
Cod, Atlantic	*Gadus morhua*	Seatrout, sand	*Cynoscion arenarius*
Crab, Atlantic horseshoe	*Limulus polyphemus*	Seatrout, spotted	*Cynoscion nebulosus*
Crab, Atlantic rock	*Cancer irroratus*	Shad, American	*Alosa sapidissima*
Crab, blue	*Callinectes sapidus*	Shad, gizzard	*Dorosoma cepedianum*
Crab, florida stone	*Menippe mercenaria*	Shad, hickory	*Alosa mediocris*
Crab, golden deepsea	*Chaceon fenneri*	Shark, Atlantic sharpnose	*Rhizoprionodon terraenovae*
Crab, green	*Carcinus maenas*	Shark, blacknose	*Carcharhinus acronotus*
Crab, jonah	*Cancer borealis*	Shark, blacktip	*Carcharhinus limbatus*
Crab, spider	*Libinia emarginata*	Shark, blue	*Prionace glauca*
Crabs	*Cancer* spp.	Shark, bonnethead	*Sphyrna tiburo*
Croaker, Atlantic	*Micropogonias undulatus*	Shark, bull	*Carcharhinus leucas*
Dogfish, smooth	*Mustelis canis*	Shark, common thresher	*Alopias vulpinus*
Dogfish, spiny	*Squalus acanthias*	Shark, dusky	*Carcharhinus obscurus*
Dolphinfish	*Coryphaena hippurus*	Shark, finetooth	*Carcharhinus isodon*
Drum, black	*Pogonias cromis*	Shark, great hammerhead	*Sphyrna mokarran*
Drum, freshwater	*Aplodinotus grunniens*	Shark, lemon	*Negaprion brevirostris*
Drum, red	*Sciaenops ocellatus*	Shark, makos	*Isurus* spp.
Eel, American	*Anguilla rostrata*	Shark, porbeagle	*Lamna nasus*
Flounder, fourspot	*Paralichthys oblongus*	Shark, sand tiger	*Odontaspis taurus*
Flounder, southern	*Paralichthys lethostigma*	Shark, sandbar	*Carcharhinus plumbeus*
Flounder, summer	*Paralichthys dentatus*	Shark, scalloped	*Sphyrna lewini*

Common Name	Scientific Name	Common Name	Scientific Name
		hammerhead	
Flounder, windowpane	*Scophthalmus aquosus*	Shark, silky	*Carcharhinus falciformis*
Flounder, winter	*Pseudopleuronectes americanus*	Shark, smooth hammerhead	*Sphyrna zygaena*
Flounder, witch	*Glyptocephalus cynoglossus*	Shark, spinner	*Carcharhinus brevipinna*
Flounder, yellowtail	*Limanda ferruginea*	Shark, tiger	*Galeocerdo cuvier*
Flounder,American plaice	*Hippoglossoides platessoides*	Sharks	*Chrondrichthys*
Gag	*Mycteroperca microlepis*	Shrimp, brown	*Farfantepenaeus aztecus*
Goosefish (monkfish)	*Lophius americanus*	Shrimp, dendrobranchiata	*Dendrobranchiata* spp.
Grouper, black	*Mycteroperca bonaci*	Shrimp, marine, other	Caridea
Grouper, red	*Epinephelus morio*	Shrimp, pink	*Farfantepenaeus duorarum*
Grouper, snowy	*Hypothodus niveatus*	Shrimp, rock	*Sicyorzia brevirostris*
Grouper, yellowedge	*Hyporthodus flavolimbatus*	Shrimp, royal red	*Pleoticus robustus*
Grouper, yellowfin	*Epinephelus cyanopodus*	Shrimp, white	*Litopenaeus setiferus*
Groupers	*Serranidae* spp.	Skate, barndoor	*Dipturus laevis*
Haddock	*Melanogrammus aeglefinus*	Skate, little	*Leucoraja erinacea*
Hagfish	*Myxine glutinosa*	Snapper, blackfin	*Lutjanus buccanella*
Hake, Atlantic, red/white	*Urophycis* spp.	Snapper, cubera	*Lutjanus cyanopterus*
Hake, offshore silver	*Merluccius albidus*	Snapper, gray	*Lutjanus griseus*
Hake, red	*Urophycis chuss*	Snapper, lane	*Lutjanus synagris*
Hake, silver	*Merluccius bilinearis*	Snapper, mutton	*Lutjanus analis*
Hake, white	*Urophycis tenuis*	Snapper, red	*Lutjanus campechanus*
Halibut, Atlantic	*Hippoglossus hippoglossus*	Snapper, silk	*Lutjanus vivanus*
Herring, Atlantic	*Clupea harengus*	Snapper, vermilion	*Rhomboplites aurorubens*
Herring, Atlantic thread	*Opisthonema oglinum*	Snapper, yellowtail	*Ocyurus chrysurus*
Herring, blueback	*Alosa aestivalis*	Snappers	*Lutjaninae* spp.
Herrings	*Clupea* spp.	Spot	*Leiostomus xanthurus*
Hind, red	*Epinephelus guttatus*	Squid, longfin	*Loligo pealei*
Hind, rock	*Epinephelus adscensionis*	Squid, northern shortfin	*Ilex Illex illecebrosus*
Hogfish	*Lachnolaimus maximus*	Squids	Squid spp.
Tilefish, blueline	*Caulolatilus microps*	Swordfish	*Xiphias gladius*
Lobster, American	*Homarus americanus*	Tautog	*Tautoga onitis*
Lobster, Caribbean spiny	*Panulirus argus*	Tilefish, golden	*Lopholatilus chamaeleonticeps*
Lobster, slipper	*Scyllarides aequinoctialis*	Tilefish, sand	*Malacanthus plumieri*
Mackerel, Atlantic	*Scomber scombrus*	Tilefishes	*Malacanthidae spp.*
Mackerel, chub	*Scomber colias*	Triggerfish, gray	*Balistes capriscus*
Mackerel, king	*Scomberomorus cavalla*	Tuna, albacore	*Thunnus alalunga*
Mackerel, king and cero	*Scomberomorus* spp.	Tuna, bigeye	*Thunnus obesus*

Common Name	Scientific Name	Common Name	Scientific Name
Mackerel, Spanish	*Scomberomorus maculatus*	Tuna, blackfin	*Thunnus atlanticus*
Mako, shortfin	*Isurus oxyrinchus*	Tuna, bluefin	*Thunnus thynnus*
Menhaden	*Brevoortia tyrannus*	Tuna, skipJack	*Katsuwonus pelamis*
Mullet, striped (liza)	*Mugil cephalus*	Tuna, yellowfin	*Thunnus albacares*
Mullet, white	*Mugil curema*	Tunas	*Thunnus* spp.
Mullets	*Mugil* spp.	Tunny, little	*Euthynnus alletteratus*
Oyster, eastern	*Crassostrea virginica*	Wahoo	*Acanthocybium solandri*
Oyster, European flat	*Ostrea edulis*	Weakfish	*Cynoscion regalis*
		Wolffish, Atlantic	*Anarhichas lupus*

Appendix Table B–2. Endangered, threatened, and species of concern (fish) in the Atlantic and Gulf of Mexico Outer Continental Shelf regions (NMFS 2013a).[1]

Common Name	Scientific Name	Range	Status; Date listed
Alabama Shad	*Alosa alabamae*	Gulf of Mexico: Alabama and Florida	Species of concern; 2004
Alewife	*Alosa pseudoharengus*	Atlantic: Newfoundland to North Carolina	Species of concern; 2006 and candidate Species
American eel	*Anguilla rostrata*	Atlantic Ocean: Greenland to Brazil	Under status review; 2011
Atlantic Bluefin tuna	*Thunnus thynnus*	Atlantic Ocean and adjacent seas	Species of concern; 2010
Atlantic halibut	*Hippoglossus hippoglossus*	Atlantic: Labrador to southern New England	Species of concern; 2004
Atlantic salmon	*Salmo salar*	Atlantic: Gulf of Maine (other populations in streams and rivers in Maine outside the range of the listed Gulf of Maine DPS); anadromous	Endangered; 2000
Atlantic sturgeon	*Acipenser oxyrinchus oxyrinchus*	North America, Atlantic coastal waters; anadromous	Endangered (New York Bight, Chesapeake Bay, Carolina, and South Atlantic DPS), Threatened (Gulf of Maine DPS); 2012
Atlantic wolffish	*Anarhichas lupus*	Atlantic: Georges Bank and western Gulf of Maine	Species of concern; 2004
Barndoor Skate	*Dipturus laevis*	Atlantic: Newfoundland, Canada to Cape Hatteras, North Carolina.	Former species of concern; 2007
Blueback Herring	*Alosa aestivalis*	Atlantic: Cape Breton, Nova Scotia, to St. John's River, Florida	Species of concern; 2006 and Candidate Species
Cusk	*Brosme brosme*	Atlantic: Gulf of Maine	Species of concern; 2004 and candidate Species
Drawf Seahorse	*Hippocampus zosterae*	Gulf of Mexico (Florida Keys to Texas) and the Bahamas	Candidate Species; 2012
Dusky Shark	*Carcharhinus obscurus*	Western Atlantic	Species of concern; 1997
Great Hammerhead	*Sphyrna mokarran*	Western Atlantic	Candidate Species; 2013

[1] See http://www.nmfs.noaa.gov/pr/species/fish/.

Common Name	Scientific Name	Range	Status; Date listed
Gulf Sturgeon	*Acipenser oxyrinchus desotoi*	Gulf of Mexico, Louisiana to Florida coastal waters; anadromous	Threatened; 1991
Large Sawtooth	*Pristis pristis*	Gulf of Mexico, Caribbean south through Brazil	Endangered; 2011
Manta Rays	*Manta alfredi* *Manta birostris*	Global; Gulf of Mexico, the Caribbean, and along the eastern coast of the United States	Proposed; 2012
Nassau grouper	*Epinephelus striatus*	Atlantic: North Carolina southward to Gulf of Mexico	Species of concern; 1991
Night Shark	*Carcharinus signatus*	Western Atlantic: Gulf of Mexico, South Atlantic and Caribbean	Species of concern; 1997
Porbeagle	*Lamna nasus*	Atlantic: Newfoundland, Canada to New Jersey	Species of concern; 2006
Rainbow smelt	*Osmerus mordax*	Atlantic: Labrador to New Jersey; anadromous	Species of concern; 2004
Sand tiger Shark	*Carcharias taurus*	Atlantic; Gulf of Mexico	Species of concern; 1997
Scalloped hammerhead	*Sphyrna lewini*	Western Atlantic	Candidate species; 2011
Shortnose sturgeon	*Acipenser brevirostrum*	Western Atlantic: New Brunswick to Florida; anadromous	Endangered; 1967
Smalltooth sawfish	*Pristis perotteti*	Atlantic: New York to Brazil	Endangered, U.S. distinct population segment; 2003
Speckled hind	*Epinephelus drummondhayi*	Atlantic: North Carolina to Gulf of Mexico	Species of concern; 1997
Striped croaker	*Bairdiella sanctaelucíae*	Western Atlantic: Florida	Species of concern; 1991
Thorny Skate	*Amblyraja radiata*	Atlantic: West Greenland to New York	Species of concern; 2004
Warsaw grouper	*Epinephelus nigritus*	Atlantic: Massachusetts southward to Gulf of Mexico	Species of concern; 1997

Box 1: NOAA Definitions of Designation Titles

Endangered*: Defined under the ESA as "any species which is in danger of extinction throughout all or a significant portion of its range."*

Threatened: *Defined under the ESA as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."*

Candidate Species*: any species that is undergoing a status review that NMFS has announced in a Federal Register notice. Thus, any species being considered by the Secretary (of the Department of Commerce or Interior) for listing under the ESA as an endangered or a threatened species, but not yet the subject of a proposed rule (see 50 CFR 424.02). NMFS' candidate species also qualify as species of concern. "Candidate species" specifically refers to--*

- *species that are the subject of a petition to list and for which we have determined that listing may be warranted, pursuant to section 4(b)(3)(A), and*
- *species that are not the subject of a petition but for which we have announced the initiation of a status review in the Federal Register.*

Proposed species*: Those candidate species that were found to warrant listing as either threatened or endangered and were officially proposed as such in a Federal Register notice after the completion of a status review and consideration of other protective conservation measures. Public comment is always sought on a proposal to list species under the ESA. NMFS generally has one year after a species is proposed for listing under the ESA to make a final determination whether to list a species as threatened or endangered.*

Species of Concern*: species about which NMFS has some concerns regarding status and threats, but for which insufficient information is available to indicate a need to list the species under the ESA. This may include species for which NMFS has determined, following a biological status review, that listing under the ESA is "not warranted," pursuant to ESA section 4(b)(3)(B)(i), but for which significant concerns or uncertainties remain regarding their status and/or threats. Species can qualify as both "species of concern" and "candidate species."*

Appendix Table B–3. Common and scientific names of major commercial species of fish and invertebrates in the Gulf of Mexico Outer Continental Shelf region.

Common Name	Scientific Name	Common Name	Scientific Name
AmberJack	*Seriola* spp.	Grouper, yellowedge	*Hyporthodus flavolimbatus*
AmberJack, greater	*Seriola dumerili*	Grouper, yellowfin	*Epinephelus cyanopodus*
AmberJack, lesser	*Seriola fasciata*	Grouper, red	*Epinephelus morio*
Ballyhoo	*Hemiramphus brasiliensis*	Grunts	*Haemulon spp.*
Barracudas	*Sphyraena spp.*	Hake, Atlantic, red/white	*Urophycis* spp.
Barrelfish	*Hyperoglyphe perciformis*	Herring, Atlantic thread	*Opisthonema oglinum*
Bass, Longtail	*Hemanthias leptus*	Herrings	*Clupea* spp.
Black Driftfish	*Hyperoglyphe bythites*	Hind, red	*Epinephelus guttatus*
Bluefish	*Pomatomus saltatrix*	Hind, rock	*Epinephelus adscensionis*
Bonito, Atlantic	*Sarda sarda*	Hind, Speckled	*Epinephelu drummondhayi*
Brotula, Bearded	*Brotula barbata*	Hogfish	*Lachnolaimus maximus*
Butterfish	*Peprilus burti*	Jack, Almaco	*Seriola rivoliana*
Clam, quahog	*Mercenaria campechiensis*	Jack, Bar	*Caranx ruber*
Cobia	*Rachycentron canadum*	Jack, Crevalle	*Caranx hippos*
Crab, blue	*Callinectes sapidus*	Jack, Horse-eye	*Caranx latus*
Crab, florida stone	*Menippe mercenaria*	King Whiting	*Menticirrhus americanus*
Crabs	*Cancer* spp.	Ladyfish	*Elops saurus*
Croaker, Atlantic	*Micropogonias undulatus*	Leather Jacket	*Oligoplites saurus*
Cusk	*Brosme brosme*	Lionfish	*Pterois volitans*
Atlantic Cutlassfish	*Trichiurus lepturus*	Lobster, Caribbean spiny	*Panulirus argus*
Dolphinfish	*Coryphaena hippurus*	Lobster, slipper	*Scyllarides aequinoctialis*
Drum, black	*Pogonias cromis*	Lookdown	*Selene vomer*
Drum, freshwater	*Aplodinotus grunniens*	Mackerel, chub	*Scomber colias*
Drum, red	*Sciaenops ocellatus*	Mackerel, king	*Scomberomorus cavalla*
Escolar	*Lepidocybium flavobrunneum*	Mackerel, king and cero	*Scomberomorus* spp.
Flounder, southern	*Paralichthys lethostigma*	Mackerel, Spanish	*Scomberomorus maculatus*
Flounder, summer	*Paralichthys dentatus*	Mantis shrimps	Stomatopoda
Flyingfishes	Exocoetidae	Margate	*Diabasis aurolineatus*
Gag	*Mycteroperca microlepis*	Menhaden	*Brevoortia spp.*
Graysby	*Cephalopholis cruentata*	Mojarras	*Eucinostomus spp.*
Grouper, black	*Mycteroperca bonaci*	Mullet, striped (liza)	*Mugil cephalus*
Grouper, Marbled	*Dermatolepis inermis*	Mullet, white	*Mugil curema*
Grouper, Misty	*Epinephelus mystacinus*	Mullets	*Mugil* spp.
Grouper, red	*Epinephelus morio*	Octopus	Octopoda
Grouper, snowy	*Hypothodus niveatus*	Oilfish	*Ruvettus pretiosus*

Common Name	Scientific Name	Common Name	Scientific Name
Opah	*Lampris guttatus*	Shark, Shortfin Mako	*Isurus oxyrinchus*
Oyster, Eastern	*Crassostrea virginica*	Shark, silky	*Carcharhinus falciformis*
Parrotfishes	Scaridae	Shark, spinner	*Carcharhinus brevipinna*
Permit	*Trachinotus falcatus*	Shark, tiger	*Galeocerdo cuvier*
Pigfish	*Orthopristis chrysoptera*	Sharks	*Chrondrichthys*
Pinfish	*Lagodon rhomboides*	Sheepshead	*Archosargus probatocephalus*
Pomfrets	*Brama spp.*	Shrimp, brown	*Farfantepenaeus aztecus*
Pompano, African	*Alectis ciliaris*	Shrimp, dendrobranchiata	*Dendrobranchiata spp.*
Pompano, Florida	*Trachinotus carolinus*	Shrimp, pink	*Farfantepenaeus duorarum*
Porgy, jolthead	*Calamus bajonado*	Shrimp, rock	*Sicyorzia brevirostris*
Porgy, knobbed	*Calamus nodosus*	Shrimp, royal red	*Hymenopenaeus robustus*
Porgy, Longspine	*Stenotomus caprinus*	Shrimp, seabob	*Xiphopenaeus kroyeri*
Porgy, red	*Pagrus pagrus*	Shrimp, white	*Litopenaeus setiferus*
Puffers	*Sphoeroides spp.*	Snapper, Black	*Apsilus dentatus*
Ray,Stingrays	*Dasyatis spp.*	Snapper, blackfin	*Lutjanus buccanella*
Rays	Myliobatiformes	Snapper, cubera	*Lutjanus cyanopterus*
Rosefish, Blackbelly	*Helicolenus dactylopterus*	Snapper, dog	*Lutjanus jocu*
Rudderfish, Banded	*Seriola zonata*	Snapper, gray	*Lutjanus griseus*
Runner, Blue	*Caranx crysos*	Snapper, lane	*Lutjanus synagris*
Sand Perch	*Diplectrum formosum*	Snapper, mutton	*Lutjanus analis*
Sardine, Spanish	*Sardinella aurita*	Snapper, queen	*Etelis oculatus*
Scad, Bigeye	*Selar crumenophthalmus*	Snapper, red	*Lutjanus campechanus*
Scads	*Decapterus spp.*	Snapper, silk	*Lutjanus vivanus*
Scamp	*Mycteroperca phenax*	Snapper, vermilion	*Rhomboplites aurorubens*
Scorpionfish, Spinycheek	*Neomerinthe hemingwayi*	Snapper, yellowtail	*Ocyurus chrysurus*
Scups or porgies	*Sparidae spp.*	Snappers	*Lutjaninae* spp.
Sea bass, black	*Centropristis striata*	Spadefishes	*Chaetodipterus faber*
Sea bass, rock	*Centropristis philadelphica*	Sponges	Porifera
Sea Catfishes	Ariidae	Spot	*Leiostomus xanthurus*
Seatrout, sand	*Cynoscion arenarius*	Squids	Squid spp.
Seatrout, spotted	*Cynoscion nebulosus*	Squirrelfishes	Holocentridae
Shad, gizzard	*Dorosoma cepedianum*	Swordfish	*Xiphias gladius*
Shark, Atlantic sharpnose	*Rhizoprionodon terraenovae*	Tilefish, Blueline	*Caulolatilus microps*
Shark, blacknose	*Carcharhinus acronotus*	Tilefish, golden	*Lopholatilus chamaeleonticeps*
Shark, blacktip	*Carcharhinus limbatus*	Tilefish, Goldface	*Caulolatilus chrysops*
Shark, bull	*Carcharhinus leucas*	Tilefish, sand	*Malacanthus plumieri*
Shark, Hammerhead	*Sphyrna spp.*	Tilefishes	*Malacanthidae spp.*
Shark, lemon	*Negaprion brevirostris*	Triggerfish, gray	*Balistes capriscus*
Shark, sandbar	*Carcharhinus plumbeus*	Tripletail	*Lobotes surinamensis*

Common Name	Scientific Name	Common Name	Scientific Name
Tuna, albacore	*Thunnus alalunga*	Tuna, yellowfin	*Thunnus albacares*
Tuna, bigeye	*Thunnus obesus*	Wahoo	*Acanthocybium solandri*
Tuna, blackfin	*Thunnus atlanticus*	Weakfish	*Cynoscion regalis*
Tuna, bluefin	*Thunnus thynnus*	Wenchman	*Pristipomoides aquilonaris*
Tuna, Little Tunny	*Euthynnus alletteratus*	Wreckfish	*Polyprion americanus*
Tuna, skipJack	*Katsuwonus pelamis*		