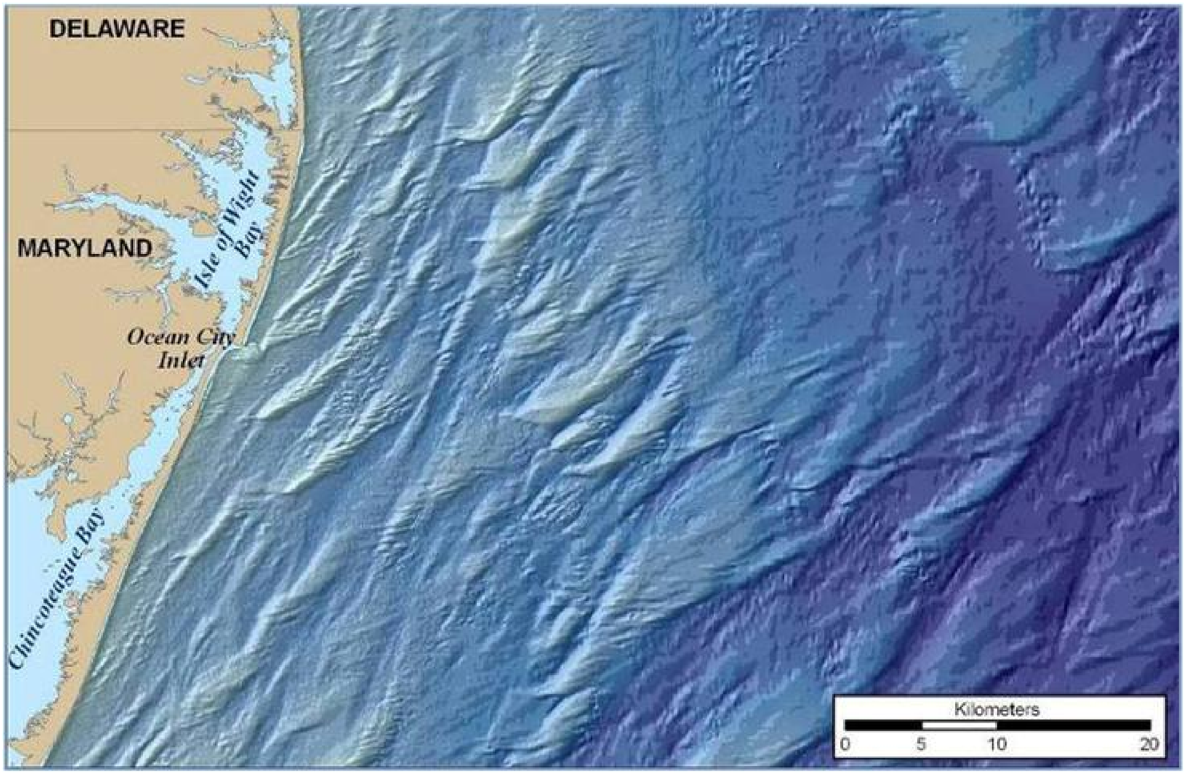
OCS Study
BOEM 2015-012

# Understanding the Habitat Value and Function of Shoals and Shoal Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf

## Literature Synthesis and Gap Analysis



U.S. Department of the Interior
Bureau of Ocean Energy Management
Headquarters
Herndon, VA

# Understanding the Habitat Value and Function of Shoals and Shoal Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf

## Literature Synthesis and Gap Analysis

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Prepared under BOEM Contract M12PS00009
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Published by
**U.S. Department of the Interior**
**Bureau of Ocean Energy Management**
**Headquarters**

# DISCLAIMER

Study concept, oversight, and funding were provided by the US Department of the Interior, Bureau of Ocean Energy Management, Environmental Studies Program, Washington, DC, under Contract Number M12PC00009. This report has been technically reviewed by BOEM and it has been approved for publication. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the opinions or policies of the US Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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# CITATION

Suggested Citation:

Rutecki, D., T. Dellapenna, E. Nestler, F. Scharf, J. Rooker, C. Glass, and A. Pembroke. 2014. Understanding the Habitat Value and Function of Shoals and Shoal Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf. Literature Synthesis and Gap Analysis. Prepared for the U.S. Dept. of the Interior, Bureau of Ocean Energy Management. Contract # M12PS00009. BOEM 2015-012. 176 pp.

# About the Cover

Regional bathymetric map showing the classic ridge and swale topography on the mid-Atlantic continental shelf, Maryland and Delaware. From CSA et al. (2010).

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## Acronyms and Abbreviations

| | |
|---|---|
| BACI | Before-and-After Control Impact |
| BMP | Best Management Practices |
| BOEM | Bureau of Ocean Energy Management (United States) |
| cm | centimeter |
| Corps | U.S. Army Corps of Engineers (United States) |
| CSA | Continental Shelf Associates |
| EFH | Essential Fish Habitat |
| ESA | Endangered Species Act |
| EEZ | Exclusive economic zone |
| FMP | Fishery Management Plan |
| FWS | U.S. Fish and Wildlife Service |
| GMFMC | Gulf of Mexico Fishery Management Council |
| GOM | Gulf of Mexico |
| HAPC | Habitat Areas of Particular Concern |
| H/BD | ratio of shoal height (distance from crest to base of shoal) to base depth |
| kHz | kilihertz |
| km | Kilometer |
| LGM | Last Glacial Maximum |
| LME | Large Marine Ecosystem |
| MAFMC | Mid-Atlantic Fishery Management Council |
| Magnuson-Stevens Act | Magnuson-Stevens Fishery Conservation and Management Act (United States) |
| m | Meter |
| mm | Millimeter |
| MMP | Marine Minerals Program |
| MMS | Minerals Management Service (precursor to BOEM) (United States) |
| m/y | meters per year |
| NEFMC | New England Fishery Management Council |
| NEPA | National Environmental Policy Act |
| nm | Nautical Miles |
| NMFS | National Marine Fisheries Service (United States) |
| NOAA | National Oceanic and Atmospheric Administration (United States) |
| OI | Oregon Inlet |
| OCS | Outer Continental Shelf |
| ROV | Remotely operated vehicle |
| SAFMC | South Atlantic Fishery Management Council |
| VIE | visible implant elastomer |
| ybp | years before present |

# 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*** (OCS) (3 nautical miles [nm] offshore of most states, with the exception of Texas and the Gulf coast of Florida, where it is 9 nm) (See Glossary). This management includes the Oil and Gas, the 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 October 31, 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 Oceanographic and Atmospheric Administration's Fisheries Service (NOAA Fisheries) regarding the Endangered Species Act (ESA) and the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act) and with the Fish and Wildlife Service (FWS) regarding the ESA to ensure that the sensitive biological resources considered under these mandates are carefully evaluated.

Under the Magnuson-Stevens Act, which was written in 1976 and amended in 1996 and 2007, NOAA's National Marine Fisheries Service (NMFS) is responsible for the identification and protection of essential marine and anadromous fish habitats. Each regional office of NOAA Fisheries, in conjunction with the regional Fishery Management Councils, defines ***Essential Fish Habitat*** (EFH) for federally managed species, supporting a primary goal of maintaining sustainable fisheries. Criteria for EFH designation were developed independently in each region. ***Habitat Areas of Particular Concern*** (HAPCs) can be identified as a subset of EFH for areas that a region considers to have special characteristics or value, although HAPCs have no additional regulatory status. NOAA Fisheries has identified ridge and ***swale*** and cape-associated ***shoal complexes*** as EFH and in some areas as HAPCs (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.

## 1.1 Background

There has been an increasing demand for OCS sand due to severe weather conditions which, coupled with chronic erosion, has led to substantial coastal damage, which places a higher demand on diminishing offshore sand resources in state waters (Drucker et al. 2004). A number of sand sources suitable for these coastal projects have been identified along the OCS in the Atlantic and the Gulf of Mexico (GOM). In addition, there are also likely a number of unidentified sources that BOEM, the US Army Corps of Engineers (Corps), the US Geological Survey, states (including all Atlantic coastal states from Maine to Florida and GOM coastal states from Florida to Texas) and specific localities have been working to characterize. Some of 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 shore-attached ***sand ridges*** (Drucker et al. 2004). The widespread coastal impacts imposed by Hurricane Sandy in October 2012 helped trigger a renewed emphasis on cooperative relationships between BOEM and affected states. In 2014, BOEM executed cooperative agreements with 13 Atlantic coastal states to identify offshore sand resources that could be used for shoreline resiliency efforts. In addition, BOEM contracted for geological and geophysical surveys on the Atlantic OCS (up to 8 miles offshore) to identify sand resources that could be used for coastal restoration, beach nourishment, and wetland restoration projects. Prior to BOEM's recent actions, numerous studies identified potential offshore sand resource areas, including: 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 2006b; 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. (2004b and 2004c), 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 inner shelf (0-30 meters water depth), locations with geomorphic features similar 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 GOM. Marine mineral leases for OCS sand have been issued to New Jersey, 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, 2004a, 2004b, 2004c; Cutter et al. 2000; Minerals Management Service [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 GOM 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.

## 1.2 Approach

The BOEM MMP convened a workshop on January 24, 2014 in Charleston South Carolina in conjunction with the Southern Division - American Fisheries Society meeting *to discuss and identify the most critical information needs and data gaps* that should 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 GOM OCS (Figures 1-1 and 1-2). The agenda and presentations from this meeting are provided in Appendix A.

To help focus the workshop participants and to support a productive discussion, a draft Literature Synthesis summarizing current knowledge of the topic was made available to participants prior to the workshop. This draft Synthesis also provided initial identification of information needs and data gaps as a basis for workshop discussions.

This final Literature Synthesis (or Synthesis) has been prepared by updating the draft Synthesis to incorporate key findings from the workshop. Information that has become available through June 2014 has also been added to this Synthesis. The focus of this Synthesis is on the interactions of fish, fisheries, and invertebrates of the U.S. Atlantic and GOM OCS with various types of offshore shoal complexes. This Synthesis is intended to be narrowly focused on hopper dredging along the OCS (not within estuaries, navigation channels, etc.) because that is the primary technique used for offshore sand mining. It does not include review of potential EFH implications from cutterhead dredging (e.g., pitting, anoxia). This Synthesis only focuses on the use of sand shoals and not on any other geological features that may be utilized for renourishment.

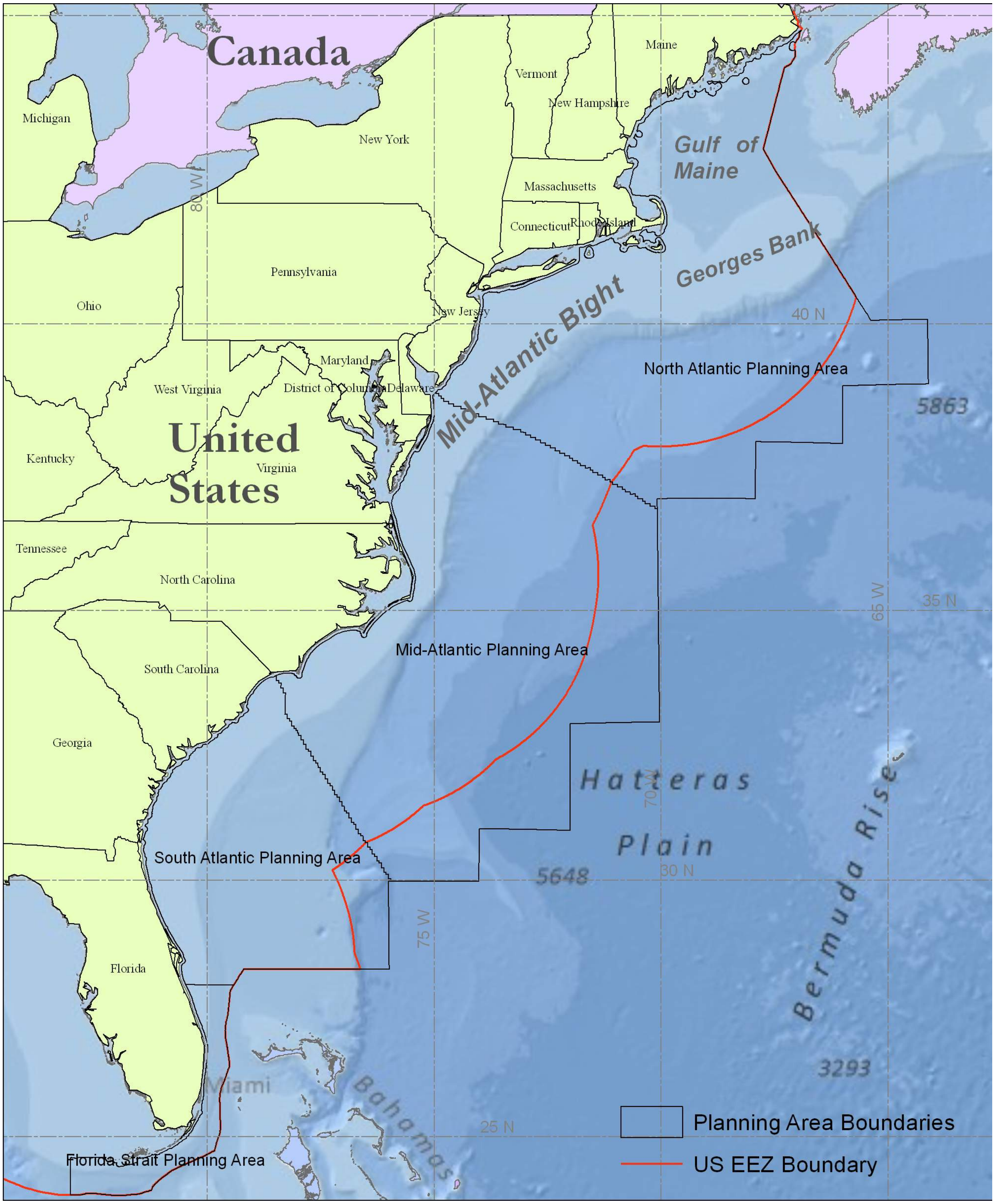


**Figure 1-1. U.S. Atlantic Outer Continental Shelf region showing the Bureau of Ocean Energy Management Planning Area boundaries and the U.S. Exclusive Economic Zone (EEZ) boundary.**

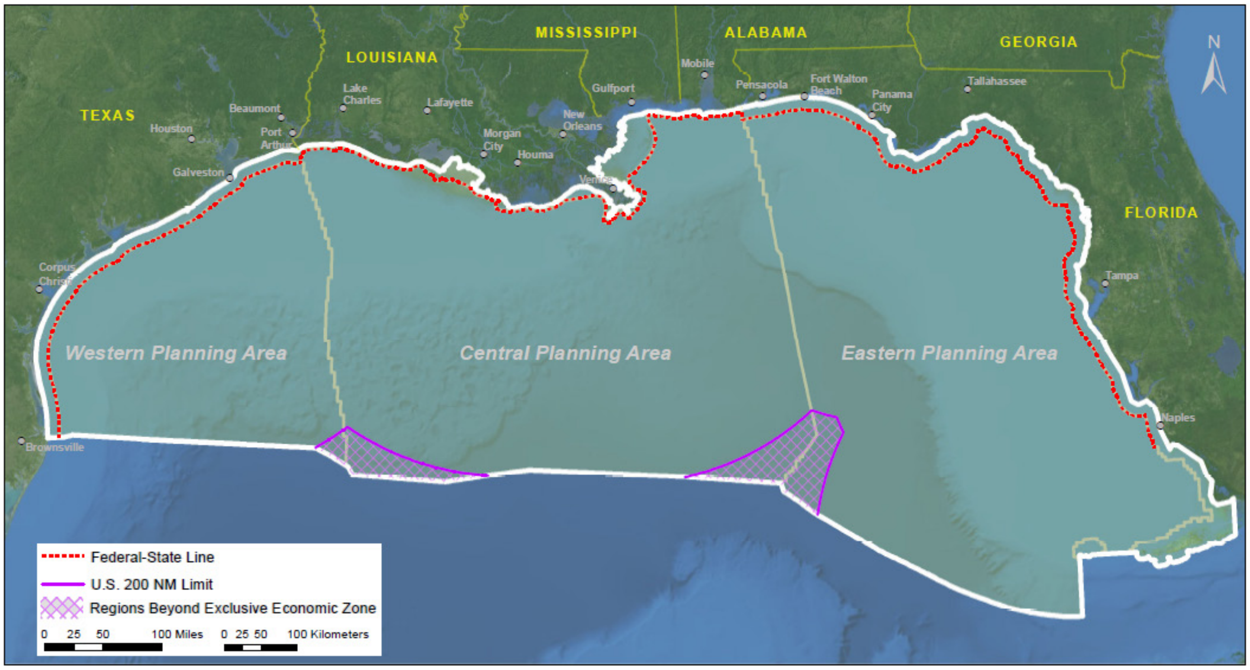


**Figure 1-2. U.S. Gulf of Mexico Outer Continental Shelf region showing the Bureau of Ocean Energy Management Planning Area boundaries and the U.S. Exclusive Economic Zone (EEZ) boundary.**
Source: BOEM 2013.

BOEM's specific objectives for this Synthesis were to:

- Identify the habitat value and functions of shoals and shoal complexes to priority fishes on the Mid-Atlantic, South Atlantic, and GOM 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.

## 1.3 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: 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.

## 1.4 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 GOM 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:

- South Atlantic Fishery Management Council (SAFMC) (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 SAFMC.

- GOM Fishery Management Council (GMFMC) (1998) — Information on the habitat requirements for species managed by the GMFMC.
- 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.
- NOAA Technical Memorandum NMFS-NE series: Essential Fish Habitat species source documents (1999-present, available at http://www.nefsc.noaa.gov/nefsc/habitat/efh/) — Compilations of the available information on the distribution, abundance, and habitat requirements for each of the species managed by the New England Fishery Management Council (NEFMC)and the Mid-Atlantic Fishery Management Council (MAFMC).
- Brooks et al. (2005) — A USGS synthesis of the Southeast Area Monitoring and Assessments Program's Groundfish Survey database for 1982-2000.
- Brooks et al. (2006) — A paper that reviews the existing literature on the benthic faunal resources for the US Atlantic and GOM continental shelf.
- Gilmore (2008) — A regional fishery resource survey and synthesis in a Florida county for comprehensive beach and offshore monitoring program.
- Johnson et al. (2008) — A NOAA technical memorandum on the impacts to marine fisheries habitat from nonfishing activities.
- NMFS (2009) — Amendment 1 to the Atlantic Highly Migratory Species Fishery Management Plan (FMP) designating Essential Fish Habitat. This document contains information on the life history and habitat requirements for Atlantic tunas, swordfish, and sharks managed under this FMP.
- Continental Shelf Associates (CSA) International, Inc. et al. (2010) — An analysis of potential biological and physical impacts of dredging on offshore shoal features.
- Dibajnia and Nairn (2011) — A BOEM investigation of dredging guidelines to maintain and protect the geomorphic integrity of offshore shoal regimes.
- Kaplan (2011) — A literature synthesis of the oceanographic resources in the North and Central Atlantic Ocean.
- Michel et al. (2013) — A BOEM review of biological and biophysical impacts from dredging offshore sand.

## 1.5 Organization

Section 2 provides background information on the geology of shoals, the primary physical forces affecting them, and the distribution throughout the study area. Section 3 discusses the linkage between the geophysical environment and biological assemblages. In Section 4, information on the use of shoals by benthic invertebrates (Section 4.1) and fishes (Section 4.2) is presented. Section 5 focuses on the questions arising from discussions, the literature synthesis, and the workshop and identifies areas of potential future research. Throughout the document, species are referred to by their common names (most invertebrates and all fishes. A listing of the scientific names of species cited in the document is provided in Appendix B. A glossary is included in

Section 7.0 to define many of the terms used in this Synthesis. Terms appearing in the glossary appear in ***bold italics*** when first used in the report.

# 2.0 Geology and Geography

Ecological functions of a habitat are highly influenced by the physical attributes. In the case of offshore shoals, geological origin, structure, and the physical forces affecting shoals are all important to understanding the ability of associated organisms to adapt to changing conditions such as those that might result from sand removal. One question leading to this study was whether all shoal types have similar habitat value for fishes and invertebrates. To evaluate this question, it is essential to understand the range of shoal types that exist in the U.S. Atlantic and GOM OCS.

## 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, resulting in shallower water depths than surrounding areas. The term ***shoal complex*** refers to two or more shoals (and includes adjacent morphologies, such as troughs separating shoals) that are interconnected by past and or present sedimentary and hydrodynamic processes. These complexes are also known as shoal fields.

For the USA, from the Mid-Atlantic, southward to the southern tip of Florida and along the northern and northeastern GOM offshore shoals are sedimentary deposits, typically dominated by sand or gravel (Finkl and Hobbs 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 (but more frequent), northern meteorological 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: 1) shoals associated with relict Holocene or Pleistocene sedimentary deposits exposed/sourced by ***ravinement***; 2) active and ***relict cape-associated shoals***; and 3) a shelf morpho-sedimentary continuum of ***bedforms***. Nomenclature used for shoals has varied greatly in the past, with both regional and temporal patterns of usage. One of the goals of this section is to establish a consistent nomenclature and to place older usage in the context of the new terminology used here. Current synonyms for shoal nomenclature used in the past literature are shown in Table 2-1. The following subsections provide a brief description of the geological history of shoals in the Mid-Atlantic and GOM, followed by a summary of each of the three broad categories of shoals found within these regions.

### 2.1.1 Geological History of Shoals

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 meters (m) lower than current levels (Clark et al. 2009). Much of the continental shelf of the GOM and the Atlantic coast of North America were subaerially 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, 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 (wave-generated erosion down to the depth of the wave-base). Although a highly variable process, in many cases ravinement 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 left 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 on the shelf are either Holocene or Pleistocene in age.

**Table 2-1. Classification of shoals**

| | **Shoals associated with Relict Holocene or Pleistocene Deposits** | | **Cape-Associated Shoals** | **Bedform Shoals** | |
|---|---|---|---|---|---|
| | **Isolated Shelf Shoals** | **Shoal Fields** | **Relict Shoals** | **Sorted** | **Ridges** |
| Synonyms | Banks | Shelf retreat massifs | Shelf retreat massifs (along Raleigh Bay) and Wimble Shoals | Rippled Scour depressions | Ridge and trough, Ridge and swale |
| Examples | Sabine Bank, Heald Bank, St. Bernard Shoal, Ship shoal | Platt Shoal, Oregon Shoal, Albermarle Shoal | Cape Lookout Shoals, Diamond Shoals, Frying Pan Shoals, Wimble Shoals-(abandoned Cape) | Shoals along Wrightsville Beach shoreface and inner shelf | Shoals along the inner shelf north of Cape Lookout, along MD, DE, NJ, NY inner shelves |

## 2.1.2 Relict Holocene and Pleistocene Deposit Shoals

These shoals are formed from relict coastal sedimentary deposits exposed by ravinement or are proximally sourced by these deposits. These can be further subdivided into ***isolated inner shelf shoals*** and shoal fields. Isolated inner shelf shoals are discrete features, generally associated with a single relict coastal landform and/or shoreline position. Shoal fields are typically formed from proximally exposed deposits where the shoals are displaced from the source deposit. Along the Texas shelf, the term “bank” is used to refer to both of these types of shoals. Along the Louisiana shelf, the term “shoal” is used.

### *Isolated Inner Shelf Shoals*

Sabine Bank Shoal, Heald Bank Shoal, and Ship Shoal are examples of isolated inner shelf shoals. Sabine Bank Shoal is situated ~26 kilometers (km) offshore of the Texas-Louisiana border and is delineated by the 10 m isobaths. It is 50 km long, 7.5 km wide, and shoals to less than 4.5 m. Morton and Gibeaut (1995) estimated Sabine Bank to contain $1.8 \times 10^9$ $m^3$ sandy sediment, by extrapolating the geographic extent of the bank (bathymetric expression) relative to adjacent seafloor. It consists of the basal barrier island and tidal inlet deposits; the surface of Sabine Bank consists largely of a lag shell deposit and sand (Morton and Gibeaut 1995; Dellapenna et al. 2009, 2010, 2011; Figure 2-1).

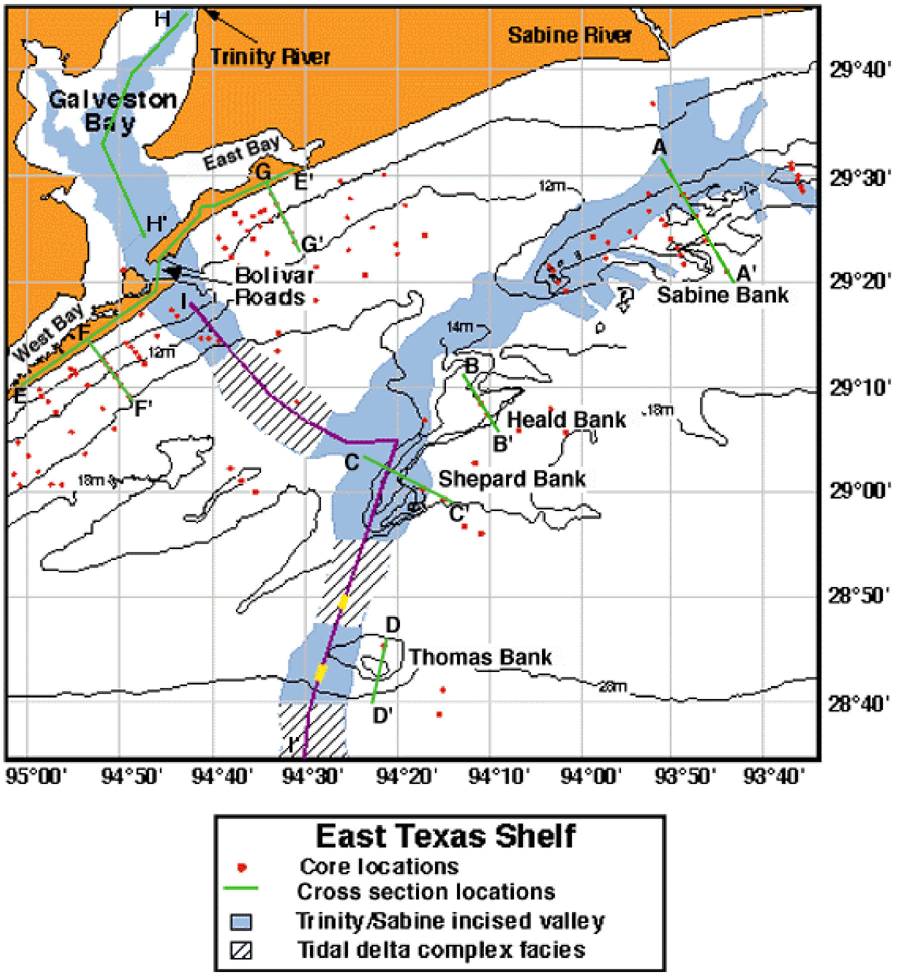


**Figure 2-1a.**

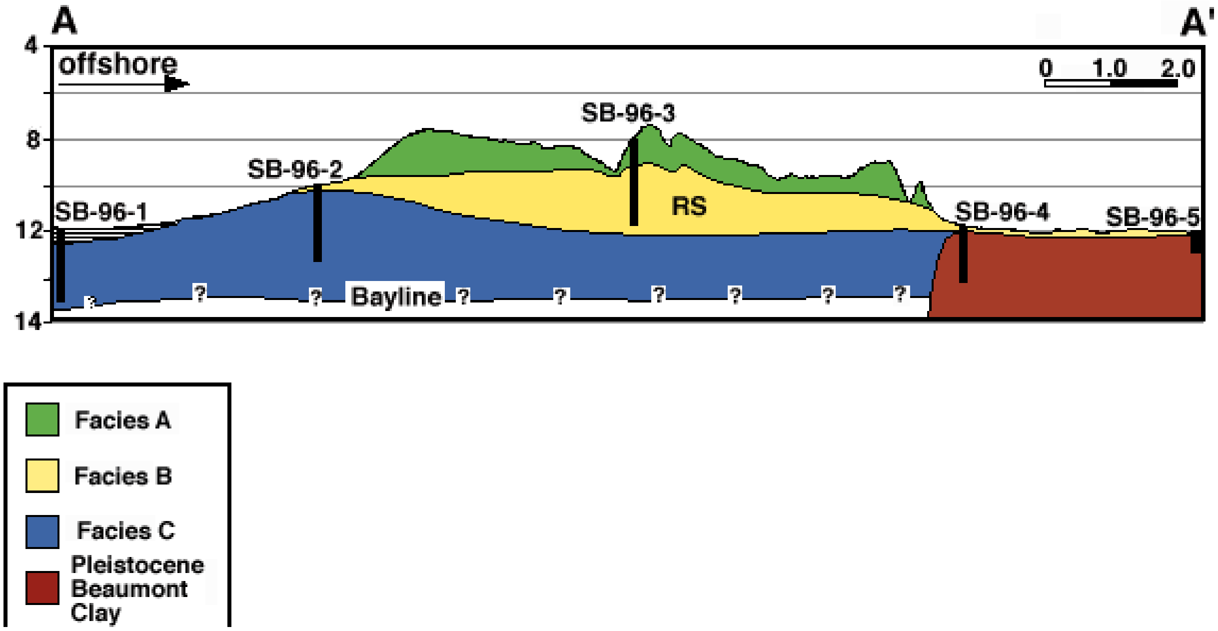


**Figure 2-1b.**

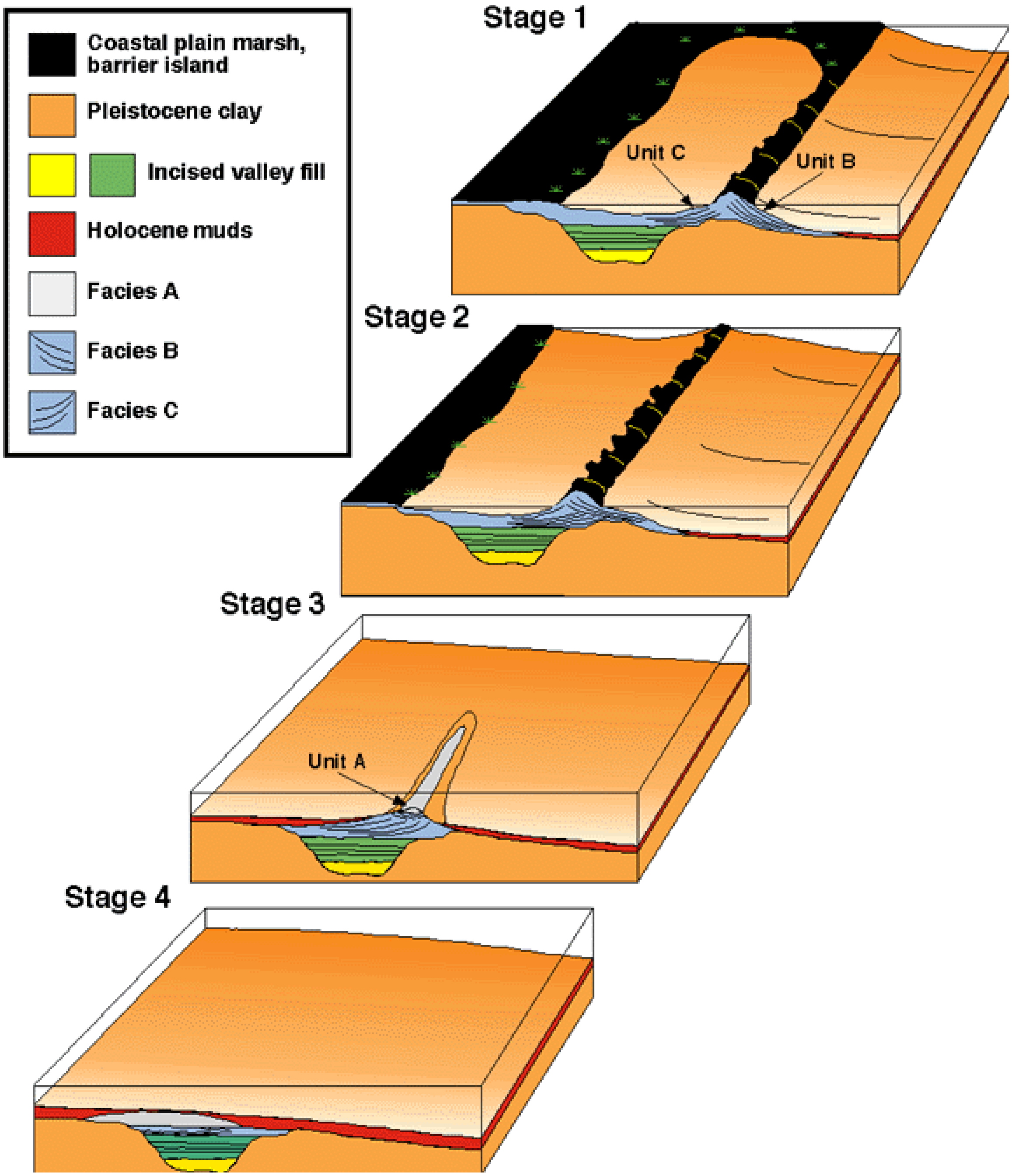


**Figure 2-1c.**

**Figure 2-1. Geology of Sabine Bank.**
**a)** Paleogeographic map showing the Trinity River incised valley extending from Galveston Bay and the Neches-Sabine Rivers incised valley extending from Sabine River. The map also shows the locations of Sabine, Heald, Shepard and Thomas Banks on the seaward flank of the incised valley system. **b)** Cross section A-A' from Sabine Bank showing the vertical distribution of facies. **c)** Oblique cross sections showing the evolution of Sabine Bank. Sources: a) http://gulf.rice.edu/ETexas/gulfeTexasS_T_SJ_tst.html b), c) Anderson et al. 2013.

Rodriguez et al. (1999) identified three ***facies***, two of which (Facies A and B) are sand bearing. Facies C constitutes the basal layer of the bank, contains the bulk of Sabine Bank Shoal's volume and is mud dominated. Dellapenna et al. (2010a, b, 2011) estimated a total of $638 \times 10^6$ $m^3$ of sand within the two sand-bearing facies (Facies A and B) of the bank.

Heald Bank Shoal is a relict bayhead delta complex exposed by ravinement (Rodriguez et al., 1999). 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. (2010a, b) estimated a total of $81 \times 10^6$ $m^3$ of sand within Heald Bank.

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 meters/year (m/y) (Penland et al. 1988). Ship Shoal is ~50 km long, with a width ranging from 5-12 km. Vertical relief of the shoal varies from 5-7 m and the surface of the shoal is between the 3 and 8 m isobaths.

### *Shoal Fields*

The area called St. Bernard Shoals is an example of a shoal field. St. Bernard Shoals consists of a series of discrete sand bodies ranging in size from 0.05 to 44 $km^2$ that are located 25 km southeast of the Chandeleur Islands, offshore of the southeastern side of the Mississippi Delta, in water depths of 15-18 m (Figure 2-2; Rogers et al. 2009). The St. Bernard Shoals formed by the reworking of relict Mississippi delta distributary channel deposits exposed on the inner- to mid-shelf during and subsequent to ***shoreface*** ravinement (Rogers et al. 2009) and continue to be maintained by modern shelf processes.

Shoals that have been referred to in the past as "***shelf retreat massifs***" are poorly defined sand ridges and likely fall into one of two different classifications within the new nomenclature presented here, one of which is "relict cape-associated shoals" (see Section 2.1.3) and the other is the "relict Holocene or Pleistocene deposit shoals." We believe that shoal retreat massifs are not unique features that warrant their own separate classification and that the term should be abandoned. The shelf retreat massifs were originally thought to have formed on the flanks of shelf valleys, marking the retreat paths of the littoral-drift depositional centers along estuary mouths (Swift et al. 1978). 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). According to Swift et al. (1978), each massif consists of a series of sand ridges generally trending north-south in a comb-like array (Figure 2-3).

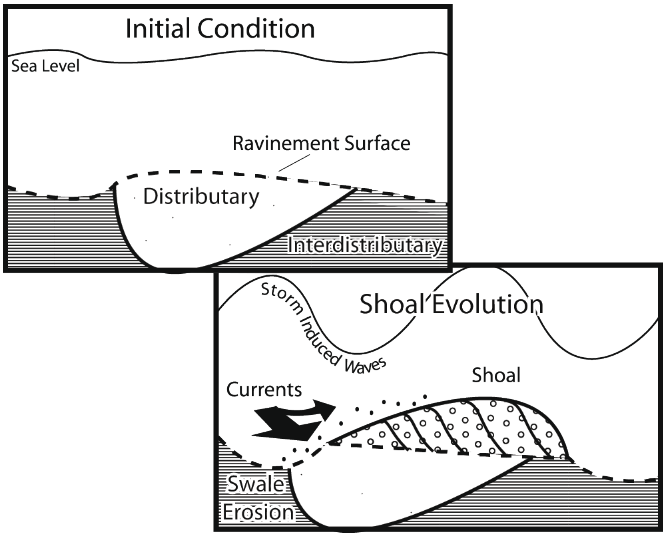


**Figure 2-2a.**

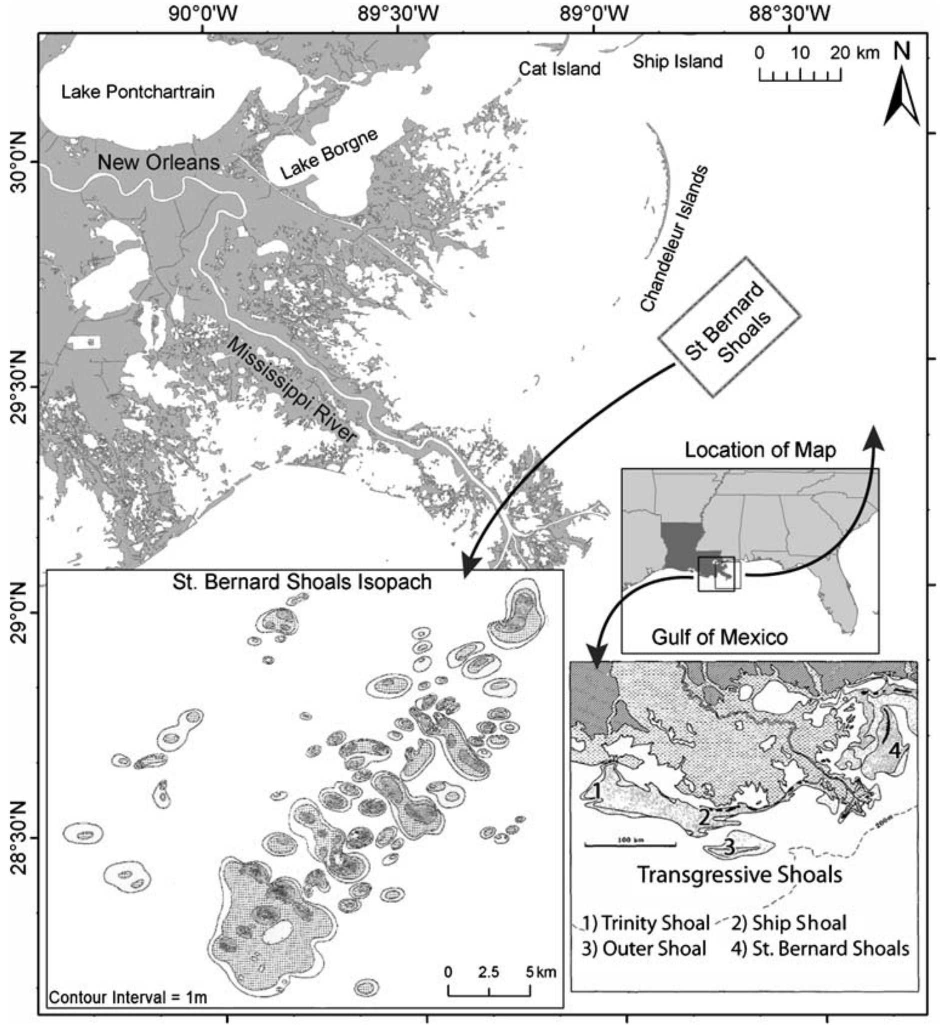


**Figure 2-2b.**

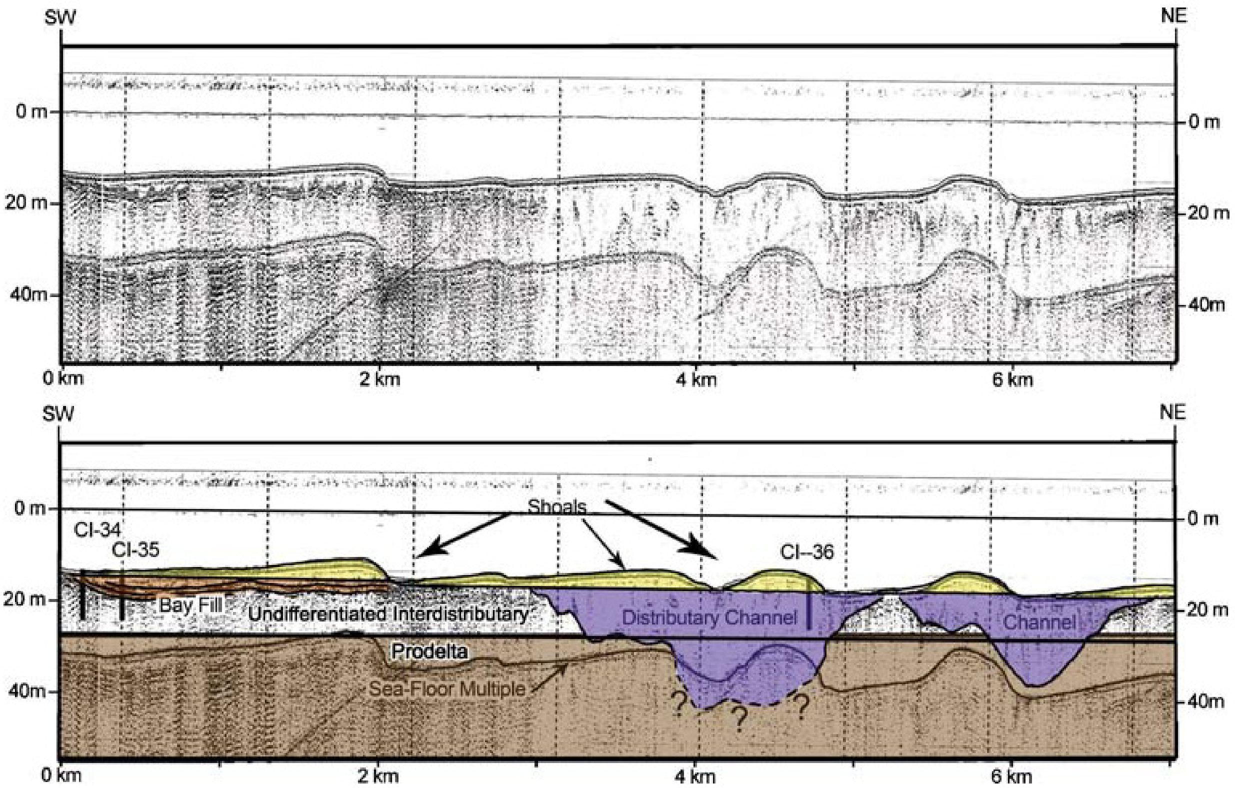


Figure 2-2c.

**Figure 2-2. Evolution and current characteristics of St. Bernard Shoals.**
**a)** Model depicting the evolution of the St. Bernard Shoals. Initially, transgression truncated the upper portion of a delta lobe. Ravinement and heterogeneity of the geotechnical properties of the seabed produced an irregular seafloor, with sand deposits slightly elevated above adjacent mud deposits. Wave generated bottom currents eroded the inshore side of the sand deposits, depositing the sand atop the original sand deposits. The shoals are oriented sub-parallel to the main current and the shoal's elevation above the surrounding sealfloor causes secondary currents to transport entrained sediment over the shoals. **b)** Basemap showing location of St. Bernard Shoals in relation to the Mississippi Delta, within the Gulf of Mexico. **c)** Seismic and interpreted seismic cross section of St. Bernard Shoal showing facies distributions. The individual shoals are asymmetrical and the present day seabed is at a lower elevation than the ravinement surface underlying the shoals. Source: Rogers et al. 2009

Along the North Carolina coast, some shoals formerly classified as "shelf retreat massifs" are actually relict Pleistocene deposits. 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 shoal complex is approximately 18 km wide, 25-35 km long, with each individual shoal ranging up to 4-6 km wide. Thieler et al. (2014) concluded that the Platt Shoals are eroded Pleistocene remnants with a modern Holocene aged sand cap.). Other shoals previously classified as shoal retreat massifs include the Susquehanna Massif off of the Eastern Shore of VA, the Virginia Beach Massif, the Albemarle Massif and the Diamond Shoals Massif, both off of NC Outer Banks (Figures 2-3 and 2-4).

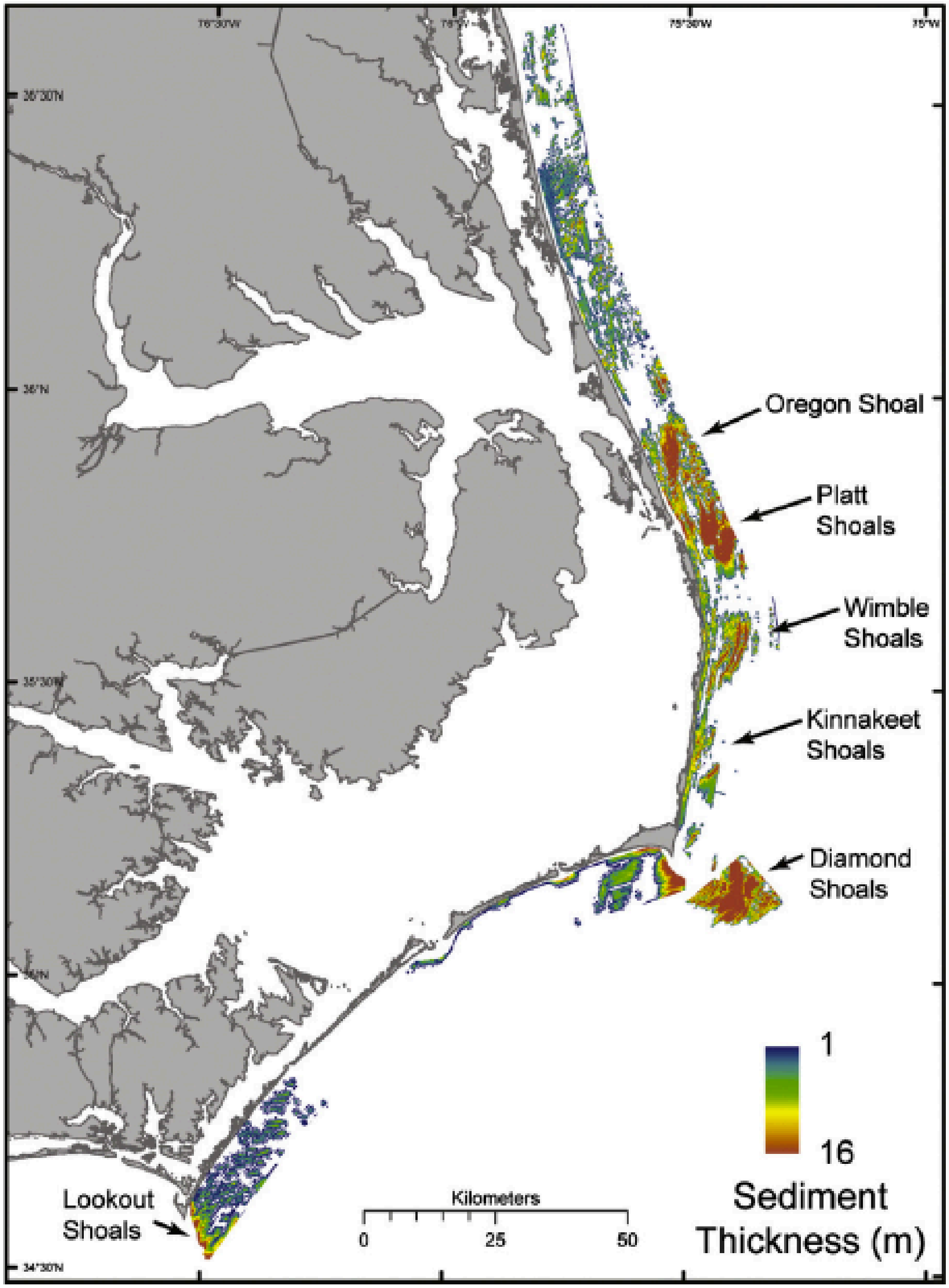

76°30'W
76°W
75°30'W
75°W
36°30'N
36°N
35°30'N
35°N
34°30'N
Oregon Shoal
Platt Shoals
Wimble Shoals
Kinnakeet Shoals
Diamond Shoals
Lookout Shoals
Kilometers
0
25
50
1
16
Sediment Thickness (m)

**Figure 2-3a.**

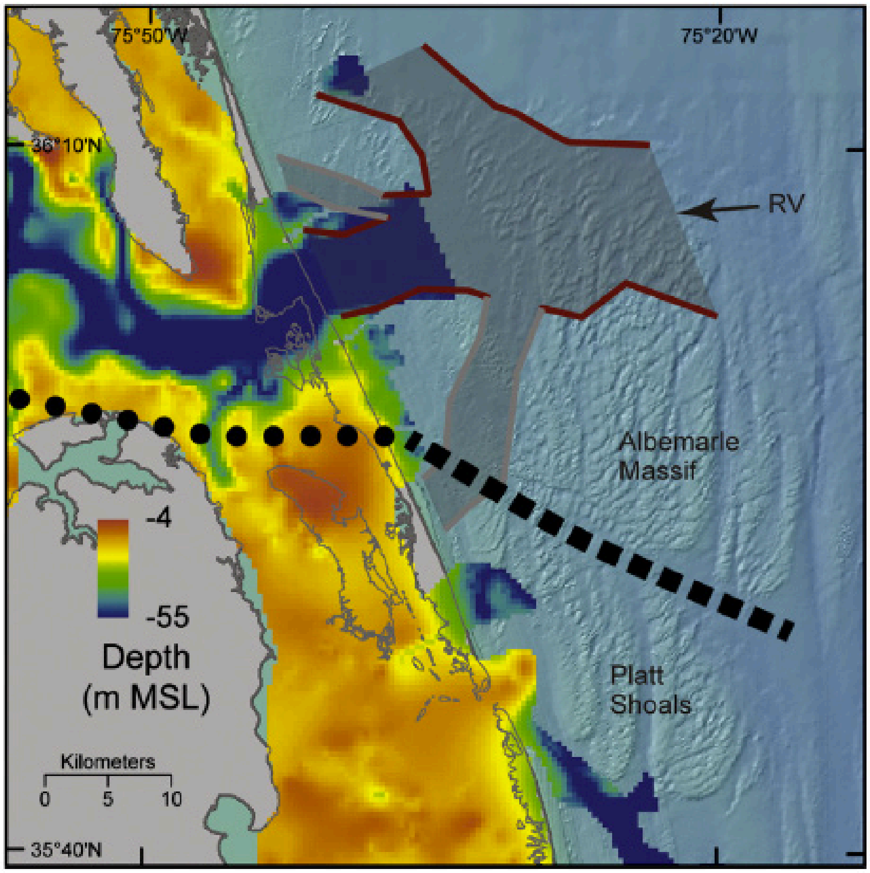


**Figure 2-3b.**

**Figure 2-3. Relict Pleistocene/Holocene Deposit Shoals.**
**a)** Shoals formerly named "Shelf Retreat Massifs" are re-classified here as either "Relict Pleistocene/Holocene Deposit Shoals" (Oregon, Platt, and Kinnakeet Shoals) or "Cape-Associated Shoals" (Wimble Shoals, Diamond Shoal and Lookout Shoals). **b)** In Swift et al. (1978), Albemarle and Platt Shoals were originally classified as "Shelf Retreat Massifs) based on the assumption that the Roanoke Valley divided the two massifs. In Thieler et al. (2014) it is demonstrated that the Roanoke Valley actually extends north of Albemarle Massif and that both Albemarle Massif and Platt Shoals are actually relict Pleistocene outcrops with a Holocene deposit of reworked Pleistocene sediment comprising the shoals. Source: Theiler et al. 2014.

## 2.1.3 Cape-Associated Shoals

Cape-associated shoals are active sedimentary systems that extend from cuspate foreland promontories formed by two barrier islands (Figures 2-3 and 2-5) or mainland beach ridges joined at approximately right angles (McNinch and Luettich, 2000). Examples include Cape Lookout Shoals, NC; Frying Pan Shoals, NC; and Canaveral Shoals, FL. In general, cape-associated shoals form due to the convergence of two longshore drift cells, and as a result of self-organization of the coast in response to a high-angle-wave instability in shoreline shape. Cape-associated shoals can also be influenced by the pre-existing geological framework (Figure 2-4; Thieler and Ashton 2011). A 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).

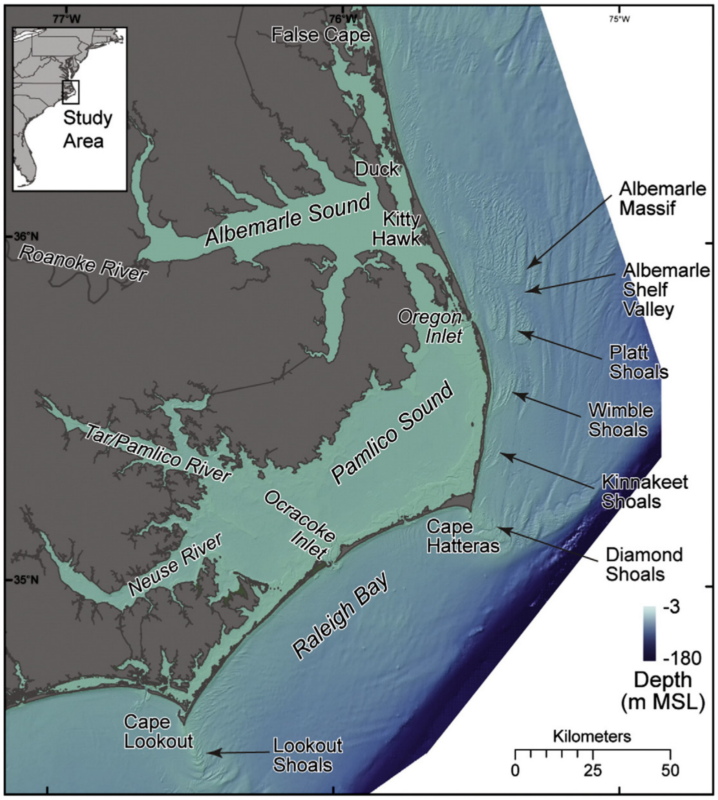


**Figure 2-4a.**

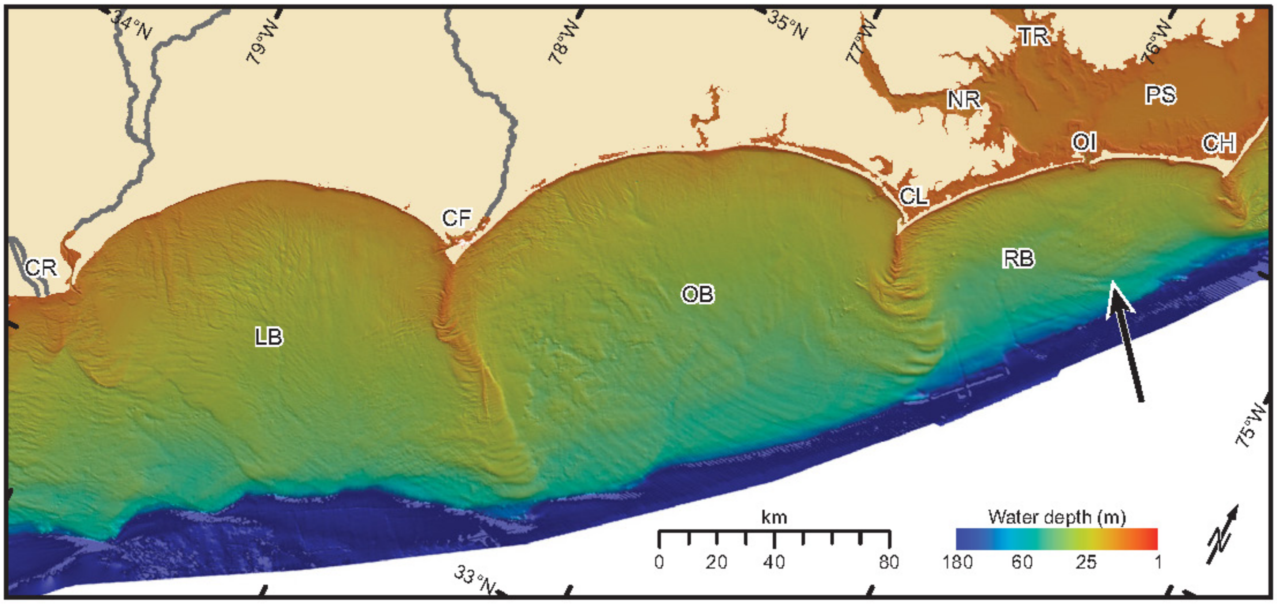


**Figure 2-4b.**

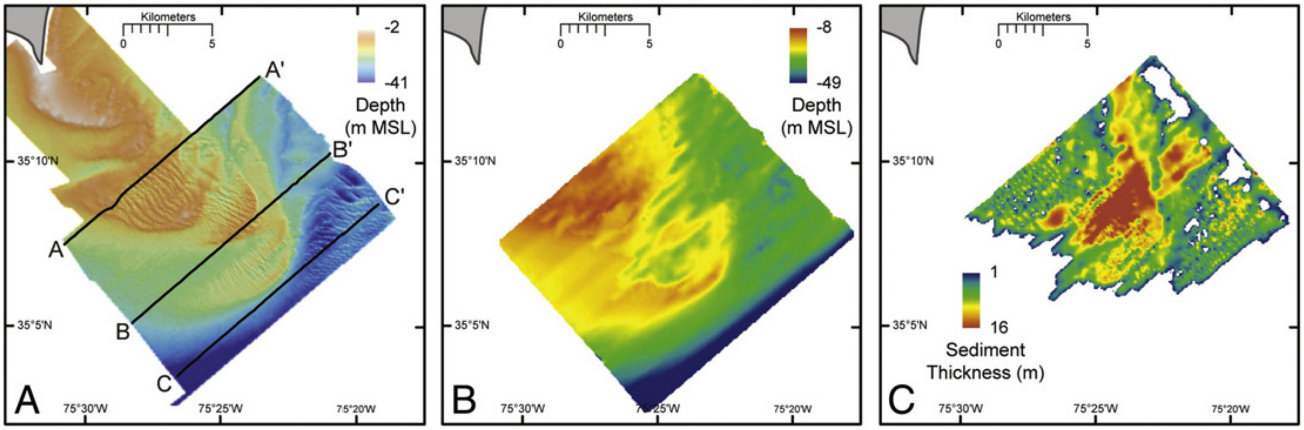


Figure 2-4c.

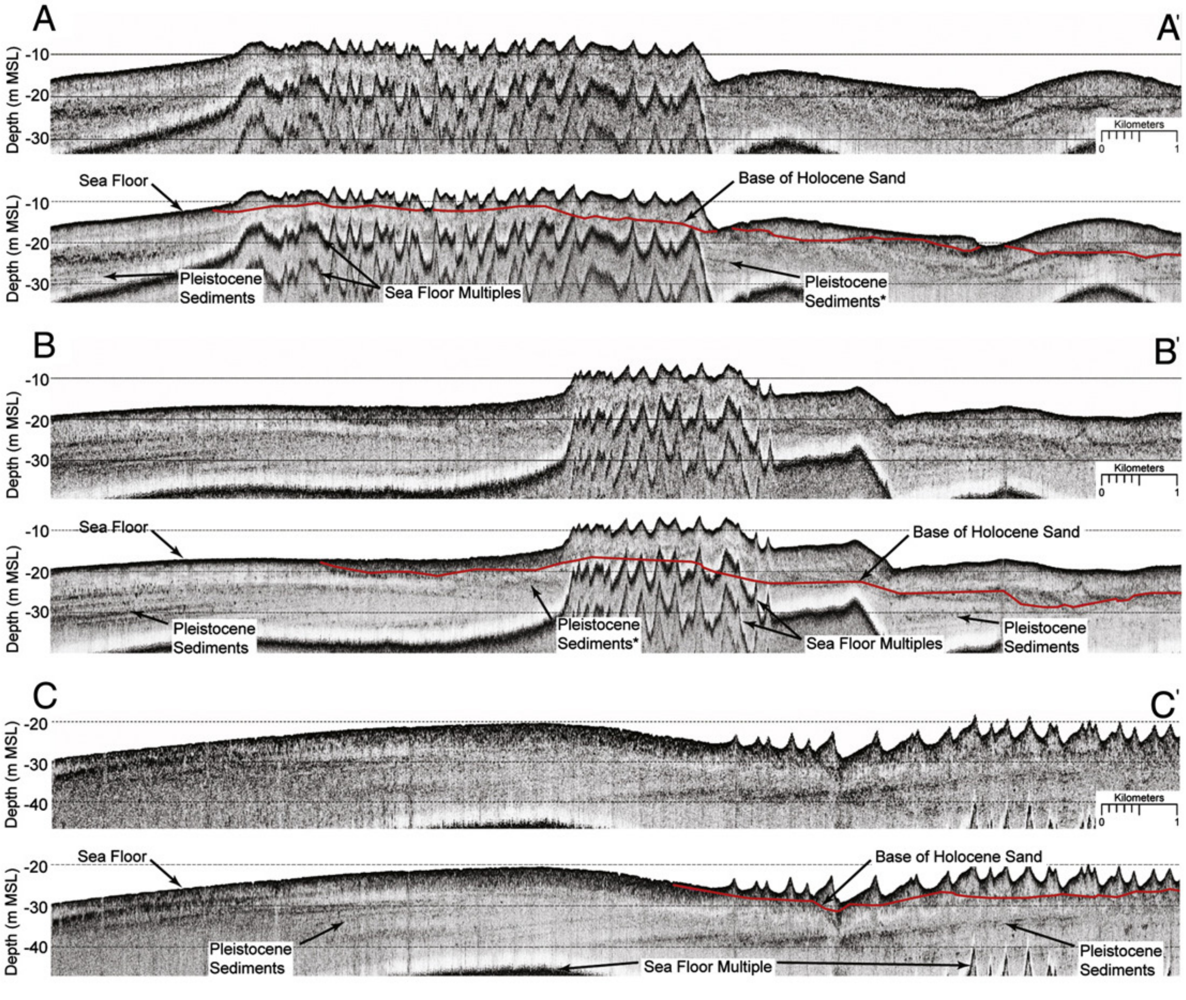


Figure 2-4d.

**Figure 2-4. Cape associated shoals and "Massifs."**
**a)** Map of Outer Banks (NC) showing Raleigh Bay, cape-associated and linear shelf shoals. **b)** Map of coast south of Cape Hatteras, with location of cape-associated shoals. **c)** Bathymetry of Diamond Shoals. **d)** Seismic profiles across Diamond Shoals. Sources: a), c), d) Theiler et al. 2014; b) Theiler and Ashton 2011.

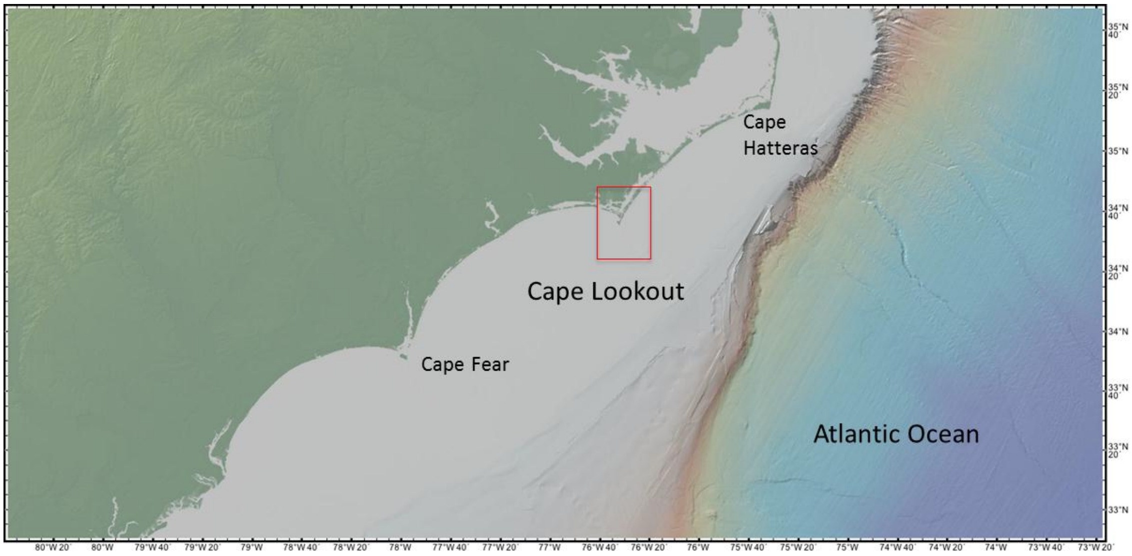


**Figure 2-5a.**

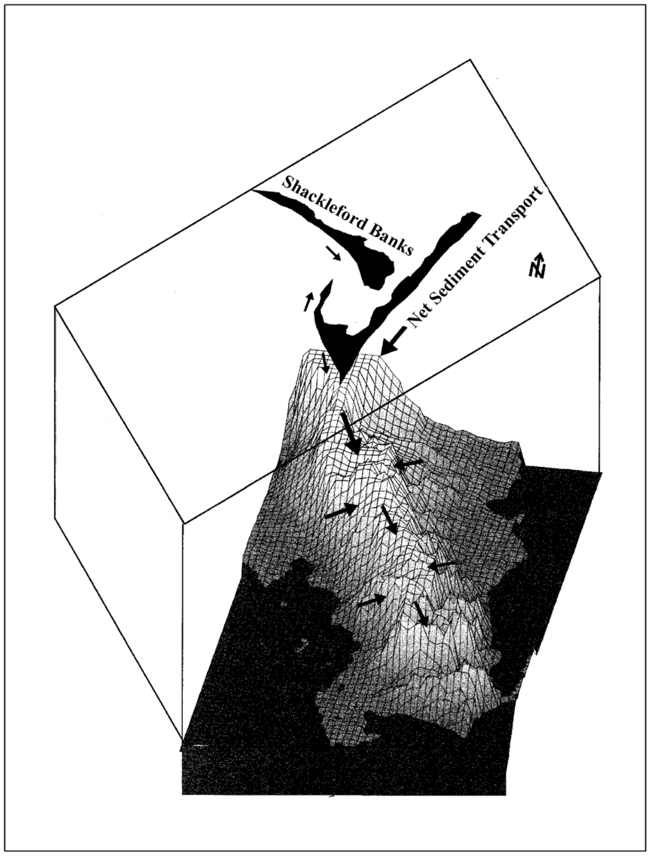


**Figure 2-5b.**

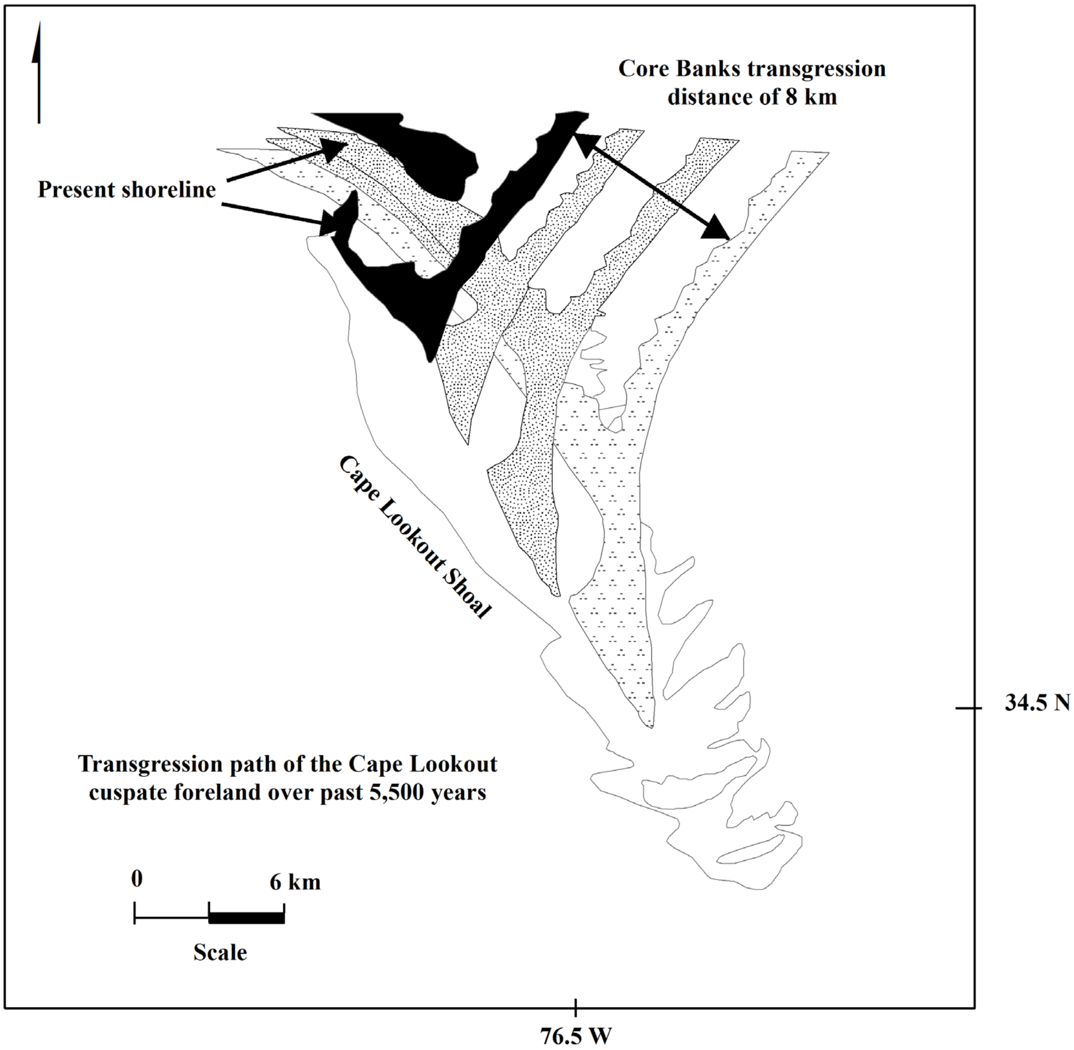


Figure 2-5c.

**Figure 2-5. Characteristics of Cape Lookout Shoal, a cape-associated shoal.**
**a)** Map showing location of Cape Lookout Shoal. **b)** 3-dimensional perspective of bathymetric map showing location of cape-associated shoals sourced from Cape Lookout and depicting formation of Cape Lookout due to the convergence of long-shore drift cells (arrows show the sediment transport directions associated with these currents). Shoals form as sediment accumulates offshore due to this current convergence. **c)** Formation of cape-associated shoals; as the shoreline retreats during transgressive sea level rise, the cape also retreats, leaving behind a series of "cape-associated shoals, with shoals increasing in age with distance from shore and increased water depth. Source: McNich and Wells 1999.

The Cape Lookout Shoals contain a series of shoals extending ~20 km offshore of the tip of Cape Lookout. The shoals are ~7-10 km wide and have a relief of up to 10 m and have migrated 8 km landward in ~5500 years. Cape-associated 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. Thieler and Ashton (2011) make a compelling case that for the Raleigh Bay section of the NC Outer Banks, the previously classified shelf retreat massifs are actually relict cape associated shoals from an abandoned cape (Figure 2-4; Thieler et al. 2014; Thieler and Ashton 2011). They found through both observations and modeling that there had been an additional cape located inshore of the shoals. However, they found that the coast has re-aligned and the cape has disappeared, leaving behind relict cape-associated shoals. An example of this would be Wimble Shoals (Thieler et al. 2014).

### 2.1.4 Bedform Shoals

According to Theiler et al. (2014), a continuum of ***morpho-sedimentary bedforms*** exists along the inner- and mid-continental shelf of siliciclastic passive ***continental margins***. The continuum ranges from ***sorted bedforms*** occupying the sediment-starved end of the continuum and linear shoals and ***shore-attached ridges*** on the sediment abundant end of the continuum. For the remainder of this report, shoals that fall within this continuum will be referred to as "***bedform shoals***" or by their specific bedform name. Theiler et al. (2014) developed this continuum based on their work along the Outer Banks, where they found well-developed sorted bedforms along sections of the coast with limited sediment being transported via long-shore drift (e.g., along Wrightsville Beach). In areas of greater sediment availability, they found the inner shelf morphology to be characterized by shore-attached ridges, such as Lookout Shoals, Platt Shoals, and Oregon Shoals (Theiler et al. 2014; Figure 2-4). The sediment-abundant end-member includes shore-attached ridges along the shoreface (0-3 m isobaths) and linear, shore-normal sand ridges offshore of the shoreface. As discussed below, near-shore and offshore ridges are believed to have started off as shore-attached ridges and are now in deeper water due to sea level rise (Swift and Field 1981).

Offshore of Long Island, Schwab et al. (2000) found well developed sorted bedforms along the eastern half of the island where sediment availability is relatively low. Along the central portion of Fire Island, where sediment availability is higher, Schwab et al. (2000) found well-developed shore-attached ridges rather than sorted bedforms. Theiler et al. (2014) concluded that this pattern is similar to the continuum they described for the North Carolina shelf.

As stated above, sand ridges are the high-sediment-availability end-member of the bedform shoals. "Ridge and swale" and "Ridge and trough" are two other terms for linear shore-normal sand shoals, typically found along the inner- and mid-shelf within the abundant-sediment end of the continuum. A more detailed explanation of sorted bedforms and linear shore-normal sand shoals are provided below. It should be noted that the deposits associated within the bedform shoals consist primarily of Holocene shelf sands, Holocene muds, and exposed Pleistocene deposits (Theiler et al. 2014).

#### *Sorted Bedforms*

Sorted bedforms (also called rippled scour depressions) are bathymetrically subtle, large-scale bed features that are characterized by alternating bands of coarse- and fine-grained sediment with wavelengths of hundreds of meters (Van Oyen et al. 2011), and negative relief of ~1m that trend obliquely to the coast (Figure 2-6; Guitierrez et al. 2005).

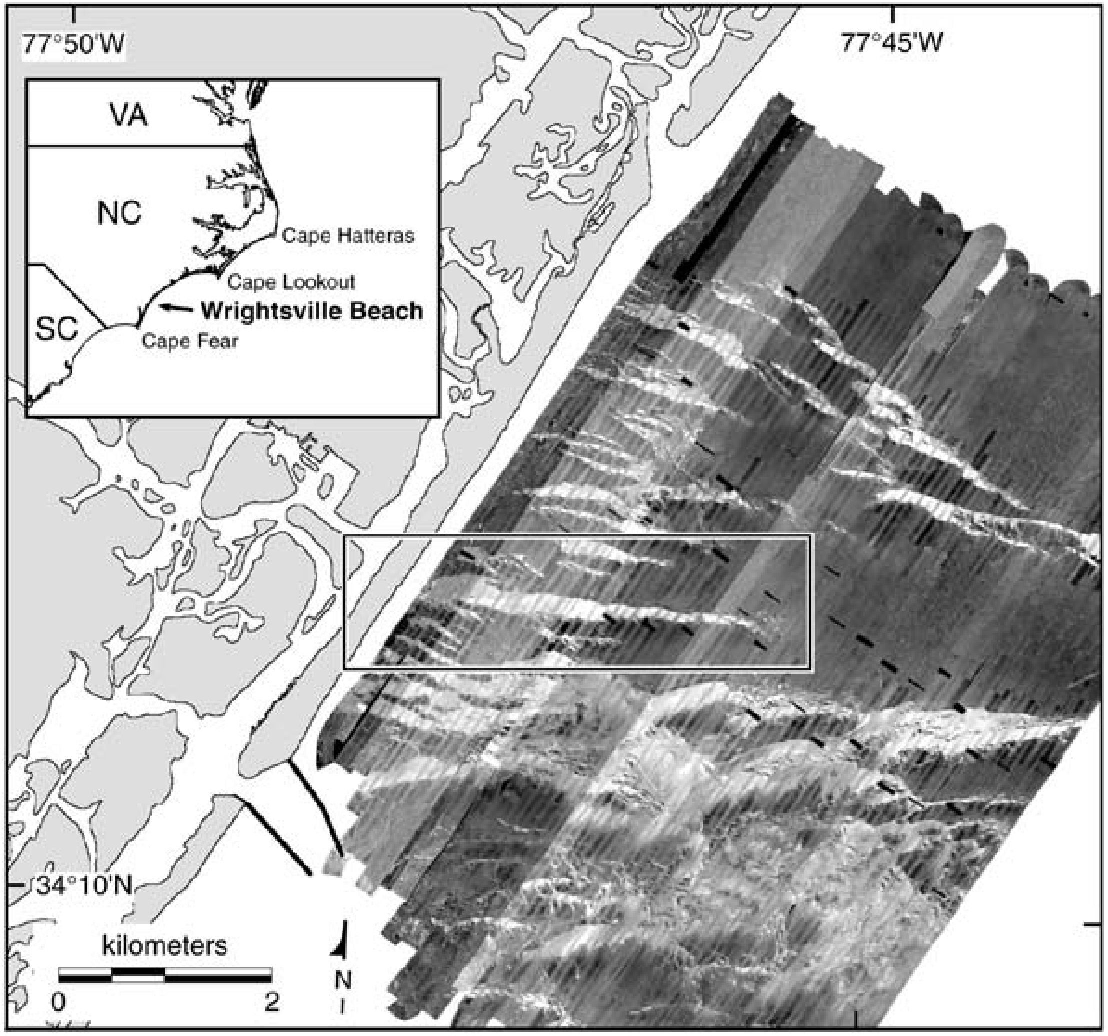


**Figure 2-6a.**

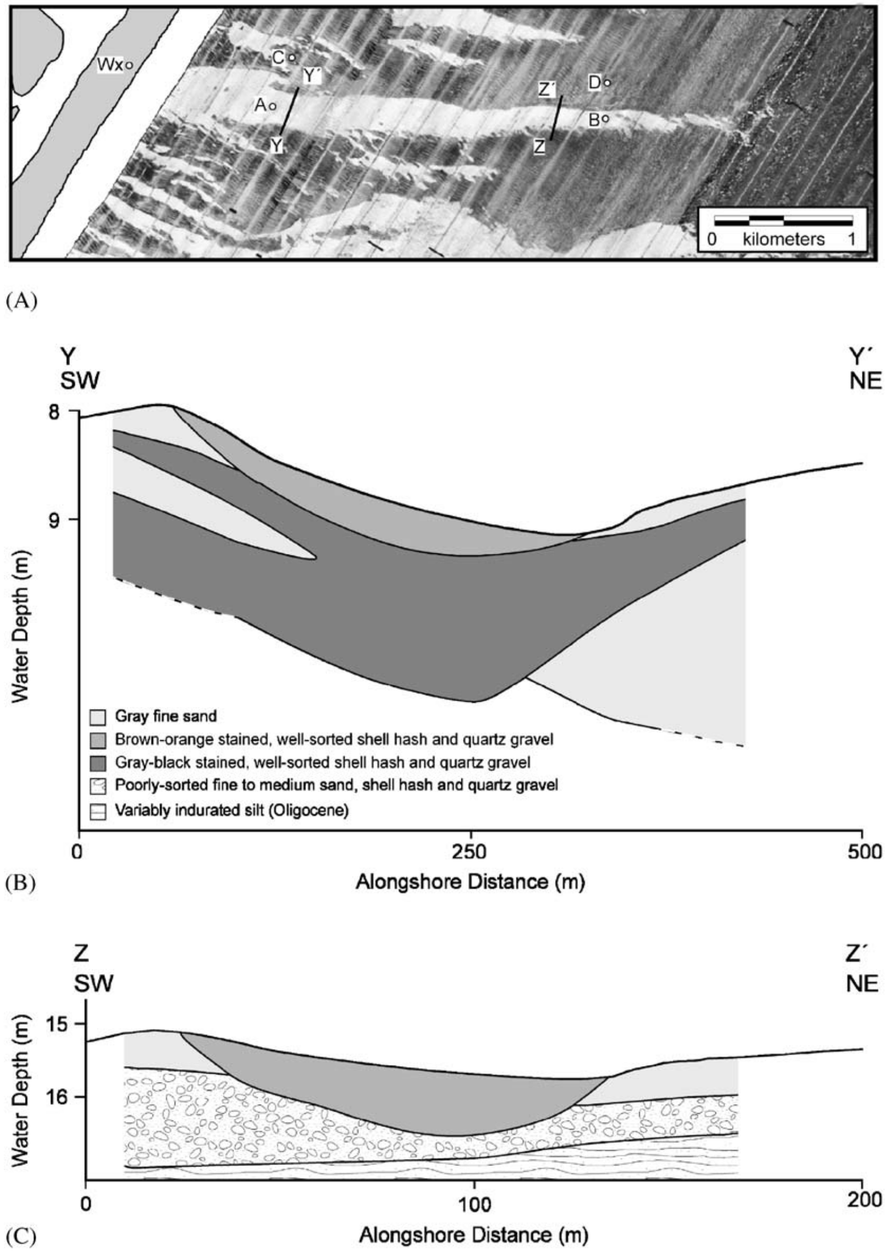


**Figure 2-6b.**

**Figure 2-6. Characteristics of sorted bedform shoals off of Wrightsville Beach, NC.**
**a)** A sidescan sonar mosaic covering the lower shoreface and inner-shelf of Wrightsville Beach, North Carolina denoting 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 by Guitierrez et al (2005). **b)** Closeup portion of the sidescan mosaic shown in a, with cross sections Y-Y' and Z-Z' showing the vertical distribution of facies. Note that the coarser sand is located within the troughs and the sediment on the ridges is actually finer grained. Source: Guitierrez et al. 2005.

According to Theiler et al. (2014), where there is a dominant direction of suspended sediment transport, sorted bedforms tend to be asymmetrical, with coarser flanks facing updrift, into the direction of dominant sediment transport (Murray and Theiler, 2004: Goff et al. 2005; Gutierrez et al. 2005). Theiler et al. (2014) state that in locations where there is no dominant current direction, sorted bedforms tend to be symmetric (e.g., Goff et al. 2005; Diesing et al. 2006). The coarse material is in the troughs (or swales) and the ridges are finer grained. 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 2-6). Active bedforms can migrate tens of meters in a month in some cases, as Goff et al. (2005) found off of Martha's Vineyard, MA. Other sorted bedforms can be relatively stable as Diesing et al. (2006) found off the German Bight in the North Sea where the bedforms had not migrated in 26 years.

A regionally extensive field of sorted bedforms is found offshore of the NC Outer Banks, extending between Capes Hatteras and Lookout (an area known as Raleigh Bay) and covering over 1000 km$^2$ (Figure 2-7; Murray and Thieler 2004). Along their study area, according to Thieler et al. (2014), the northeastern margin of the sorted bedforms is found about 10 km west of Cape Hatteras and can be divided into four distinct regions, based on bedform characteristics (Figure 2-7). This includes:

- Region A) shore perpendicular and moderately asymmetrical (wavelengths of 1.5 km and heights of 0.75-1.5 m) south of Cape Hatteras;
- Region B) north-central Raleigh Bay, where they are slightly shore oblique, with very low amplitude (>50 cm);
- Region C) south-central Raleigh 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; and,
- Region D) in southern Raleigh Bay the crests and troughs of the sorted bedforms are less continuous and their orientation is increasingly shore oblique towards Cape Lookout, and they have the morphology consistent with shore-oblique ridges.

### *Linear Shelf Sand Shoals (Ridges)*

Along the mid-Atlantic coast, linear shore-normal shelf sand shoal complexes are most prominent along the Delaware-Maryland-Virginia inner shelf, where they are the dominant features (Hayes and Nairn 2004; Swift and Field 1981; Figures 2-8 and 2-9). According to Swift and Field (1981), there are three basic types of linear shore-normal shelf sand shoal (called ridge and swale by the authors) morphologies found within the Delaware-Maryland system, they include shore-attached ridges (0-3 m isobaths), ***nearshore*** ridges (6 to 18 m isobaths and within 10 km off shore) and offshore ridges (greater than 10 km offshore). 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.

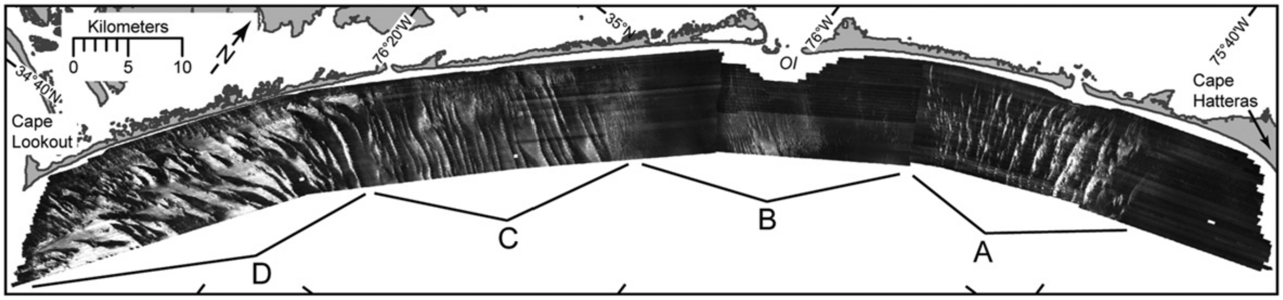


Figure 2-7a.

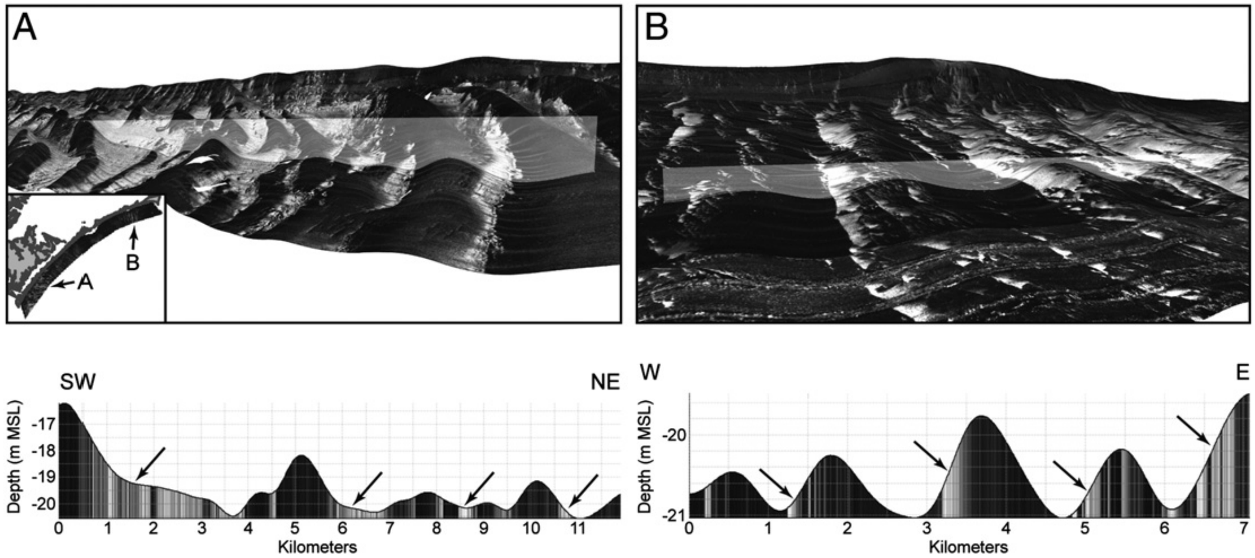


Figure 2-7b.

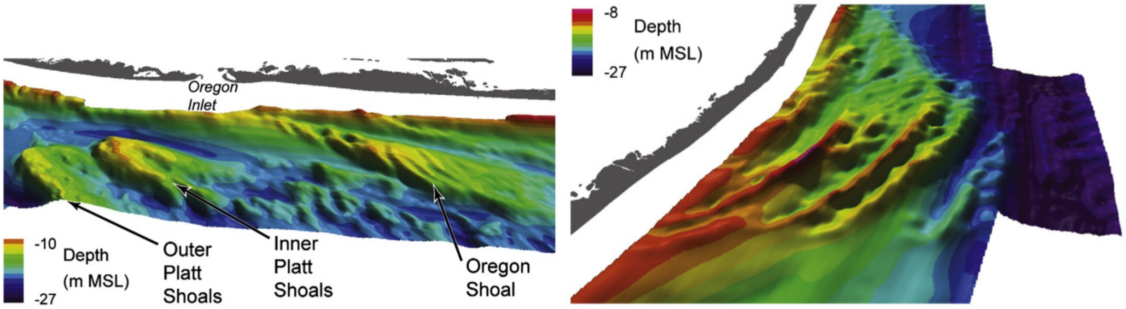


Figure 2-7c.

**Figure 2-7. Characteristics of the Continuum of Morpho-Sedimentary Bedforms.**
**a)** Sidescan sonar mosaic of the lower shoreface and inner shelf of Raleigh Bay from Cape Hatteras to Cape Lookout (Outer Banks of NC), with four distinct regions along a continuum of morpho-sedimentary bedforms. Darkest areas have the least sand and are dominated by sorted bedforms (e.g. due south of Cape Hatteras and both north and south of Oregon Inlet [OI]). Increased sand in longshore drift creates larger shoals (e.g., just north of Cape Lookout, where shore-attached ridges are found). Intermediate sand volumes in the longshore drift create linear, shore-normal to oblique ridges. **b)** Sidescan data draped over bathymetry and rotated to a perspective view along the southern (A) and northern (B) ends of Raleigh Bay with profiles showing relative seafloor bathymetry and backscatter intensity with coarse sediments denoted by arrows. **c)** Shaded relief of Oregon Shoal and Platt Shoals looking west, and of Wimbel Shoals looking north. Source: Theiler et al. 2014.

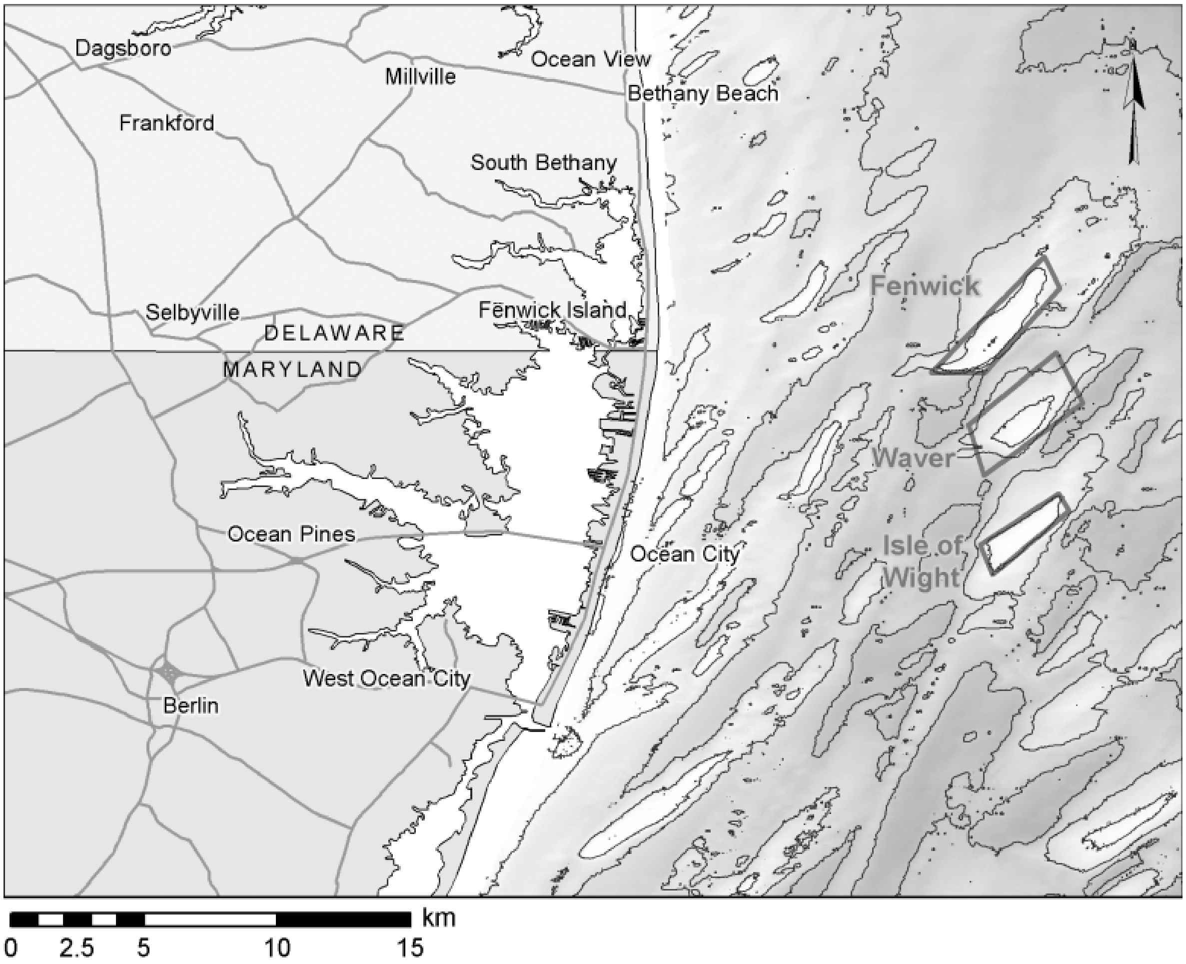
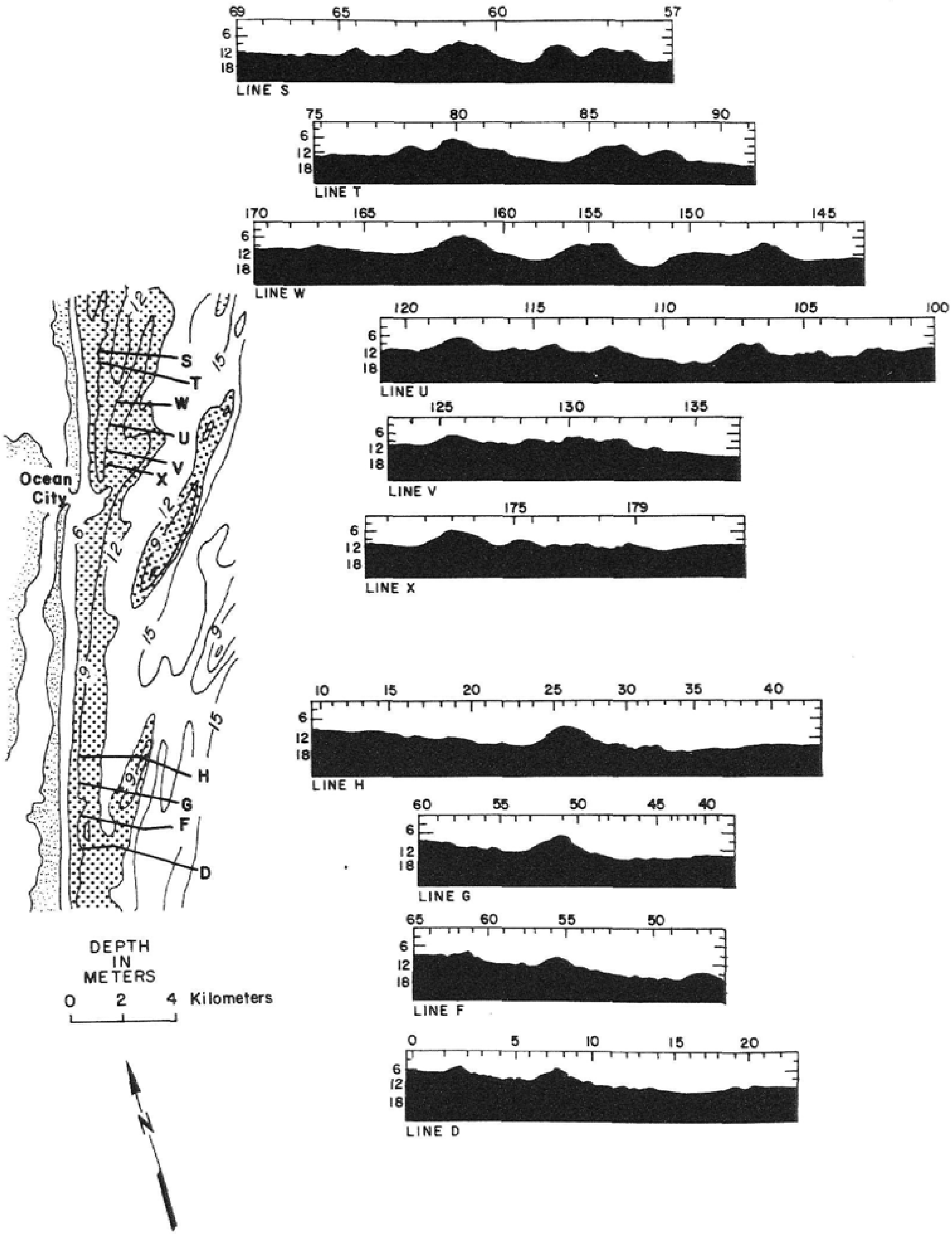


**Figure 2-8. Shoal fields off of the Maryland-Delaware coast.**
An example of the offshore linear shoal found off of Delaware and Maryland. The shoals are similar to those found off of North Carolina, exhibiting the continuum of morpho-sedimentary bedforms described in Fig. 2-7 and comparable shoal fields extend up through New Jersey and along the Long Island shelf. Source: Conkwright and Gast, 1995.


LINE S
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65
60
57
LINE T
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LINE W
170
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100
LINE V
125
130
135
LINE X
175
179
LINE H
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LINE G
60
55
50
45
40
LINE F
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60
55
50
LINE D
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5
10
15
20
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12
18
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X
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DEPTH IN METERS
0 2 4 Kilometers
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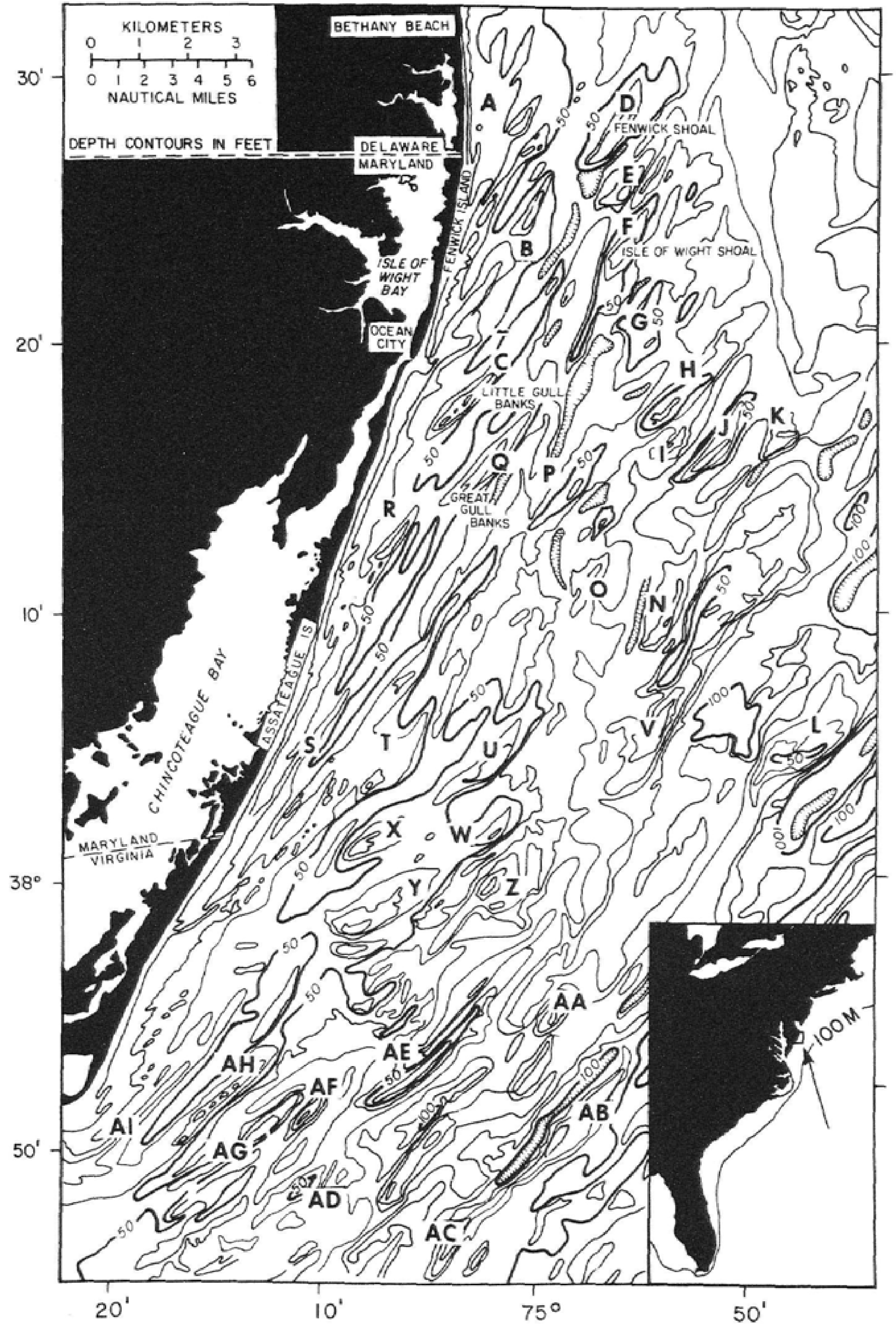
Figure 2-9a.


KILOMETERS
0 1 2 3
0 1 2 3 4 5 6
NAUTICAL MILES
DEPTH CONTOURS IN FEET
BETHANY BEACH
DELAWARE
MARYLAND
FENWICK ISLAND
ISLE OF WIGHT BAY
OCEAN CITY
FENWICK SHOAL
ISLE OF WIGHT SHOAL
LITTLE GULL BANKS
GREAT GULL BANKS
ASSATEAGUE IS
CHINCOTEAGUE BAY
MARYLAND
VIRGINIA
A
B
C
D
E
F
G
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J
K
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AF
AG
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20'
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75°
50'

Figure 2-9b.

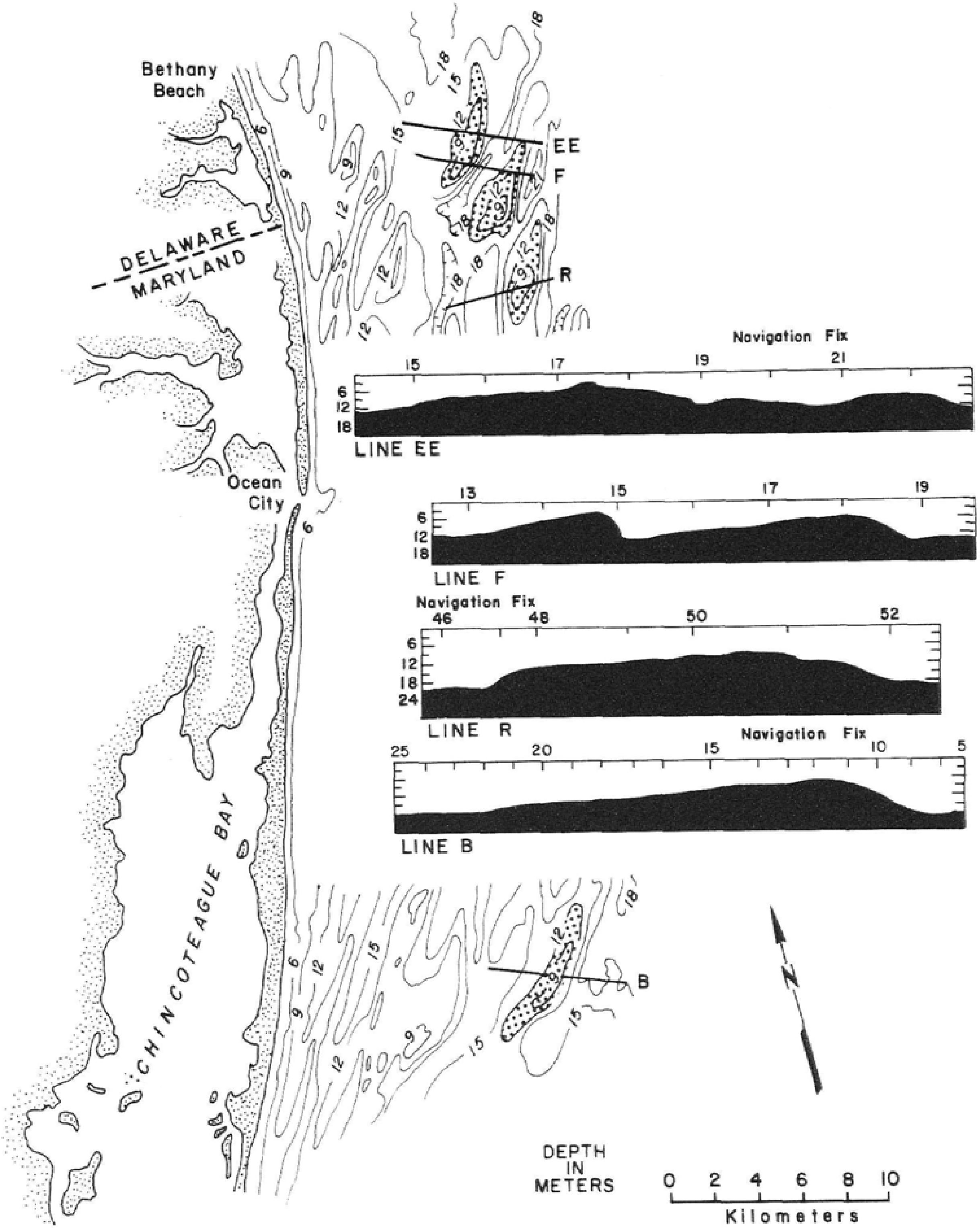
Bethany Beach
DELAWARE
MARYLAND
Ocean City
CHINCOTEAGUE BAY
EE
F
R
B
Navigation Fix
15 17 19 21
6 12 18
LINE EE
13 15 17 19
6 12 18
LINE F
Navigation Fix
46 48 50 52
6 12 18 24
LINE R
Navigation Fix
25 20 15 10 5
LINE B
N
DEPTH IN METERS
0 2 4 6 8 10
Kilometers

Figure 2-9c.

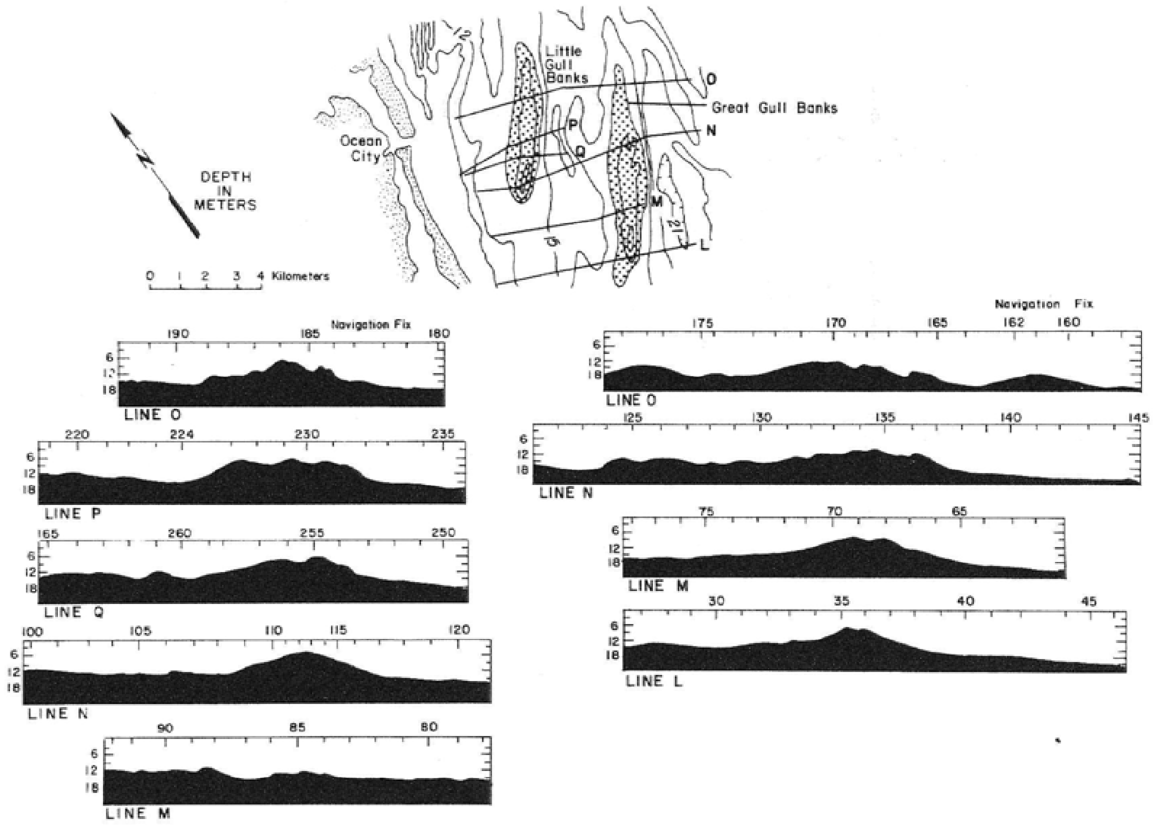

**Figure 2-9d.**

**Figure 2-9. Shoals along the Mid-Atlantic Bight.**
**a)** Map view and fathometer profiles of shore-attached shoals. **b)** Bathymetry of Assateague Shoal Field, showing near shore and offshore linear shore oblique shoals. **c)** Map view and fathometer profiles from transects across offshore shoals. **d)** Map view and fathometer profiles across nearshore shoals. Source: Swift and Field, 1981.

Swift and Field (1981) state that there is a continuum in linear shore-normal shelf sand shoal complex evolution (which is a subset of the overall shelf morpho-sedimentary continuum of bedforms described above). Swift and Field (1981) describe this continuum of "ridge and swale" evolution with the features beginning as shore-attached ridges that extend offshore, oriented obliquely extending roughly northeast-southwest, where they lose their identity along ~3 m isobaths. The shore-attached ridges tend to occur in clusters. Nearshore ridges generally occur between the 6 and 18 m isobaths and occur within 10 km of shore. Nearshore ridges have lower gradients on their flanks than the shore-attached, have their shallowest points on their southern ends and also bifurcate into sub-ridges. The swales associated with the nearshore ridges, however, have lower negative relief than the swales associated with the shore-attached ridges. The offshore ridges are found 10 m and further offshore, 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) pointed 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 within the swales, with the ridges being dominated by sand and a shell-lag/gravel mix 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 along-shelf transport at a rate of 1 km/1000 yrs or 1 m/y.

Linear ridge complexes comparable to the Delaware-Maryland-Virginia shelf, oriented parallel to the dominant wave approach direction are the most commonly observed features along the continental shelves in the Mid-Atlantic Bight, both the Atlantic and Gulf coasts of Florida, and the northeastern GOM (see examples in Figures 2-8 through 2-10. Waves approach from the northeast in the Mid-Atlantic Bight and from the southeast in the northeastern GOM. These sand ridges are generally over 1000 m long, 1 to 4 km wide with wavelengths of 1 to 11 km, with relief up to 12 m, and side slopes that average approximately 1° (McBride and Moslow 1991, Hayes and Nairn 2004, Byrnes et al. 2004b). These well-developed sand ridge fields are found predominantly along wave-dominated barrier island coastlines with small tidal ranges (McBride and Moslow 1991). The sand ridges in the Mid-Atlantic Bight on the Delaware-Maryland shelf occur in all stages of formation (Figure 2-9) and demonstrate the systematic change from shore-attached ridge through nearshore ridge to offshore ridge, reflecting the changes in the hydraulic regime (Swift and Field 1981). Fenwick, Weaver, and Isle of Wight Shoals in the Mid-Atlantic Bight; Anclote and Captiva; and Resource Area 2 off the coast of Alabama (Figure 2-10) are examples of these ridge and trough complexes (Finkl et al. 2007b, Byrnes et al. 2004b).

The west-central Florida shelf is unique in comparison to the other sections of the coast discussed in this synthesis. It consists of a ***veneer*** of unconsolidated carbonate and siliciclastic sediment ranging in thickness from a few centimeters (cm) to 4 m and is underlain be an irregular base of Miocene limestone bedrock (Brooks et al. 2003; Duncan et al. 2003; Hine et al. 2003; Locker et al. 2003). A series of sand ridges exists along the inner to mid shelf 3-25 km offshore. These were characterized in detail off of Sanibel Island, FL (Figure 2-11) along the west central section of the Florida peninsula (Twichell et al. 2003). Each ridge is about 0.5-1.5 km wide and 1-15 km long (Finkl et al. 2007b; Figure 2-11). The ridges appear in form and process to be on the sediment-starved sorted-bedform portion of the bedforms-shoals continuum. It should be noted that the West Florida shelf is quite different from the other shelves discussed herein, because of its geologic setting. The West Florida shelf is situated on a carbonate platform and the shelf is generally 250 to 325 km wide. In many places the siliciclastic shoals are situated proximal to limestone outcrops, which are hard bottoms that provide unique habitats.

## 2.2 Physical Processes Governing Shoals

### 2.2.1 Regional Differences between Shelf/Shoal Settings

Physical oceanographic conditions vary among the different shoal settings. This arises both because of variations among dominant processes between systems as well as variations in shelf configuration.

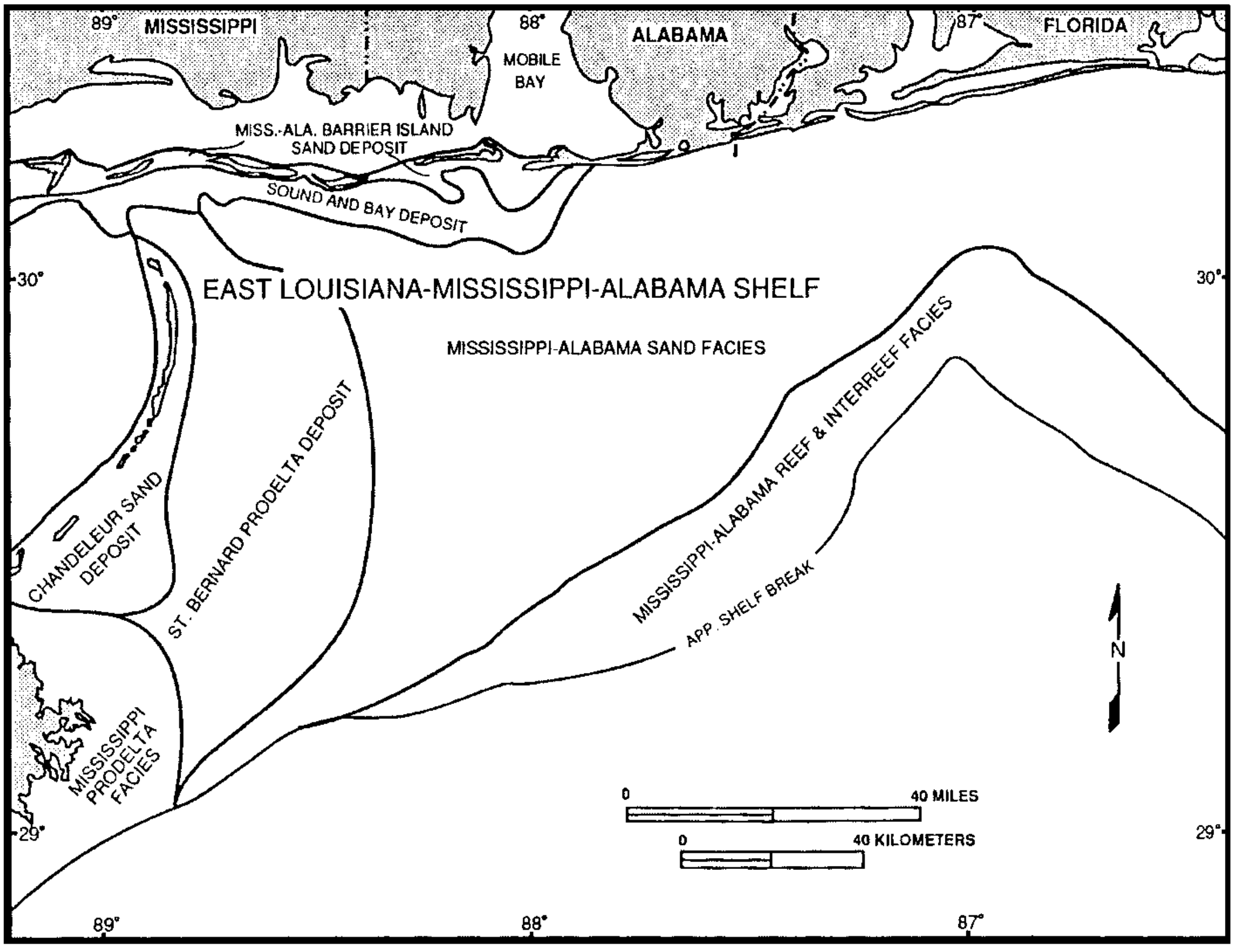

Figure 2-10a.

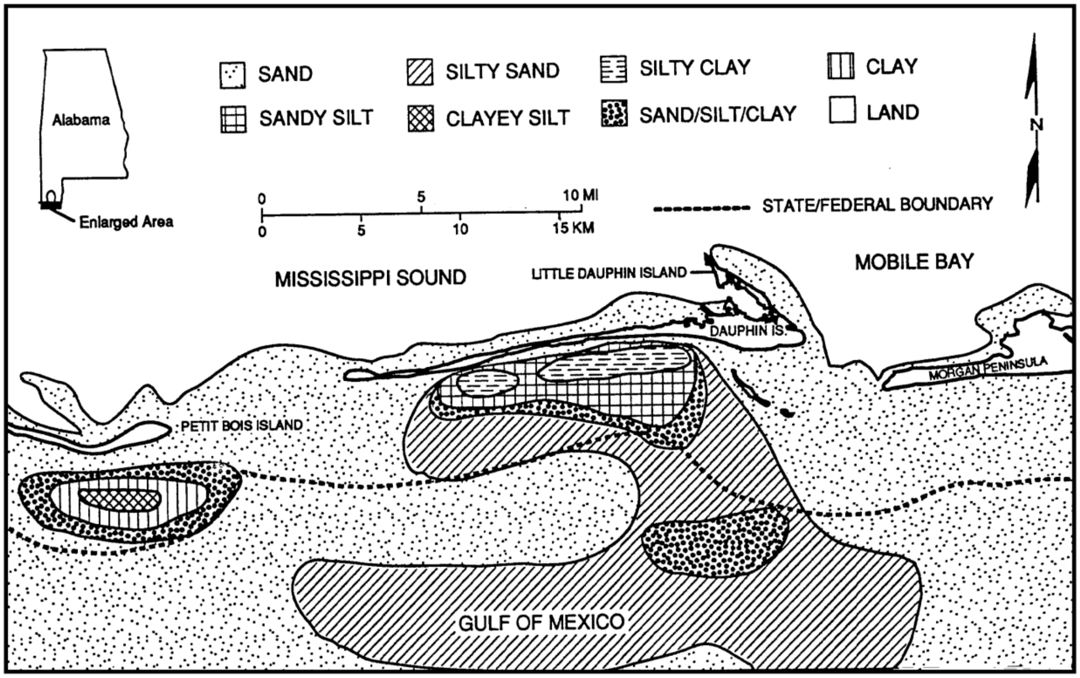

**Figure 2-10b.**

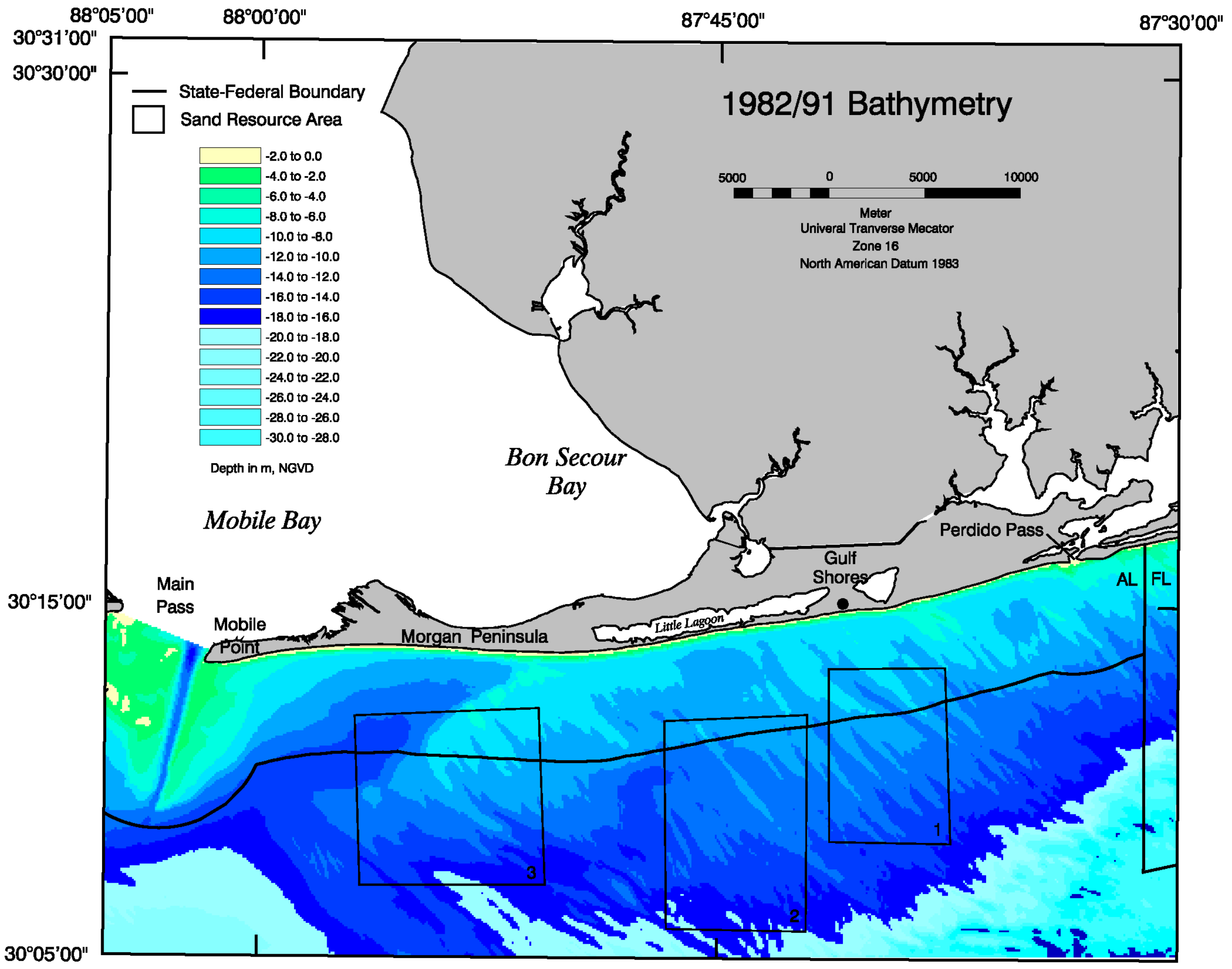

Figure 2-10c.

**Figure 2-10. Characteristics of Resource Area 2 shoals off the coast of Alabama.**
**a)** Sedimentary facies on east Louisiana-Mississippi-Alabama Shelf. **b)** Surface sediment distribution in west Alabama inner continental shelf. **c)** Nearshore bathymetry for the northeastern Alabama coastal zone showing shore oblique shoals comparable to those found off the Mid-Atlantic coast of the USA (Figures 2-8 and 2-9), demonstrating the presence of the continuum of morpho-sedimentary bedforms along the northeastern GOM coast. Source: Byrnes et al. 1999.

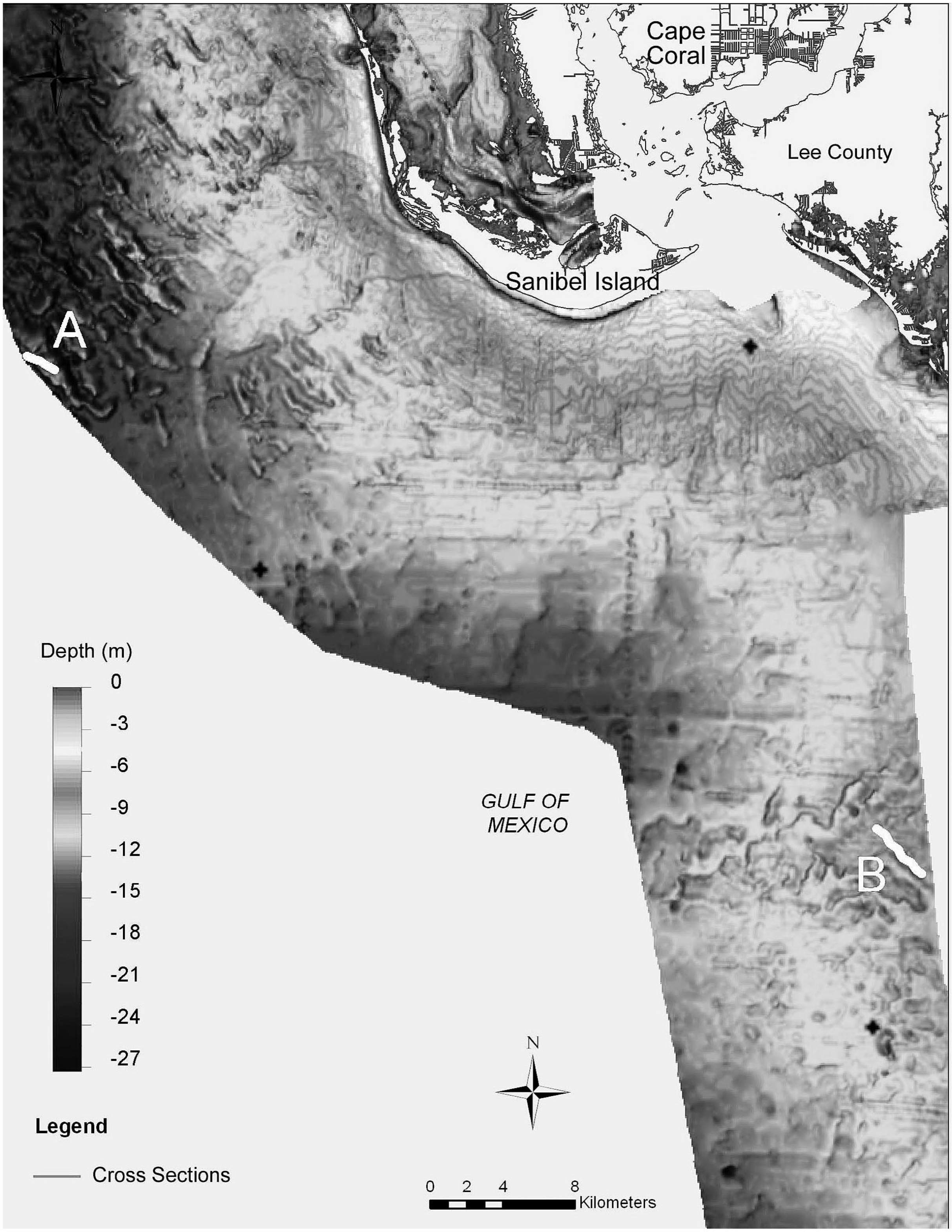
N
Cape Coral
Lee County
Sanibel Island
A
B
GULF OF MEXICO
Depth (m)
0
-3
-6
-9
-12
-15
-18
-21
-24
-27
Legend
Cross Sections
N
0 2 4 8
Kilometers

Figure 2-11a.

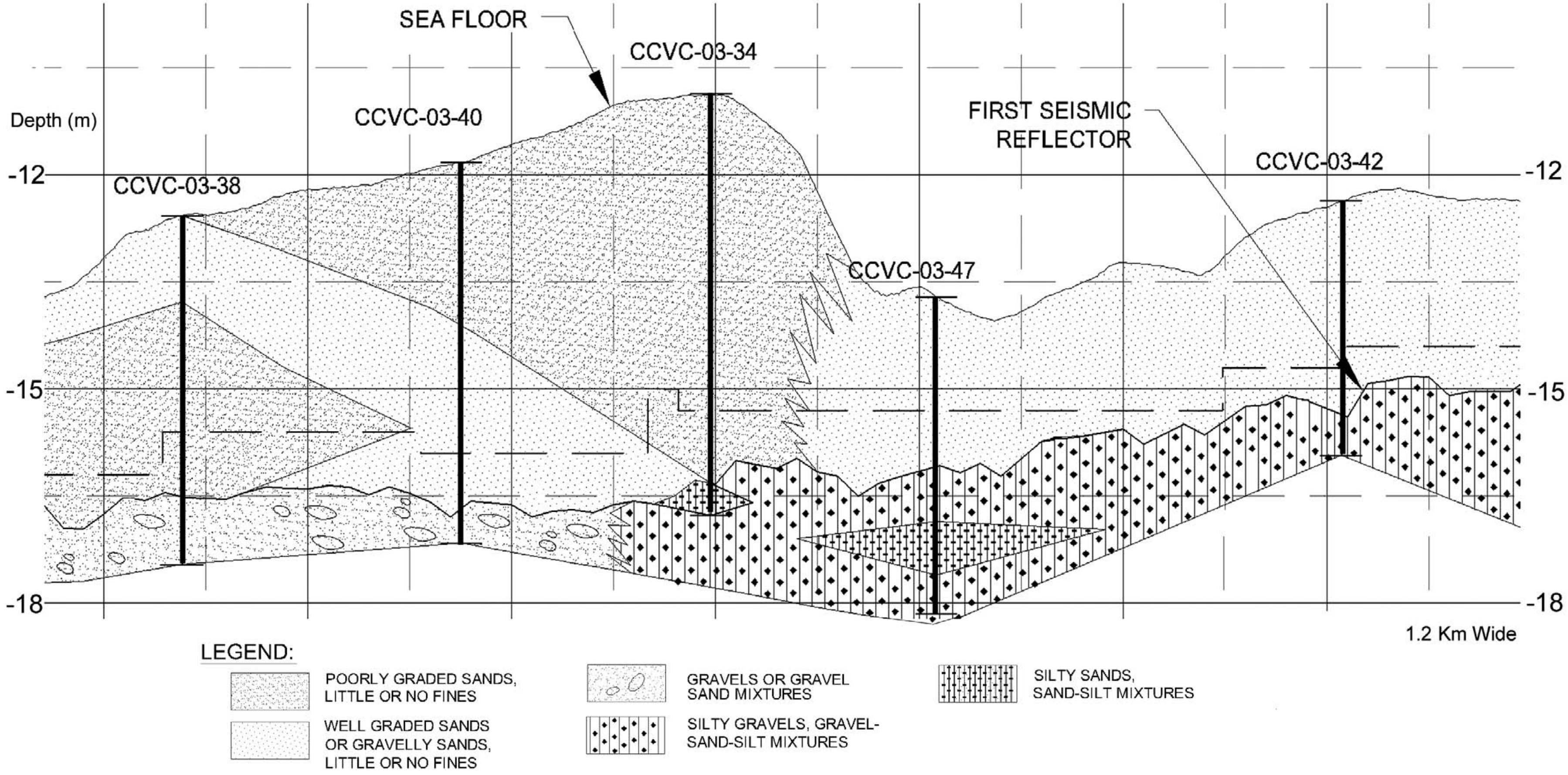
SEA FLOOR
CCVC-03-34
CCVC-03-40
CCVC-03-38
FIRST SEISMIC REFLECTOR
CCVC-03-42
CCVC-03-47
Depth (m)
-12
-15
-18
-12
-15
-18
1.2 Km Wide
LEGEND:
POORLY GRADED SANDS, LITTLE OR NO FINES
WELL GRADED SANDS OR GRAVELLY SANDS, LITTLE OR NO FINES
GRAVELS OR GRAVEL SAND MIXTURES
SILTY GRAVELS, GRAVEL-SAND-SILT MIXTURES
SILTY SANDS, SAND-SILT MIXTURES

**Figure 2-11b.**

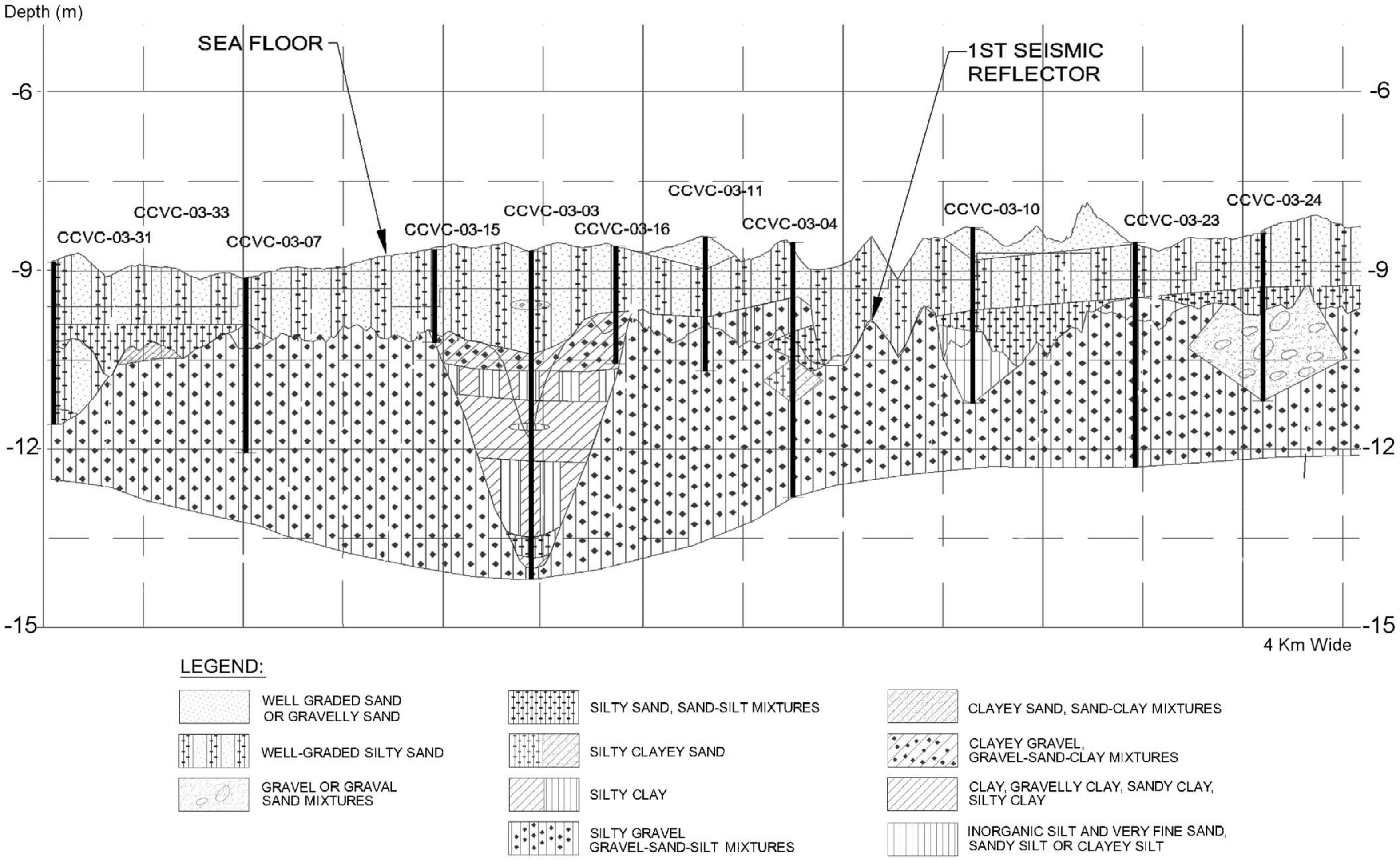

**Figure 2-11c.**

**Figure 2-11. Linear Shoals-Eastern Gulf of Mexico.**
**a)** Side scan sonar mosaic showing linear sand shoals off of the west coast of Florida. The shoals are widely spaced sand ridges interspersed with karstified limestone hard grounds. **b)** cross-section A showing distribution of sedimentary facies within the shoal. **c)** cross section B showing distribution of sedimentary facies within the shoal. Source: Finkl et al., 2007b.

The inner continental shelf extends across the region immediately seaward of the surf zone where waves typically (or frequently) agitate the bed (Wright 1995), and for most coasts, this is generally between the 30 and 50 m isobaths. Both the Atlantic and GOM coasts in North America are along tectonically passive continental margins. The shape of wave-dominated inner continental shelves, and in particular the shoreface profile, of passive margin coasts represents a dynamic equilibrium balanced by the input of wave dynamics and sediment supply (Wright 1995). The noted exception to this would be coasts with drastic alterations to sediment supply such as those occurring along active or recently abandoned delta systems where the shoreface profile and shoreline orientation are still striving to reach a dynamic equilibrium configuration relative to dominant wave and/or tidal conditions. According to Nittrouer and Wright (1994) and Wright (1995), the physical oceanographic processes that control sediment transport and ultimately control the fluxes of sediment and shape of the profiles of the continental shelves include: 1) wind-driven currents along the shelf and across- theshelf (upwelling and downwelling); 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 (Figure 2-12). Process gradients are steep across the inner shelf; as the shelf is traversed from deep water to the surf zone, the relative intensities and sometimes the prevailing orientations of the different types of flows change (Wright 1995).

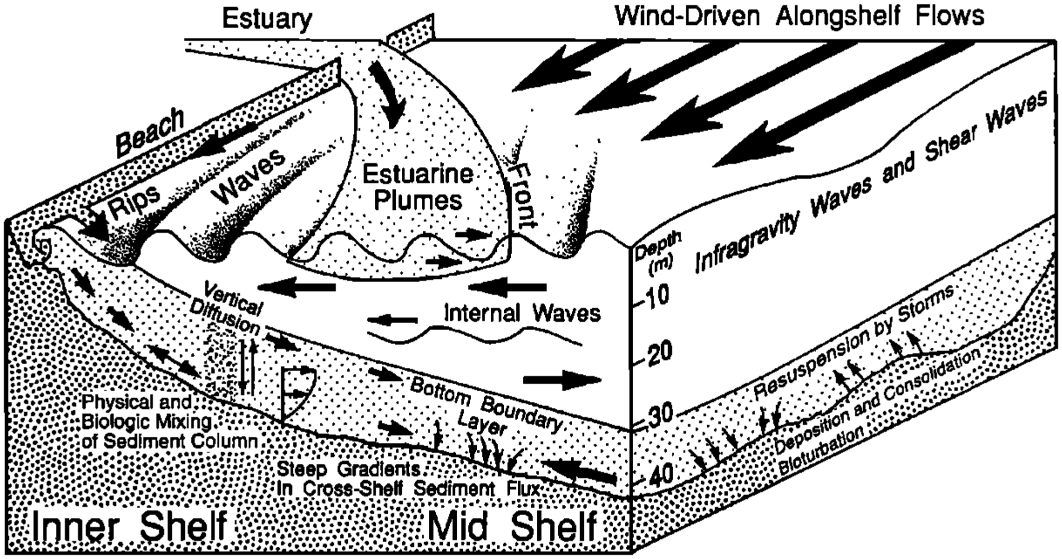

**Figure 2-12. Conceptual diagram illustrating the major physical processes responsible for across-shelf particulate transport.**
Source: Nittrouer and Wright, 1994.

Bathymetric profiles differ along the continental shelf in the Atlantic and GOM study areas. Figure 2-13 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 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 North Carolina, across a series of cape-associated shoals that appear to extend to the shelf break 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 the 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 relatively narrow in this area and the outcrops of limestone on the mid and outer shelf may be a significant influence on this profile. Along the Mississippi-Alabama GOM shelf (Profile E), there is a break in slope around 30 m, representing the inner-mid shelf division and a second break in slope around 40 m proximal to the shelf break.

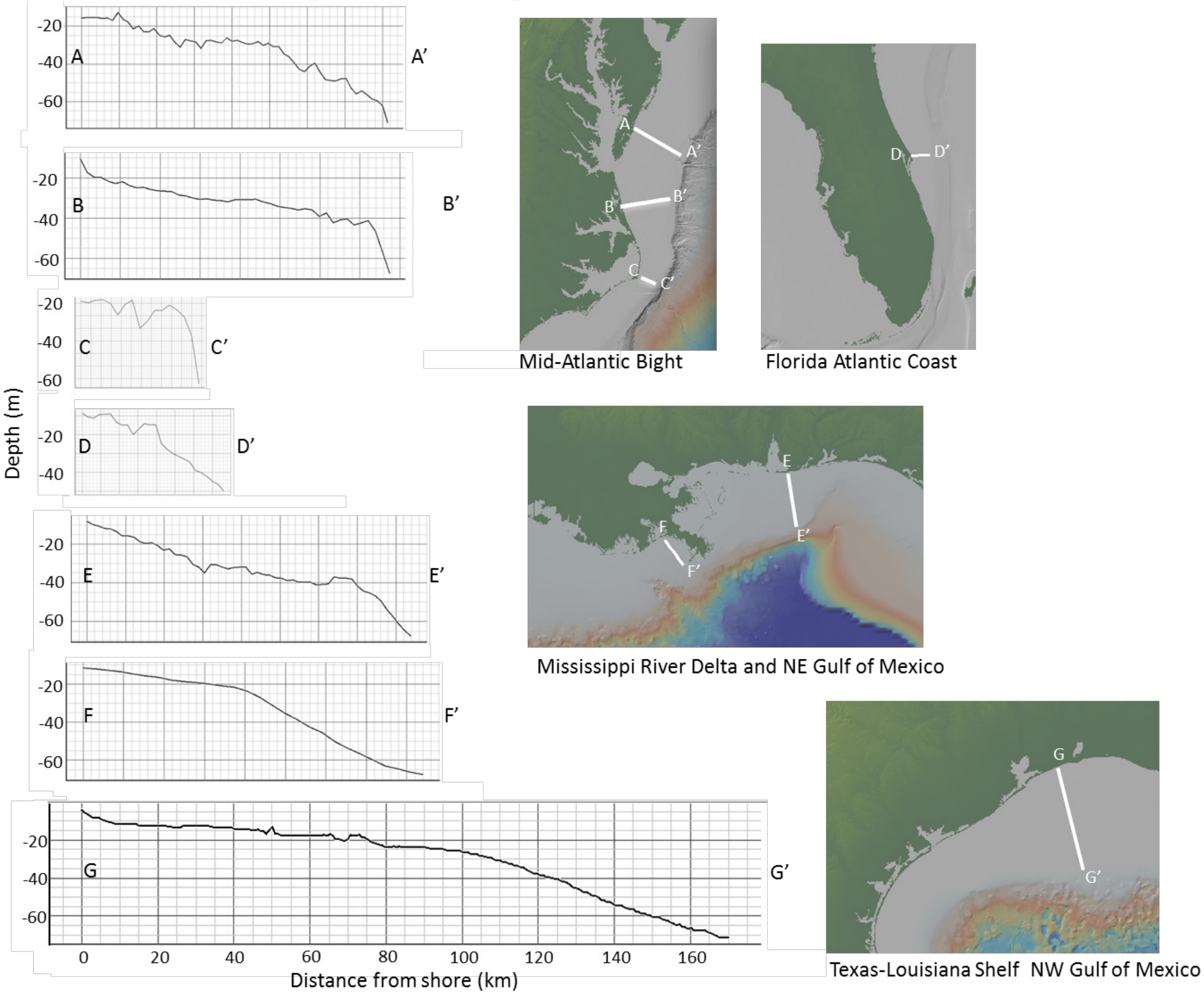

**Figure 2-13. Cross-shelf bathymetric profiles of the continental shelves of the US Atlantic and Gulf of Mexico OCS.**
Profiles and maps generated using Geomap App 3.4.1. (Ryan et al., 2009 ).

The Mississippi River Delta shelf (Profile F) is in a low-energy area and the break in slope for the inner-mid shelf is at around 20 m. The inner-mid shelf break along the western Louisiana and eastern Texas shelf occurs around 25 m. Thus, as Figure 2-13 demonstrates, there is a high degree of spatial heterogeneity in shelf geometry across the regions examined in this synthesis. As shelf width and slope of the shelf control process gradients, steep and narrow shelves will generally have steeper gradients in process than will flatter and wider shelves (Wright 1995).

### 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 contrast between the two regions where offshore sand banks are discussed in this synthesis.

#### *Atlantic*

According to Wright (1995), the near-bottom flows that facilitate sediment transport and morphodynamics in the Mid-Atlantic Bight are storm-dominated. The highest bed stresses and highest sediment transport rates coincide with wind events; fair weather flows and tidal currents are generally weak. The storms that dominate this region are primarily extratropical storms, typically "northeasters," 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 northeasters (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 Mid-Atlantic Bight. The Gulf Stream turns eastward south of Cape Hatteras and does not directly impinge on the shelf of the Mid-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).

Along the Atlantic coast, with the noted exception of the southern tip of Florida, the frequency of hurricanes striking a specific section of the coast ranges from once every 4.7 years for the Outer Banks of North Carolina to 1-5 strikes in between 1900 and 2010 and major strikes averaging once every 1.5 years, with most regions having a strike every 10 years or less and major strikes every 50 years or less, The Atlantic coast south of Cape Hatteras is subjected to a much higher incidence of hurricanes than along the Mid-Atlantic. These storms are capable of suspending and transporting large amounts of sediment. Wren and Leonard (2005) measured sediment transport in Onslow Bay associated with the Category 5 hurricane Isabel in 2003. Several days before the hurricane passed through the area, it generated long-period swells up to 4 m high resulting in shear velocities ranging from 6 to 10 cm $s^{-1}$ that caused bedload and suspended sediment transport. The storm's winds altered the subtidal currents from 15 cm $s^{-1}$ towards the southwest to 16 cm $s^{-1}$ towards the northeast. Sediments were reworked 7 cm by the wind-driven waves and currents.

#### *Gulf of Mexico*

The northern GOM is, in general, a much lower energy regime than the Mid-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 Atchafalaya River plumes, whereas waters to the west can be. Tidal ranges along the northern GOM coast are generally less than 40 cm, as a result, tidal currents tend to be weak. Sedimentary processes in the GOM are affected by several weather conditions (cold fronts, tropical storms, hurricanes, and extratropical storms as well as discharge from the Mississippi and Atchafalaya Rivers. Effects of each are discussed in this section.

### *Cold Fronts*

Although there are no coastal jet-like currents generated by offshore winds along the GOM equivalent to those found on the East Coast (Wright 1995), cold fronts and extra-tropical storms can still have an impact along the GOM. On the average, there are 46 cold fronts per year that pass through the northern GOM (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).

Along the Louisiana shelf west of the Mississippi Delta, from mid-spring to mid-fall, the winds are predominantly from the south to southwest and the dominant wave approach is from the southwesterly quadrant, with a 40% probability of occurrence (Georgiou et al. 2005). According to Georgiou et al. (2005), during the late fall and early spring, the wind regime is controlled by the passage of cold fronts, which commonly produce winds blowing from the northeasterly to southerly quadrants. However, they note that northeasterly winds blow offshore in central Louisiana, and because the fetch is too small to generate waves, the dominant waves (probability ~80%) propagate from the southwesterly quadrant. Consequently, it is the southwesterly winds that control sediment transport along the central Louisiana coast and shelf. They further note that waves typically vary from ~0.07 to 0.8 meters although during winter months, cold fronts can generate larger waves. For example, in the winter of 2001-2002, 30% of the cold front generated waves greater than 1-2 meters (Georgiou et al. 2005).

Moeller et al. (1993) found that cold front passage can have a significant influence on the dispersal of both river plume sediment and resuspended sediment from waves. They found that, in the chilled shelf waters during the winter, the cold front season can spread suspended sediment progressively seaward from the inner shelf to the shelf edge. Pepper et al. (1999) also found that cold fronts are an important mechanism for sediment transport within the inner shelf, however, the magnitude and transport direction can be highly variable. Kineke et al. (2004) found that cold front passage off of the Atchafalaya coast (west of Mississippi delta) resulted in sediment mixed through the entire water column during the pre-frontal passage, with a high concentration boundary layer extending 1 meter thick above the seabed. They further found that the cold front passage resulted in onshore transport of sediment both during the pre- and post-frontal passage. They concluded that the sediment transport during cold front passage drives the chenier-plain progradation along this section of the coast while most of the remainder of the Gulf shoreline is eroding.

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 also result in high-energy conditions. To date, the only peer reviewed published data on the role cold fronts play in the morphodynamics of the Texas coast is Davis and Fox (1975), which was largely a study of beach dynamics off of Mustang Island along the south central Texas coast. It is assumed that the same general processes that govern the sediment dynamics of cold front passage along the western Louisiana shelf influence sediment dynamics along the Texas coast, however, because the Texas coast has a different orientation than Louisiana, further research in this area is warranted for the Texas shelf.

### *Tropical Storms and Hurricanes*

Two storm sources dominate the creation of large wave events along the GOM coast: winter storms and hurricanes. The most energetic disturbances and highest waves are produced during major hurricanes. On average, 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). Figure 2-14 shows the hurricane strike frequency along the GOM and Atlantic coasts. With the noted exception of the southern tip of Florida, the frequency of hurricanes striking a specific section of the GOM coast ranges from once every 4.5 years to once every 14 years, with large storm strikes ranging from once every 116 years (Apalachee Bay) to once every 12 years (Mississippi River delta region).

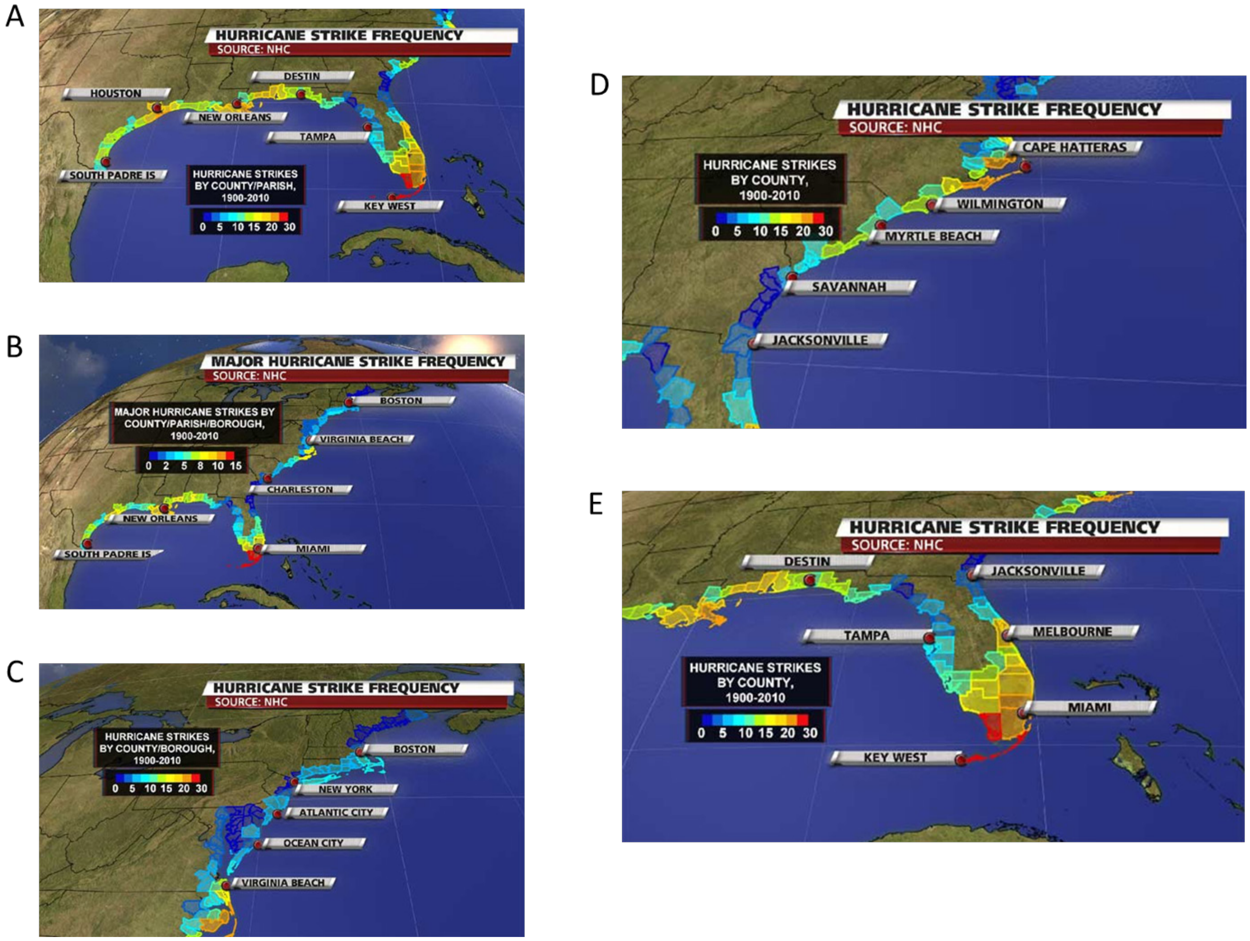

**Figure 2-14. Hurricane strike frequency throughout the study area.**
Source: http://www.weather.com/weather/hurricanecentral/article/hurricane-strike-frequency_2011-08-12

### *Relative Importance of Hurricanes/Tropical Storms vs Extra-Tropical Storms*

Extra-tropical storms associate with cold fronts occur far more frequently than hurricanes and tropical storms, with between 20-40 cold fronts a year passing through coastal Louisiana (Chaney 1996; Moeller 1993). Although individual cold fronts are generally less intense than hurricanes and tropical storms, Roberts et al. (1987) speculate that cold fronts may exert a greater cumulative influence on sediment transport and morphodynamic evolution than tropical storms and hurricanes because of their much higher frequency.

#### *Mississippi Plume Influence*

Proximal to and toward the west of the Mississippi and Atchafalaya River mouths positively buoyant, sediment-laden water from 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 distributaries turns westward as a buoyant coastal plume of reduced salinity that 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). According to Stone et al. (2009), coincident with high discharge events from the Atchafalaya River and post-frontal phases of cold front events, sediment from the river plume can reach and be deposited on Ship Shoal. Ship Shoal is one of the large, sand-dominated shoals in the GOM and is located 50 km offshore of Louisiana. Sediment resuspension from the Atchafalaya shelf can also transport fluvially-derived fine-grained sediment to Ship Shoal. This appears to result in seasonally ephemeral deposition of cohesive sediment, occasionally even fluid mud, onto the flanks of Ship Shoal, in layers of up to 15 cm thick.

Both observational and modeling studies of Ship Shoal (Stone et al. 2009) reveal that from the seaward to the landward flank of the shoal, there was a significant wave height attenuation of 22% for southerly waves and 28% for northerly waves. This dissipation of wave energy over the shoal resulted in resuspension and transport of shoal sediment during storm events. This wave attenuation also demonstrates the significance of the shoal in shielding the coast from frequent cold front and occasional hurricane-derived waves.

### 2.2.3 Variability of Sediment Transport among Shoals

How a shoal recovers from either a natural physical disturbance such as the impact of a hurricane, tropical storm, a severe extra-tropical storm or from an anthropogenic impact, such as ship grounding or from sand mining is largely a function of sediment transport, 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 and Gulf coasts. Consequently, water depth is the major factor determining 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 similar water depths, but across shoals, water depths will vary and so will wave-generated currents, sediment transport rates and fluxes. For example, sediment transport among cape-associated shoals is primarily controlled by water depth: shallow cape shoals are active features still forming, deeper-water cape shoals are largely relict features trapped below the fair weather wave base. There may be sediment transport on the surfaces of these features, but the shoals themselves are not actively migrating.

Recovery rate between different shoal types relates specifically to the shoal type as well as water depth. For example, sorted bedforms are sedimentary features that are actively migrating, but the rate of migration is highly variable. 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 the sorted bedforms found off of the German Bight that did not migrate for a 26-year period (Diesing et al. 2006). Among sand shoals and shoal fields, both Ship Shoal and

St. Bernard Shoals, although originating from Holocene sand bodies, are actively migrating features. Ship Shoal migrated at an average rate of 10 m/y from 1887-1983 (Penland et al. 1988). It appears the West Florida Shelf Sand Ridges have largely remained in fixed positions (Finkl et al. 2007b; Locker et al. 2003). The large relict sand banks off of Texas/western Louisiana, including Sabine and Heald Banks and Freeport Rocks, have also remained in a relatively 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 (shell-hash) ridges on the surface of Sabine Bank immediately after the passage of the storm, but they were covered seven months later (Dellapenna et al. 2011).

#### *Geotechnical Factors Contributing to Ecosystem Response to Shoal Disturbances*

For ecosystems associated with these features to survive, they must have some degree of resilience to frequent natural disturbance associated with reworking of seafloor sediment during the passage of extratropical and tropical storms (e.g. Posey et al., 1996). Dernie et al. (2003) found that within estuaries, benthic ecosystems within sand-dominated substrates recover after a physical disturbance much more quickly than those in mud-dominated substrates. They speculate that the rapid recovery within clean sand (sand with no clay) is likely due to the ability for sand to be easily transported as bed load. Presumably, this means ecosystems within sandy substrates are capable of tolerating disturbances because the substrate is regularly disturbed. In contrast, because clay is cohesive, substrates containing clay have a higher critical shear stress and are less readily resuspended in a comparable wave environment (Wright 1995). The noted exceptions to this would be nephaloid layers, where the mud is “fluffy” and easily resuspended, fluid muds and areas where there has been recently deposited mud, where the sediment has yet to dewater, such as within an active delta or mudbelt. Sand shoals are generally not found within active mud belts because they would become buried and no longer be shoals. Ephemeral mud accumulation has been documented on some shoals, such as Ship Shoal (Stone et al. 2009), however, the mud is subsequently eroded. The impact of this temporary mud deposition on the benthic community has yet to be addressed.

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

Sediment transport rates and fluxes will be major factors in facilitating the natural recovery of a shoal after sand mining. However, borrow design, size and location of borrow sites on shoal, depth of excavation, water depth, and orientation of the excavation all major factors in shoal recovery (e.g. Xu et al. 2014). Assessing how these factors influence shoal recovery can be tested using numerical modeling based on an understanding of the pre-mining conditions, and physical processing occurring on the shoals in question, as well as details of shoal configuration and location. Necessary modeling inputs include the detailed surface morphology of the shoal; surficial and subsurface sediment type and geotechnical property distributions; benthic boundary current measurements for different energy conditions; physical oceanographic time series data for currents and waves; long-term meteorological time series of wind, pressure and temperature and climate data, capturing interannual and decadal variability; and specifics of the dredging design (e.g., location on shoal, excavation depth, orientation, and design geometry.

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 they collect side-scan sonar and swath bathymetry in a single co-registered unit (e.g. Teledyne Benthos C3D® or Edgetech 6205®). Subsurface extent and distribution of strata is accomplished with high-resolution subbottom profiler surveying coupled with submersible vibracoring. Because the shoals of interest are sand dominated, vibracoring 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, and grain size 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 wind speed, 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.

Several recent studies have addressed various aspects of the impacts due to shoal mining and the rates and degree of recovery associated with this mining. BOEM funded a study of Ship Shoal (Stone et al. 2009), one of the largest offshore sand resources along the northern GOM, containing an estimated 1.22 billion $m^3$ of fine sand. Ship Shoal sits 50 km offshore of the Atchafalaya river mouth. Stone et al. (2009) included data from instrumented pods and sediment sampling as well as model simulations. The study revealed that there is modest sediment transport occurring across the shoal due to wave attenuation from both the passage of northern fronts as well as the passage of tropical storms. When the Atchafalaya River floods, during the passage of northern fronts, suspended sediment deposits on the flanks of Ship Shoal and can even form fluid muds. Stone et al. (2009) also found that Ship Shoal protects the highly vulnerable coastline from incoming waves, providing up to 28% wave energy attenuation. Modeling efforts reported in this study revealed that waves and wave-induced sediment re-suspension would be significantly altered by complete shoal removal. For the case of partial removal of the shoal (up to about 1% of shoal volume), Stone et al. (2009) found that changes in the wave environment and wave-induced sediment re-suspension would be insignificant. However, partial removal of sediment could significantly alter the distribution of surface sediments. Deeper areas of the shoal tend to accumulate mud (even fluid mud) thus Stone et al.

(2009) concluded that dredged pits might also accumulate mud rather than sand after dredging. For this to be the case on other shoals, there must be a source of fine-grained particles to be transported to the excavated area.

Xu et al. (2014) investigated the composition of sediment at two offshore sites within Port Royal Sound SC, within the Coosawhatchie River Ebb tidal delta, a borrow site 2 km offshore and a control site 10 km offshore. Although ebb tidal deltas are not discussed in detail in this report because they are typically located within state waters, this particular study had relevance beyond the study of such systems and the results lend themselves to project designs that may be of broader interest to our understanding of shoals. The two sites were monitored for changes in sediment composition during an 18-month timeperiod, including 6 months prior to mining sand at the borrow site as well as 0, 3 6, 9 and 12 months after mining. The borrow site was excavated as a wide pit with shallow sloping walls, with the intent that currents would flush any mud deposited in it. Although there was mud deposition proximal to the borrow pit, samples collected within the pit post-dredging revealed no mud deposition. This study demonstrates that a borrow site can be constructed such that it will not accumulate mud, but will accumulate sand, allowing it to be re-used as a borrow site when it fills back in with sand. This is likely only true for sites where there is a high flux of sand across the site.

CSA et al. (2010) examined potential impacts of dredging on the biology and physical oceanography of offshore ridge and shoal features offshore of Fenwick, MD. They examined a series of dredging scenarios using three interrelated numerical models (tidal hydrodynamics, wave process, and sediment transport):

- Dredging a deep excavation (glory hole) in a specific location on the shoal
- Dredging only the leading edge of the shoal
- Dredging only the trailing edge of the shoal
- Dredging longitudinally in a striped pattern along the crest.

The shoals they examined were far enough offshore that prevailing tidal velocities were small and sediment movement was governed by incident wave energy. They found that the likelihood a dredged portion of the shoal would refill was related to the site specific physical regime; a typically quiescent area would be unlikely to have a sand source for replenishment and only major storm conditions would be the primary mechanism enhancing refilling. Conversely, areas that are routinely exposed to wave action would be quickly refilled. On the three shoals CSA et al. (2010) examined, the shallow crests and leading edges were found to be active areas of erosion and deposition. Models predicted that the leading edges are the most active areas and would, therefore, refill more quickly than the crest. Trailing edges would refill most slowly. Models predicted that refilling of crests dredged in longitudinal stripes, with alternating untouched areas would be uniform along the length of the excavation. This approach would also have the potential to enhance biological recruitment.

CSA et al. (2010) concluded that adverse physical effects could be minimized by:

- Extracting sand from depositional areas, the leading edge, or downdrift margin of a shoal

- Avoiding dredging in upstream erosional areas that feed the depositional areas
- Shallow dredging spread out over a larger area rather than deep dredging in a smaller area
- Alternating dredged versus undredged areas down the longitudinal axis of the shoal crest
- Excavation in the higher portions of the shoal that are exposed to wave-generated turbulence.

The authors concluded that the geological models suggested that the dominant physical processes would maintain the structural integrity of a shoal of this type even after repeated dredging.

Dibajnia and Nairn (2011) used numerical modeling for a BOEM study titled *Investigation of Dredging Guidelines to Maintain and Protect the Geomorphic Integrity of Offshore Ridge and Shoal Regimes* that analyzed more than 180 offshore shoals offshore of the Delmarva Atlantic coast, with a wide range of sizes and water depths across the shelf. The study found that shoals most influenced by waves had a maximum ***base depth*** (water depth at the base of the shoal) of 30 m. Wave-induced currents were found to be the primary factor in shoal height growth and maintenance while tidal and general circulation currents have a greater influence on shoal migration. The study determined that a ***relative shoal height*,** defined as the ratio of shoal height (distance from crest to base of shoal) to base depth (H/BD) was an appropriate indicator of shoal height growth. They determined that the maximum relative shoal height, $(H/BD)_{max}$ varies from 0.5 at 10 m depth to 0.75 at 20 m depth. The authors concluded that a shoal that has reached the maximum relative shoal height of its base depth can be considered as a "fully grown" shoal, in terms of height, at the respective depth, but may still grow with rising sea level, as water depth deepens. They surmise that a "fully grown" shoal is more likely to re-grow and rebuild itself to the same height after dredging compared to a shoal that has not reached its theoretical maximum height potential. In addition, Dibajnia and Nairn (2011) found that shoals in water depths deeper than 30 m showed a decrease in height with increasing depth, representing a possible "shoal height decrease zone" beyond 30 m depth for this part of the Atlantic shelf. They concluded that shoals in this zone would not be expected to grow and would likely not recover in height once they are dredged.

Dibajnia and Nairn (2011) noted that the modeling efforts were challenging, with one of the challenges related to the representation of benthic boundary layer currents in the model. They were able to get the model to successfully re-create the evolution of the Isle of Wight shoal from 1929, 1975 and 2002 surveys. Eleven shoal-dredging scenarios were run using the model, and for each scenario, the Isle of Wight shoal was partially excavated to the -10 m contour to provide sand volumes in the range of 1 to 2 million cubic meters. Running the model to predict changes in morphology over a 10 to 15 year period, the authors found that after removal of material from the shoal, the shoal would reform itself with a smaller volume. They concluded that the volume loss was not compensated by transport of sediment from outside of the shoal area therefore. However, they found that despite the reduction in volume, the model predicted that the reformed shoal can attain the same height as that of the former, pre-dredged shoal, under some dredging scenarios. They conclude that although the shoals decrease in overall size as a result of dredging, there was no evidence in their modeling runs of possible shoal diminishing/deflation after dredging. They further conclude that there was no indication of a critical threshold for dredging that, once crossed, would cause the ridge and shoal features to lose their morphologic integrity.

This study also provides a series of dredging guidelines for shoals in the area offshore of Delaware, Maryland and Virginia along the Delmarva Peninsula. Recommendations within the guidelines include:

1) shoals with a base depth deeper than 30 m of water should not be dredged because deeper shoals have limited potential to grow after dredging;
2) shoals with a relative shoal height (defined as H/BD, or height divided by base depth) of less than 0.5 should not be dredged because shoals with a smaller H/BD ratio are not likely to recover after dredging.
3) If shoal recovery to its pre-dredge height is desired, then only shoals that have reached their maximum relative shoal height, where $(H/BD)_{max} = (BD-5)/BD$, are recommended for dredging.
4) For shoals with a BD of 21 m (as determined from the modeling of Isle of Wight Shoal), dredging from the shoal crest is not recommended and when dredging from the top of the shoal, relative shoal height should not be reduced to less than 0.65 (i.e. removal of more than 1.3 m) after dredging or the shoal will not re-grow to the same pre-dredge height.
5) Sand should not be removed from the entire length of the shoal, i.e. dredging along the axis of the shoal, because it affects wave-focusing processes and the shoal does not recover to the same pre-dredge height.
6) For the Mid-Atlantic, it is recommended that sand be dredged from the SW side of the shoal, because a) wave-focusing is concentrated on the NE side of the shoal; b) overall shoal migration is towards the southwest.

The reader is referred to Dibajnia and Nairn (2011) for further recommendations and discussion, including suggestions for studying shoal fields in other regions. Results presented here are based on modeling simulations that have not been validated with field data. Further work is warranted to field validate the model results and improve model accuracy.

## 2.3 Distribution of Shoals in BOEM OCS Planning Areas

Two main regions of interest are covered in this review: the Atlantic OCS Region and the GOM 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 Coasts 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 GOM OCS extends from the area off the western coast of Florida through Texas. Each of these regions has unique 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 B.

### 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 1-1). 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 (Figure 2-15). McBride and Moslow (1991) identified 245 shoreface-attached and detached sand ridges from navigation charts (scale 1:100,000 and 1:250,000) covering the coast from Long Island to North Carolina.

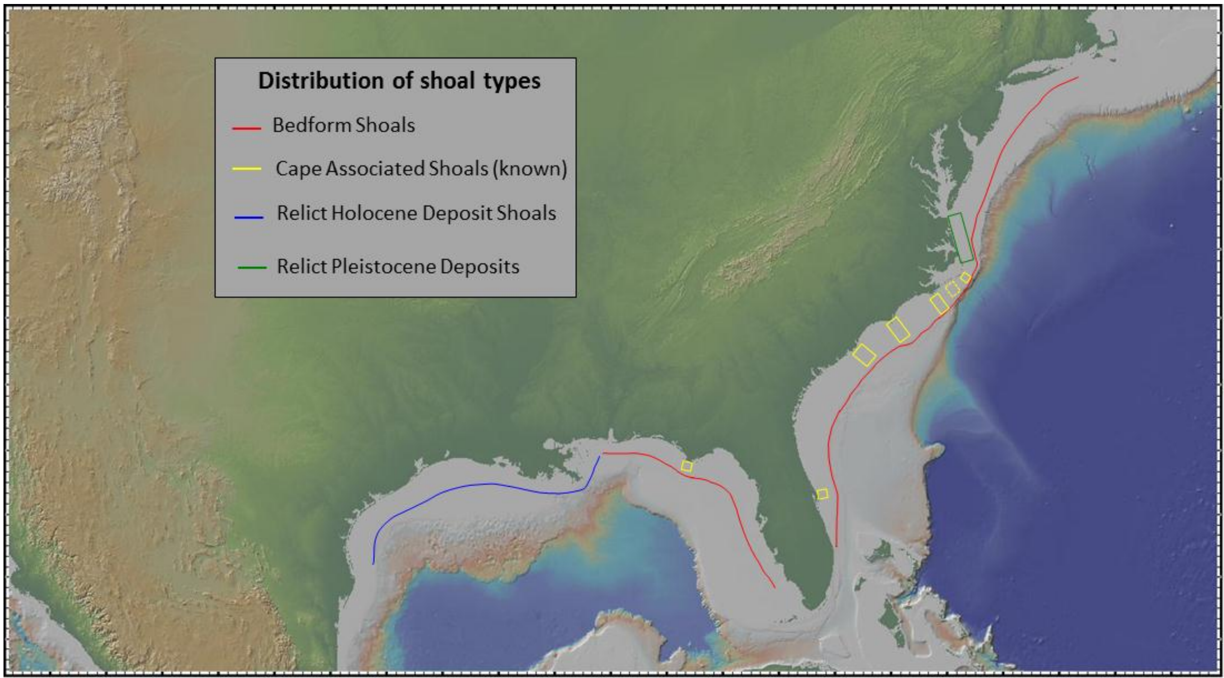

**Figure 2-15. Approximate distribution of shoals along the Atlantic and Gulf of Mexico OCS.**

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 GOM 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). 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 GOM OCS region into three planning areas: Eastern GOM, Central GOM, and Western GOM (Figure 1-2). The GOM OCS contains three of the seven GOM physiographic provinces: the South Florida Continental Shelf and Slope, the Northeast GOM, and the Northern GOM (Antoine 1972). 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 GOM contains the West Florida Shelf and Terrace which extends from the eastern side of Apalachee Bay, Florida 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 GOM 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 GOM 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).

Bedform shoals, including shore-attached ridges, shelf sand ridges and sorted bedforms have been identified along the West Florida Shelf (Figure 2-14). ***Linear shelf sand shoals*** have been identified along the Mississippi-Alabama Shelf east of the Mobile Bay (AL) entrance.

Relict Holocene coastal deposits are the major features on the inner continental shelf of the northwest GOM. These include Ship Shoal, St. Bernard Shoal, Sabine and Heald Banks as well as Freeport Rocks (Dellapenna et al. 2011; 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 – bedform shoals are prevalent in the Mid-Atlantic, southern Atlantic and eastern GOM coasts of the US, cape-associated shoals that are prevalent in the southern Mid-Atlantic to southern Atlantic coast, relict Pleistocene/Holocene deposit shoals exist along the Mid-Atlantic, and relict Holocene sand banks/shoals that are most prevalent in the GOM. 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 might also have a unique morpho-sedimentary response to sand removal. 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. Reported information for shoal habitats of the U.S. Atlantic or GOM OCS, suggests 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, known as 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). For example, 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 may provide 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. In addition,the density of benthic diatoms, which require light for photosynthesis, can influence species composition and productivity of faunal communities at multiple higher trophic levels. Increases in oxygen and/or sunlight can result in higher organic matter production. Organic matter that accumulates in the sediments as a food source 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 the same as those 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 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 milimeters [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 GOM 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 GOM: (1) the Northeast Shelf, (2) the Southeast Shelf, and (3) the GOM. 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 GOM.

Brooks et al. (2006) reviewed the available literature on benthic faunal assemblages associated with shoals in the Atlantic and GOM. 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 GOM, the spionid polychaete *Prionspio pinnata* was most often cited as the numerical dominant. Other dominant taxa from the GOM 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 GOM, 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 (cm 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 shoal crests off New Jersey differed from those occurring in adjacent troughs. Cutter et al. (2000) and Slacum et al. (2010) reported similar differences between crests and troughs; observing that 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. Each of these factors can influence the benthic community structure, but it is difficult to isolate the effect of each because they are closely linked with one another. Depth affects exposure to wave-generated currents which in turn affect sediment deposition along with other water quality parameters.

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 on the crest of the shoal, resulting in a graded substrate where much of the mud fraction (i.e. silt and clay particles) 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 in the Mid-Atlantic, sediment composition and hydrodynamics appear to be more important than depth in determining faunal-habitat associations (Byrnes et al. 2000). 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).

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 (Table 4-1). 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 GOM (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. 2004a, b, Byrnes et al. 2000) and New York (Byrnes et al. 2004a). Thus, sediment texture has been widely identified as an important microhabitat feature associated with faunal distribution.

**Table 4-1. Association of benthic infauna with sediment texture on shoals off New Jersey** (Byrnes et al. 2000).

| Class | Numerically Dominant Taxa | |
|---|---|---|
| | **Gravel** | **Sand** |
| **Bivalvia** | *Astarte castanea*<br>*Crenella decussata*<br>*Mytilus edulis* | *Tellina agilis* |
| **Gastropoda** | *Crepidula fornicata*<br>*Mitrella lunata* | |
| **Polychaeta** | *Harmothoe imbricata*<br>*Hemipodus roseus*<br>*Pisione remota* | *Caulleriella cf. killariensis*<br>*Spiophanes bombyx*<br>*Polygordius* sp. |
| **Crustacea** | | *Acanthohaustorius millsi*<br>*Pseudounciola obliquua*<br>*Protohaustorius wigleyi*<br>*Rheopoxynius hudsoni*<br>*Tanaissus psammophilus* |

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 (e.g., 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 is a notable example of a species that has been identified as preferring shoals over surrounding habitat (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 GOM. Stone et al. (2009) reported that Ship Shoal appears to provide a refuge from the seasonal hypoxia that affects the areas surrounding the shoal. A high biomass of benthic diatoms was also reported, which was attributed to light availability on the shallow shoal (5 to 11 m depth) that potentially allows for year-round benthic primary production. Increased oxygen content and sunlight 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 may serve as a link between sandy habitats along the coasts of Florida and Texas (Stone et al. 2009).

### 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). 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). Boesch (1979) found that in the Mid-Atlantic, seasonal variation in benthic communities becomes less apparent with distance offshore and increasing depth. Brooks (1991) reported a similar pattern in the western GOM and attributed it to the reduced variability in bottom temperature and salinity in deeper waters.

### 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 GOM 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 invertebrate species are found in shoal habitats off the U.S. Atlantic coast and in the GOM. These include American lobster, sea scallop, hard clam, Atlantic surfclam, white shrimp, brown shrimp, pink shrimp, ocean quahog, and blue crab. Examples from the GOM include brown shrimp, pink shrimp, royal red shrimp, white shrimp, Florida stone crab, gulf stone crab, spiny lobster, and slipper lobster. 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.

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.

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 areas in spring, and were less abundant on shoals than nearby flat-bottom areas during summer and fall.

Further south in the Mid-Atlantic Bight, squid (unspeciated), Atlantic rock crab, and blue crab have been reported from shoals off of Delaware and Maryland (Slacum et al. 2010). Atlantic rock crab were also less common on shoals than flat-bottom areas during most of the year, while blue crab were captured in low numbers on shoals, but were not found on flat-bottom areas at all (Slacum et al. 2010). Blue crab has also been identified as an important commercial species associated with shoals in the GOM (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 Louisiana. 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 GOM blue crab fishery.

Little evidence were found that white or brown shrimp, two other invertebrate species of national fisheries importance, are abundant on the Ship, Trinity, or Tiger Shoals off the Lousianna coast (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 partly dependent upon how "recovery" is defined and measured. Faunal density, faunal biomass, species richness, or community composition have all been used to measure community "recovery" (Brooks et al. 2006). Although density or biomass may provide some indication of the trophic value of recolonized benthos, species composition data are also needed to fully characterize community function. Brooks et al. (2006) reported that density may recover quickly after physical disturbance of the benthos, while diversity followed by community composition may take several years or more to recover. Thus, a community of early successional stage species that differs from the original community but provides trophic value to the overall system may indicate a partial recovery of the benthos; while full recovery may be defined as the return of a community that is highly similar to the original community composition, prior to disturbance.

The recovery of disturbed benthic communities is ultimately dependent upon colonization processes. Recolonization of the benthos involves a range of processes including larval transport, settlement, recruitment, adult migration, competition, and predation (Osman and Whitlatch 1998, Snelgrove et al. 2001). These processes are influenced by both physical and biological factors, which vary with location and habitat type. For example, communities found in sandy bottoms of high-energy environments tend to recolonize more quickly than those occurring in lower-energy environments with a higher percentage of fine particles (Dernie et al. 2003). Hence, in most cases, recovery is expected to occur more quickly on shoal ridges than in shoal troughs. Faster recolonization in shallow, high-energy environments may reflect the adaptation of communities that occur in these habitats to frequent disturbance from episodic storm events.

Brooks et al. (2006) reviewed times for species composition recovery from sand mining in U.S. Atlantic or GOM 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 mollusks 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. If dredging activities create a depression that enhances deposition of fine sediments, the associated infaunal assemblage may change from the pre-dredging assemblage. Byrnes et al. (2004a) concluded, therefore, that recovery and recolonization would be best achieved if creation of such depressions was avoided. 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. 2004a, Brooks et al. 2006).

## 4.2 Fishes

The Atlantic and GOM 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, Gulf of Mexico Fishery Management Council [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 GOM. 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. 2012). Shoals and shoal complexes characterize large areas of the Atlantic and GOM OCS however, these habitats and their use by marine organisms are among the least studied of all offshore marine habitats. 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 4-2 provides a summary of sampling approaches for some of the studies included in this Synthesis.

### 4.2.1 Description of Fishes Associated with Shoals and Shoal Complex Habitats

A diverse number of fish species utilize shoals and shoal 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 shoals and shoal 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 shoals and shoal 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 et al. 2010).

**Table 4-2. Studies investigating shoals and shoal complexes in the Atlantic and Gulf of Mexico Outer Continental Shelf regions.**

| Study | Study Area | Shoal Type | 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. | Authors: Natural sand banks<br>Synthesis Category: Isolated inner shelf shoal | 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 | Authors: Holocene lithofacies, sand ridges<br>Synthesis Category: Shore-attached and detached sand ridges | 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 | Authors: Shoals<br>Synthesis Category: Shore-attached and detached sand ridges | 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 | Authors: Shoals<br>Synthesis Category: Sorted bedform | 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. |

(continued)

**Table 4-2. (Continued)**

| Study | Study Area | Shoal Type | 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. | Authors: Linear shoal field or ridge and swale system<br>Synthesis Category: Shore-attached and detached sand ridges | 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. | Authors: Linear shoal field or ridge and swale system<br>Synthesis Category: Shore-attached and detached sand ridges | 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 | Authors: Sandy submerged barrier island<br>Synthesis Category: Shoal field | 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. |
| Vasslides 2007 | Ship Bottom Ridge, Beach Haven Ridge, and Brigantine Ridge off southern New Jersey | Author: Shoreface sand ridges<br>Synthesis Category: Shore-attached and detached sand ridges | 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. |

(continued)

**Table 4-2. (Continued)**

| Study | Study Area | Shoal Type | Sampling Approach |
|---|---|---|---|
| Vasslides and Able 2008 | Beach Haven Ridge, off the coast of southern New Jersey | Author: Shoreface sand ridges<br>Synthesis Category: Shore-attached and detached sand ridges | 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. | Authors: Unconsolidated sand sediments with interspersed rocky reefs<br>Synthesis Category: Sorted bedform | 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 (ROV) was used conducting two 15-minute drifts at eight of the ten stations. |
| Wells et al. 2009 | Freeport Rocks Bathymetric High and adjacent mud-bottom substrates, continental shelf off the Texas coast. | Authors: Drowned barrier island, natural shell bank, ridge<br>Synthesis Category: Isolated inner shelf shoal | 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). |
| Zarillo 2008 | Toms' Hills (T1 and T2 shoal system) and Siesta Shoal off the west Florida coast along Sarasota, Charlotte, Lee, and Collier Counties. | Author: Sand ridges<br>Synthesis Category: Shoal field | 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 | Author: Single linear ridge (B11 and A9), compound shoals or coalescing linear ridges (A8, A6, and A4).<br>Synthesis Category: Shore-attached and detached sand ridges | 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. |

Shoals and shoal 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 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 GOM) have been found to be associated only with the shoal areas in these complexes compared to the trough or non-shoalcontrol 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). EFH containing shoal areas has been designated for 36 Atlantic highly migratory species (tuna, swordfish, billfish, small and large coastal sharks, and pelagic sharks) in the Mid-Atlantic, South Atlantic, Straits of Florida, and/or GOM (Table 4-3; NMFS 2009).

**Table 4-3. 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.**

| **Highly Migratory Fishes** | | |
|---|---|---|
| Atlantic albacore tuna | blue shark | sand tiger shark |
| Atlantic angel shark | bonnethead shark | sandbar shark |
| Atlantic bigeye tuna | bull shark | scalloped hammerhead shark |
| Atlantic bluefin tuna | Caribbean reef shark | shortfin mako shark |
| Atlantic sharpnose shark | dusky shark | silky shark |
| Atlantic skipjack tuna | finetooth shark | spinner shark |
| Atlantic yellowfin tuna | great hammerhead shark | swordfish |
| basking shark | lemon shark | thresher shark |
| bignose shark | longbill spearfish | tiger shark |
| blacknose shark | night shark | whale shark |
| blacktip shark | nurse shark | white marlin |
| blue marlin | sailfish | white shark |

Source: 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 4-4). 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 or dredging (SAFMC 1998, SAFMC 2010).

**Table 4-4. Managed fish and invertebrate species that may utilize offshore shoals in the Mid-Atlantic.**

| Managed Fishes | Management Agencies[a] | Managed Fishes | Management Agencies |
|---|---|---|---|
| Atlantic croaker | ASMFC | sand tiger shark | ASMFC; NMFS HMS |
| Atlantic herring | ASMFC | sandbar shark | ASMFC; NMFS HMS |
| Atlantic mackerel | MAFMC | scalloped hammerhead | ASMFC; NMFS HMS |
| Atlantic sharpnose shark | ASMFC; NMFS HMS | scup | ASMFC; MAFMC |
| basking shark | ASMFC; NMFS HMS | silky shark | ASMFC; NMFS HMS |
| black sea bass | ASMFC; MAFMC | spiny dogfish | ASMFC; MAFMC; NEFMC |
| blacktip shark | ASMFC; NMFS HMS | spot | ASMFC |
| bluefish | ASMFC; MAFMC | striped bass | ASMFC |
| butterfish | MAFMC | summer flounder | ASMFC; MAFMC |
| dusky shark | ASMFC; NMFS HMS | tiger shark | ASMFC; NMFS HMS |
| goosefish | NEFMC | tilefish | MAFMC |
| night shark | ASMFC; NMFS HMS | windowpane | NEFMC |
| red hake | NEFMC | winter flounder | ASMFC; NEFMC |

| Managed Invertebrates | Management Agencies |
|---|---|
| ocean quahog | MAFMC |
| short-finned squid | MAFMC |
| horseshoe crab | ASMFC |
| long-finned squid | MAFMC |
| surf clam | MAFMC |

[a] ASMFC: Atlantic State Marine Fishery Commission
MAFMC: Mid-Atlantic Fishery Management Council
NEFMC: New England Fishery Management Council
NMFS HMS: National Marine Fishery Service Highly Migratory Species
Source: CSA et al. 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 shoals and shoal 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 4-5). CSA 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.

**Table 4-5. Fish species documented on shoals and shoal complexes in the North and Mid-Atlantic.**

| **Fish Species** | | | |
|---|---|---|---|
| alewife | butterfish | northern puffer | snakeblenny |
| American shad | clearnose skate | northern searobin | snakefish |
| Atlantic angel shark | cobia | northern sennet | spanish mackerel |
| Atlantic bonito | conger eel | northern stargazer | spiny butterfly ray |
| Atlantic cod | cownose ray | ocean pout | spiny dogfish |
| Atlantic croaker | cunner | oyster toadfish | spot |
| Atlantic cutlassfish | dusky shark | pinfish | spotted goatfish |
| Atlantic herring | feather blenny | planehead filefish | spotted hake |
| Atlantic mackerel | fourbeard rockling | pollock | striped anchovy |
| Atlantic menhaden | fourspine stickleback | red hake | striped bass |
| Atlantic moonfish | fourspot flounder | rock gunnel | striped burrfish |
| Atlantic sharpnose shark | gag | roughtail stingray | striped cusk-eel |
| Atlantic silverside | goosefish | round herring | striped searobin |
| Atlantic sturgeon | grubby | round scad | summer flounder |
| banded drum | haddock | sand lance species | tautog |
| banded rudderfish | harvestfish | sandbar shark | threespine stickleback |
| barndoor skate | hickory shad | scup | thresher shark |
| bay anchovy | hogchoker | sea raven | weakfish |
| bay whiff | inland silverside | seaboard goby | white bass |
| black drum | inquiline snailfish | sergeant major | white hake |
| black sea bass | inshore lizardfish | short bigeye | white mullet |
| blue runner | lined seahorse | silver anchovy | windowpane |
| blueback herring | little skate | silver hake | winter flounder |
| bluefish | longhorn sculpin | silver perch | winter skate |
| bluespotted cornetfish | naked goby | smallmouth flounder | witch flounder |
| bluntnose stingray | northern kingfish | smooth butterfly ray | yellowtail flounder |
| bullnose ray | northern pipefish | smooth dogfish | |

Sources: Able et al. 2006, CSA et al. 2010, Diaz et al. 2003, 2006, Martino and Able 2003, Slacum et al. 2010, Vasslides 2007, Vasslides and Able 2008a

At a southern New Jersey shoal 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 2-8). 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 three 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, 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 shoals and shoal 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: endangered species; Table 4-6). 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 shoal complexes, could not be determined (Walsh et al. 2006). However, 19 of these species were collected in shoals and shoal 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 shoal 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.

**Table 4-6. Fish species documented on shoals and shoal complexes in the South Atlantic and Florida Straits**

**Fish Species**

Agujon
American harvestfish
American sailfin eel
Atlantic angel shark
Atlantic bumper
Atlantic croaker
Atlantic cutlassfish
Atlantic guitarfish
Atlantic menhaden
Atlantic moonfish
Atlantic sharpnose shark
Atlantic spadefish
Atlantic thread herring
balao
balloonfish
ballyhoo
band cusk-eel
banded drum
bandtail puffer
bandtail searobin
bank sea bass
bar jack
barred searobin
bay anchovy
bay whiff
bigeye anchovy
bigeye scad
bighead searobin
bignose shark
blackcheek tonguefish
blacknose shark
blacktip shark
blackwing searobin
blotched cusk-eel
blue goby
blue runner
blue shark
bluefish
bluespotted searobin
blunthead puffer
bluntnose jack
bluntnose stingray
bonnethead
bridled burrfish
broad flounder
bull pipefish
bull shark
cero
channel flounder
checkered puffer
clearnose skate
cobia
cottonmouth jack
crevalle jack
Cuban anchovy
deepwater flounder
devil ray
dolphin
dotterel filefish
duckbill flathead
dusky anchovy
dusky flounder
dusky shark
dwarf herring
dwarf sand perch
eyed flounder
false pilchard
finetooth shark
flat anchovy
flat needlefish
Florida pompano
Florida smoothhound
flying halfbeak
fourspot flounder
freckled stargazer
freckled tonguefish
fringed filefish
fringed flounder
goby flathead
gray flounder
gray triggerfish
great hammerhead
grunt (juvenile)
Gulf flounder
Gulf Stream flounder
halfbeak
highfin scorpionfish
honeycomb cowfish
honeycomb moray
horned searobin
horned whiff
horse-eye jack
houndfish
inshore lizardfish
jack-knifefish
keeltail needlefish
key worm eel
king mackerel
ladyfish
lancer stargazer
largescale tonguefish
leather jacket
leopard searobin
lined seahorse
lined sole
little tunny
longspine scorpionfish
mackeral scad
Mexican flounder
mojarra
mooneye cusk-eel
naked sole
northern puffer
northern searobin
ocean triggerfish
oceanfish sunfish
ocellated flounder
offshore tonguefish
orange filefish
orangebelly goby
orangespotted filefish
orangespotted goby
palometa
permit
pinfish
planehead filefish
planehead filefish
porcupinefish
porgy (juvenile)
pygmy filefish
pygmy tonguefish
queen triggerfish
rainbow runner
redear sardine
redtail scad
ribbon halfbeak
robins flounder
rock sea bass
rosette skate
rough scad
rough triggerfish
roughtail stingray
round herring
round scad
roundel skate
sailfish
sand perch
sand stargazer
sand whiff
sandbar shark
sargassum triggerfish
scaled sardine
scalloped hammerhead
scrawled cowfish
scrawled filefish
seaweed blenny
seminole goby
sharpnose puffer
sharptail sunfish
shelf flounder
shoal flounder
shortbeard cusk-eel
shortfin searobin
shortwing searobin
shrimp flounder
silver anchovy
silver seatrout
silverstripe halfbeak
slender filefish
slim flounder
smallmouth flounder
smalltooth sawfish
smooth butterfly ray
smooth dogfish
smooth puffer
smooth trunkfish
southern flounder
southern kingfish
southern puffer
southern sennet

(continued)

**Table 4-6 (Continued)**

| Fish Species | | | | |
|---|---|---|---|---|
| southern stargazer | 1 | spotfin goby | striped burrfish | unicorn filefish |
| southern stingray | 2 | spottail tonguefish | striped cusk-eel | unicorn whiff |
| Spanish mackerel | 3 | spotted burrfish | striped searobin | wahoo |
| Spanish sardine | 4 | spotted whiff | stripedfin flounder | whitespotted filefish |
| spinner shark | 5 | spottedfin tonguefish | summer flounder | windowpane |
| spiny flounder | 6 | stellate codlet | tarpon | wormfish |
| spiny searobin | 7 | streamer searobin | three-eye flounder | yellow jack |
| spot | 8 | striped anchovy | timucu | yellowfin menhaden |
| spotfin flounder | 9 | striped bass | trunkfish | |

Sources: Gilmore 2008 and Zarillo et al. 2009

Ichthyoplankton surveys conducted on the northeast Florida coast 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 4-7). 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 GOM, 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).

**Table 4-7. Relative abundance of the fish species documented on shoals and shoal complex habitats along the east Florida continental shelf.**

| Fish Species | Relative Abundance[a] | Fish Species | Relative Abundance |
|---|---|---|---|
| agujon | C | dolphin | C |
| Atlantic angel shark | C | dotterel filefish | R |
| Atlantic bumper | A | duckbill flathead | X |
| Atlantic cutlassfish | C | dusky anchovy | A |
| Atlantic guitarfish | C | dusky flounder | X |
| Atlantic menhaden | A | dusky shark | O |
| Atlantic sharpnose shark | A | dwarf herring | R |
| Atlantic thread herring | A | dwarf sand perch | A |
| balao | A | eyed flounder | X |
| balloonfish | O | false pilchard | R |
| ballyhoo | A | finetooth shark | C |
| bandtail puffer | C | flat anchovy | O |
| bandtail searobin | X | flat needlefish | C |
| bank sea bass | X | Florida pompano | C |
| bar jack | C | Florida smoothhound | R |
| barred searobin | X | flying halfbeak | C |
| bay anchovy | A | fourspot flounder | X |
| bay whiff | X | freckled tonguefish | X |
| bigeye anchovy | O | fringed filefish | O |
| bigeye scad | X | fringed flounder | X |
| bighead searobin | X | goby flathead | X |
| bignose shark | O | gray flounder | X |
| blackcheek tonguefish | X | gray triggerfish | C |
| blacknose shark | C | great hammerhead | O |
| blacktip shark | A | gulf flounder | X |
| blackwing searobin | X | gulf stream flounder | X |
| blue goby | X | halfbeak | A |
| blue shark | X | highfin scorpionfish | X |
| bluefish | C | honeycomb cowfish | O |
| bluespotted searobin | X | honeycomb moray | A |
| blunthead puffer | R | horned searobin | X |
| bluntnose jack | R | horned whiff | X |
| bluntnose stingray | C | horse-eye jack | C |
| bonnethead | O | houndfish | C |
| bridled burrfish | R | keeltail needlefish | C |
| broad flounder | X | king mackerel | A |
| bull shark | C | ladyfish | O |
| cero | O | lancer stargazer | X |
| channel flounder | X | largescale tonguefish | X |
| checkered puffer | C | leather jacket | X |
| clearnose skate | C | leopard searobin | X |
| cobia | C | lined sole | X |
| cottonmouth jack | R | little tunny | C |
| crevalle jack | C | longspine scorpionfish | X |
| Cuban anchovy | A | mackeral scad | A |
| deepwater flounder | X | Mexican flounder | X |
| devil ray | C | naked sole | X |

(continued)

**Table 4-7. (Continued)**

| Fish Species | Relative Abundance[a] | Fish Species | Relative Abundance |
|---|---|---|---|
| northern puffer | R | shoal flounder | X |
| northern searobin | X | shortfin searobin | X |
| ocean triggerfish | C | shortwing searobin | X |
| oceanfish sunfish | O | shrimp flounder | X |
| ocellated flounder | X | silver anchovy | O |
| offshore tonguefish | X | silverstripe halfbeak | R |
| orange filefish | O | slender filefish | O |
| orangebelly goby | X | slim flounder | X |
| orangespotted filefish | O | smallmouth flounder | X |
| orangespotted goby | X | smalltooth sawfish | R |
| palometa | C | smooth butterfly ray | C |
| permit | C | smooth dogfish | R |
| planehead filefish | C | smooth puffer | R |
| porcupinefish | O | smooth trunkfish | O |
| pygmy filefish | O | southern flounder | X |
| pygmy tonguefish | X | southern puffer | O |
| queen triggerfish | R | southern stargazer | X |
| rainbow runner | R | southern stingray | C |
| redear sardine | A | Spanish mackerel | A |
| redtail scad | X | Spanish sardine | A |
| ribbon halfbeak | X | spinner shark | A |
| robins flounder | X | spiny flounder | X |
| sand whiff | X | spiny searobin | X |
| sand perch | A | spotfin flounder | X |
| sandbar shark | A | spotfin goby | X |
| sargassum triggerfish | O | spottail tonguefish | X |
| scaled sardine | A | spotted burrfish | R |
| scalloped hammerhead | C | spotted whiff | X |
| scrawled cowfish | O | spottedfin tonguefish | X |
| scrawled filefish | O | streamer searobin | X |
| Seminole goby | C | striped anchovy | O |
| sharpnose puffer | O | striped bass | R |
| sharptail sunfish | R | striped burrfish | O |
| shelf flounder | X | striped searobin | X |

[a] Relative abundance is denoted by: A = Abundant, C = Common, O= Occasional, R = Rare, and X = documented but the relative abundance is unknown
Source: Gilmore 2008

### *The Gulf of Mexico OCS*

Studies conducted in shoals and shoal complexes in the GOM have documented 136 species of fish collected in these habitats (Table 4-8).

### *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, six species), Serranidae (sea basses and groupers, five species), Triglidae (searobins, four species), and Paralichthyidae (largetooth flounders, four 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.

**Table 4-8. Fish species documented on shoals and shoal complexes in the Gulf of Mexico.**

| **Fish Species** | | | |
|---|---|---|---|
| Atlantic bumper | Florida smoothound | ocellated flounder | silver perch |
| Atlantic croaker | freckled pike-conger | offshore lizardfish | silver seatrout |
| Atlantic midshipman | fringed filefish | offshore tonguefish | singlespot frogfish |
| Atlantic sharpnose shark | fringed flounder | orange filefish | slantbrow batfish |
| Atlantic thread herring | fringed sole | pancake batfish | smallmouth flounder |
| banded drum | gafftopsail catfish | pigfish | smooth dogfish |
| bandtail puffer | gray snapper | pinfish | smooth puffer |
| bandtail searobin | Gulf butterfish | planehead filefish | smooth trunkfish |
| bank cusk-eel | Gulf flounder | planehead filefish | smoothead scorpionfish |
| barbfish | Gulf kingfish | plumed scorpionfish | southern flounder |
| bay whiff | Gulf of Mexico barred searobin | porcupinefish | southern hake |
| bearded brotula | Gulf of Mexico ocellated flounder | pygmy seabass | southern kingfish |
| belted sandfish | halfbeak | red drum | southern puffer |
| bigeye searobin | hardhead catfish | red grouper | southern stargazer |
| bighead searobin | high-hat | red snapper | southern stingray |
| black drum | hogchoker | rock seabass | Spanish sardine |
| blackbear seabass | honeycomb cowfish | rough scad | spiny flounder |
| blackcheek tonguefish | inshore lizardfish | roughback batfish | spot |
| blackedge cusk-eel | lane snapper | roundel skate | spotted batfish |
| blackwing searobin | largescale lizardfish | sand perch | spotted tonguefish |
| blotched cusk-eel | least puffer | sand seatrout | spotted whiff |
| bluespotted searobin | leopard searobin | sash flounder | star drum |
| bluntnose stingray | lined seahorse | scad | striped anchovy |
| bonnethead | lined sole | scawled cowfish | striped burrfish |
| chain pipefish | little-eye round herring | scrawled cowfish | striped cusk-eel |
| cownose ray | littlehead porgy | scrawled filefish | tattler |
| crested cusk-eel | longnose batfish | sharptail goby | three-eye flounder |
| cubbyu | longnose cusk-eel | sheepshead | tidewater mojarra |
| dusky anchovy | longspine porgy | shelf flounder | tomtate |
| dusky carinalfish | marbled puffer | shoal flounder | twospot flounder |
| dusky flounder | margintail conger | shortnose batfish | unicorn filefish |
| dwarf goatfish | Mexican flounder | shrimp eel | white grunt |
| dwarf sand perch | mooneye cusk-eel | silver anchovy | whitespotted soapfish |
| emerald parrotfish | northern kingfish | silver jenny | yellow conger |

Sources: Brooks et al. 2005, Byrnes et al. 1999, Wells et al. 2009, Zarillo et al. 2008

### *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, six commercial species) that were collected at the Trinity Shoal, Tiger Shoal, Sabine Bank, and Heald Bank areas in the northwest GOM (Table 4-9). Of these species, five 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 GOM 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.

**Table 4-9. Catch frequency of the fish species documented on Heald Bank, Sabine Bank, Trinity Shoal, and Tiger Shoal.**

| Common Name | Heald Bank | Sabine Bank | Trinity Shoal | Tiger Shoal |
|---|---|---|---|---|
| Atlantic croaker | F[a] | C | F | F |
| Atlantic midshipman | C | R | C | C |
| Atlantic sharpnose shark | R | R | R | R |
| banded drum | R | C | R | R |
| bandtail puffer | — | — | R | — |
| bandtail searobin | R | R | R | — |
| bank cusk-eel | — | R | R | — |
| barbfish | — | R | — | — |
| bay whiff | R | R | R | C |
| bearded brotula | R | — | R | — |
| bigeye searobin | C | R | C | R |
| bighead searobin | C | C | R | R |
| black drum | — | R | R | R |
| blackbear sea bass | R | — | — | — |
| blackcheek tonguefish | R | C | R | C |
| blackedge cusk-eel | C | R | R | R |
| blackwing searobin | C | R | R | R |
| blotched cusk-eel | R | R | R | — |
| bluespotted searobin | R | — | — | — |
| bluntnose stingray | — | — | R | — |
| bonnethead * | R | R | R | — |
| cownose ray | R | R | R | — |
| crested cusk-eel | R | R | R | R |
| dusky flounder | R | R | R | — |
| dwarf goatfish | R | — | R | — |
| dwarf sand perch * | C | R | R | — |
| Florida smoothound | R | — | — | — |
| freckled pike-conger | R | — | — | — |
| fringed flounder | C | C | — | C |
| fringed sole | R | — | — | — |
| gafftopsail catfish | — | — | C | C |
| Gulf flounder | — | R | — | — |
| Gulf kingfish | — | R | R | — |
| hardhead catfish | F | C | C | C |
| hogchoker | — | R | R | R |
| inshore lizardfish | C | R | R | R |
| lane snapper * | C | R | R | R |
| largescale lizardfish | R | R | R | R |
| least puffer | C | C | C | C |
| leopard searobin | R | R | R | — |
| lined sole | — | — | R | R |
| longnose batfish | R | — | — | — |
| longspine porgy | F | R | C | — |
| marbled puffer | — | — | R | — |

(continued)

**Table 4-9. (Continued)**

| Common Name | Heald Bank | Sabine Bank | Trinity Shoal | Tiger Shoal |
|---|---|---|---|---|
| margintail conger | — | — | R | — |
| Mexican flounder | — | R | R | — |
| northern kingfish | — | R | — | — |
| ocellated flounder | R | R | R | — |
| offshore lizardfish | — | R | — | — |
| offshore tonguefish | — | R | R | R |
| orange filefish | — | R | — | — |
| pancake batfish | R | R | R | — |
| pigfish | C | C | R | — |
| pinfish | C | R | R | R |
| planehead filefish | C | R | R | R |
| pygmy sea bass | R | R | — | — |
| red drum * | — | R | R | — |
| red snapper * | F | C | R | — |
| rock seabass | C | C | C | R |
| roughback batfish | R | — | R | — |
| roundel skate | — | R | R | — |
| sand perch * | R | R | — | — |
| sand seatrout | C | C | C | F |
| sash flounder | — | — | R | — |
| scrawled cowfish | R | R | — | — |
| scrawled filefish | — | R | R | — |
| sharptail goby | — | — | R | R |
| shelf flounder | — | — | R | — |
| shoal flounder | C | R | R | R |
| shortnose batfish | R | R | — | — |
| shrimp eel | — | — | — | R |
| silver jenny | C | R | R | — |
| silver perch | — | R | — | — |
| silver seatrout | C | C | C | C |
| slantbrow batfish | R | — | — | — |
| smallmouth flounder | R | R | — | — |
| smooth dogfish | — | — | R | — |
| smooth puffer | C | R | R | R |
| smooth trunkfish | R | — | — | — |
| smoothead scorpionfish | R | R | R | — |
| southern flounder | R | R | R | R |
| southern kingfish | C | R | C | R |
| southern puffer | — | — | R | R |
| southern stargazer | — | R | R | R |
| southern stingray | — | R | R | — |
| spiny flounder | R | R | — | — |
| spot | C | C | C | C |
| spotted batfish | R | — | — | — |

(continued)

**Table 4-9. (Continued)**

| Common Name | Heald Bank | Sabine Bank | Trinity Shoal | Tiger Shoal |
|---|---|---|---|---|
| spotted tonguefish | R | — | — | — |
| spotted whiff | R | — | R | — |
| star drum | R | C | R | C |
| striped burrfish | R | R | R | R |
| tattler | — | R | — | — |
| three-eye flounder | R | — | — | — |
| unicorn filefish | R | — | — | — |
| whitespotted soapfish | R | — | — | — |
| yellow conger | — | — | R | — |

[a] Catch frequency is denoted by: F = Frequently caught, C = Commonly caught, R = Rarely caught, "—" = Never caught [b] commercial species
Source: Brooks et al. 2005

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. Surface substrate conditions on Freeport Rocks are variable, with patches of shell hash, sandy mud, and sand (Wellner and Anderson 2003; Simms et al. 2009) and this variability may explain differences in biota compared to other banks in the northwest GOM.

A number of fish species have been found to occur on shoals and shoal 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 shoal complex habitats both in the Mid-Atlantic and along the east coast of Florida; 49 species occur in shoal and shoal complex habitats both along the east coast of Florida and in the GOM; 16 species occurred in each of the Mid-Atlantic, the east coast of Florida and in the GOM; and 18 species occurred in both the Mid-Atlantic and the GOM (Table 4-10).

## Seasonal Patterns

Temporal patterns of fish occurrence on shoals and shoal 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 shoal complex fish assemblages, where the majority of the species observed were seasonal residents.

**Table 4-10. Presence of fish species on shoals and shoal complexes over large geographic ranges.**

| Fish Species | Mid-Atlantic | Eastern coast of Florida | Gulf of Mexico |
|---|---|---|---|
| American harvestfish | X | X | |
| Atlantic angel shark | X | X | |
| Atlantic bumper | | X | X |
| Atlantic croaker | X | X | X |
| Atlantic cutlassfish | X | X | |
| Atlantic menhaden | X | X | |
| Atlantic sharpnose shark | X | X | X |
| Atlantic thread herring | | X | X |
| band cusk-eel | | X | X |
| banded drum | X | X | X |
| bandtail puffer | | X | X |
| bandtail searobin | | X | X |
| bay anchovy | X | X | |
| bay whiff | X | X | X |
| bighead searobin | | X | X |
| blackcheek tonguefish | | X | X |
| blackwing searobin | | X | X |
| blotched cusk-eel | | X | X |
| blue runner | X | X | |
| bluefish | X | X | |
| bluespotted searobin | | X | X |
| bluntnose stingray | X | X | X |
| clearnose skate | X | X | |
| cobia | X | X | |
| cownose ray | X | | X |
| dusky anchovy | | X | X |
| dusky flounder | | X | X |
| dusky shark | X | X | |
| dwarf sand perch | | X | X |
| Florida smoothhound | | X | X |
| fourspot flounder | X | X | |
| fringed filefish | | X | X |
| fringed flounder | | X | X |
| Gulf flounder | | X | X |
| Gulf of Mexico barred searobin | | X | X |
| inshore lizardfish | X | X | X |
| leopard searobin | | X | X |
| lined seahorse | X | X | X |
| lined sole | | X | X |
| Mexican flounder | | X | X |
| mooneye cusk-eel | | X | X |
| northern kingfish | X | | X |
| northern puffer | X | X | |
| northern searobin | X | X | |
| ocellated flounder | | X | X |
| offshore tonguefish | | X | X |

(continued)

**Table 4-10. (Continued)**

| Fish Species | Mid-Atlantic | Eastern coast of Florida | Gulf of Mexico |
|---|---|---|---|
| orange filefish | | X | X |
| pinfish | X | X | X |
| planehead filefish | X | X | X |
| planehead filefish | | X | X |
| rock sea bass | | X | X |
| rough scad | | X | X |
| roughtail stingray | X | X | |
| round herring | X | X | |
| round scad | X | X | |
| roundel skate | | X | X |
| sand perch | | X | X |
| sandbar shark | X | X | |
| scrawled cowfish | | X | X |
| scrawled filefish | | X | X |
| shelf flounder | | X | X |
| shoal flounder | | X | X |
| shortbeard cusk-eel | | X | X |
| silver anchovy | X | X | X |
| silver perch | X | | X |
| silver seatrout | | X | X |
| smallmouth flounder | X | X | X |
| smooth butterfly ray | X | X | |
| smooth dogfish | X | X | X |
| smooth puffer | | X | X |
| smooth trunkfish | | X | X |
| southern flounder | | X | X |
| southern kingfish | | X | X |
| southern puffer | | X | X |
| southern stargazer | | X | X |
| southern stingray | | X | X |
| Spanish mackerel | X | X | |
| spiny flounder | | X | X |
| spot | X | X | X |
| spotted whiff | | X | X |
| spottedfin tonguefish | | X | X |
| striped anchovy | X | X | X |
| striped bass | X | X | |
| striped burrfish | X | X | X |
| striped cusk-eel | X | X | X |
| striped searobin | X | X | |
| summer flounder | X | X | |
| three-eye flounder | | X | X |
| twospot flounder | | X | X |
| unicorn filefish | | X | X |
| windowpane | X | X | |

Sources: Brooks et al. 2005, Byrnes et al. 1999, Diaz et al. 2003, 2006, Gilmore 2008, Slacum et al. 2010, Stone et al. 2009, Vasslides 2007, Vasslides and Able 2008, Walsh et al. 2006, Wells et al. 2009, Zarillo 2008, 2009

Species-specific temporal patterns of occurrence of benthic fish on sand banks have also been found in the GOM. 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

Shoals and shoal 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 (cm to m) 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 within a complex may have unique habitat values (Slacum et al. 2006). For example, in the northwest GOM, 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 GOM 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. Brooks et al. (2005) suggested that environmental conditions, primarily reduced oxygen levels, on these shoals may have influenced species richness and mean biomass. The Trinity and Tiger Shoal areas are located within the GOM hypoxia zone, an area that averaged 13,500 $km^2$ in size between 1985 and 2009 with nearly continuous bottom dissolved oxygen levels of 2 mg/L from mid-May to mid-September (Rabalais et al. 2010). The Tiger and Trinity Shoals experience reduced oxygen levels (as low as 0 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 shoals and shoal complexes in the northwest GOM. Geary et al. (2007) quantified densities of juvenile red snapper on Freeport Rocks (depth of 13-24 m) as well as the two banks Heald (depth of 9-14 m) and Sabine (depth of 8-11 m) surveyed by Brooks et al. (2005). The ridges of Heald and Sabine Banks consisted of shell material and the adjacent areas off the banks were comprised primarily of silt and mud. Freeport Rocks had sand habitat (with negligible shell hash) on the ridge as well. Geary et al. (2007) reported that Freeport Rocks had markedly higher red snapper densities and growth rates in 2004 than either Heald Bank or Sabine Bank in 2003; this suggests 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 in settlement patterns and growth rates cannot be completely ruled out.

Reef-associated fish species have been documented on shoals and shoal 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 GOM, 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 shoal 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 GOM 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, on shoals and shoal 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 shoal complex 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 GOM required habitat with microscale complexity, preferring shell ridge habitats compared to low-relief habitats.

### 4.2.3 Behavior of Fishes on or Around Shoals and Shoal Complexes

There is limited literature that describes how fish assemblages use specific shoals and shoal complex habitats and the relevance of specific habitat features for whole communities within the continental shelf system (Slacum et al. 2010). Shoals and shoal 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 GOM 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 shoals and shoal 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 shoal 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 shoals and shoal 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 shoals and shoal complex 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 shoal 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. Shoals and shoal 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 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).

## 4.3 Summary

- Shoals and shoal complexes are among the least-studied offshore marine habitats in the Atlantic and GOM 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 shoal complex habitats in the Atlantic and Gulf Mexico OCS, including economically and ecologically important species (Tables 4-3 through 4-8).
- Shoals and shoal 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 GOM 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 shoals and shoal complexes is believed to vary latitudinally and across the continental shelf in response 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 fish assemblages on shoals and shoal complexes.
- Diel patterns of abundance and diversity have been observed on shoals and shoal complexes where fish were more abundant on shoal habitats at night and on biogenic complex trough or flat-bottom habitats during the day.
- Shoals and shoal 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 shoal systems within a complex may also have different habitat values.
- Shoals and shoal 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).
- Shoals and shoal 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 shoals and shoal complexes is mainly provided by biogenic structures and small bedform relief.

- Shoals and shoal complexes that extend from the beach to several miles offshore may provide a corridor linking inshore and offshore movements for fish species.

# 5.0 Assessment of Information Gaps and Recommendations for Next Steps

During the preparation of the draft synthesis, subsequent workshop planning, and discussions held during the workshop, it became evident that our knowledge of the geology and ecological importance of offshore sand shoals is incomplete. Resolution of some of this information will be important to ensure that the federal agencies with regulatory interests in these resources – the BOEM and the Corps whose mandates include management, extraction and utilization of the mineral resources for various purposes and the NMFS, one of whose mandates includes habitat conservation for fisheries species that may use sand shoals for vital aspects of their life histories – are able to work cooperatively to manage these resources in an ecologically acceptable way. The goals of the discussion in this section are to evaluate how important various information gaps are to our understanding of the ecological implications of sand removal and to make recommendations on steps needed to move forward.

## 5.1 Geology and Physical Processes

Knowledge gaps related to the geology of and physical processes controlling offshore sand shoals fall into four categories:

- *Distinguishing characteristics of shoal types*
- *Extent of the resource in the OCS*
- *Applicability of physical process data from the inner continental shelf to shoals on the OCS*
- *Physical recovery of OCS shoals from disturbance*

### 5.1.1 Distinguishing Characteristics of Shoal Types

- *Differences among types of shoals*
  - *Shoal terminology – current theory that they represent a continuum – does that mean shoals from comparable variants of the continuum behave the same way in different places?*
  - *Are there geographical differences in the structure of these features and their ecological functions?*

Review of research into the origins and distribution of sand shoals revealed that the geological terminology applied to these features has been so variable as to be very confusing, with individual authors appearing to develop their own nomenclature. As described in Section 2.0, when geological origin and physical processes affecting shoal formation/maintenance are considered, there appear to be only three distinct types of shoals (shoals associated with stranded Holocene sedimentary deposits; cape-associated shoals; and sorted bedforms which encompass a continuum of variants). For the purposes of evaluating OCS sand shoals for extraction, key defining factors relate to the dynamics of the resource, i.e., the time frame under which the resource changes shape or dimensions. As discussed in Section 3 and further explored in Section 5.2, biological function is inextricably linked to physical habitat conditions.

For a simplistic evaluation, geological origin is discernable through various methods. Broad-scale bathymetry can show whether a shoal is associated with the shoreline or is isolated. Seismic profiling provides information on geology both within and below the Holocene sequence strata. Coring through the shoal can provide stratigraphic validation of the seismic interpretations. Physical processes affecting shoals are largely depth dependent, and in general, therefore, related to distance offshore. Depth affects whether waves or currents are the prevailing forces affecting sediment transport. Local weather patterns and the orientation of the shoal to the nearest boundary (shoreline – i.e., affecting fetch), including the prevalence of high energy storms, control the depth to which wind-induced waves interact with the substrate.

Distribution of the three main types of shoals on the OCS is outlined in Section 2.3. Holocene shoals have thus far only been identified in the GOM. Cape-associated shoals are restricted to the Atlantic coast. Sorted bedforms, although more prevalent in the Atlantic, are also found in the eastern GOM. However, each type is represented in both areas. Within a particular type of shoal, zoogeography of shoal-associated species is likely the major factor controlling ecological function. Within a geographic region, it is likely that there are differences in ecological function across different types of shoals related to the shoal's physical dynamics. Distribution of benthic invertebrates is partially controlled by stability of the substrate with some relatively motile species adapted to shifting sands. From this simple relationship, it can be deduced that benthic predators feeding on shoals are likely to differ among the types of shoals.

### 5.1.2 Extent of the Resource

A common thread during workshop discussions was that the location and extent of sand shoal resources is simply not known. Part of this problem relates to the fact that such information is often developed for a specific project and the supporting documentation is contained in the grey literature or in agency files that can be difficult to access. In fact, the U.S. Geological Survey has developed databases of surficial sediments offshore of the Atlantic (Reid et al. 2005) and the GOM (Buczkowski et al. 2006) coasts that compile published and unpublished data on sediment texture, geochemical, and geophysical information. While the focus of these databases appears to be on sediment texture with little detailed bathymetry, the information may be useful in contributing to an understanding of where potential resources are located.

Another contributing factor, particularly for sorted bedforms, is that the low vertical relief and long wave length of these features may make them difficult to discern, depending on the precision of the hydrographic survey methods. This issue may be partially alleviated by recent initiatives undertaken by BOEM that are geared towards identification of offshore sand resources. In one action, BOEM has awarded a contract for geological and geophysical data acquisition to identify sand resources three to eight miles offshore from Maine to Miami, Florida for potential future coastal restoration, beach nourishment, and wetland restoration projects. If data resolution is sufficient, shoals can be identified through this process. Work is scheduled to start in 2015. In addition, BOEM has signed with 13 Atlantic coastal states to evaluate sand resources for coastal resilience and restoration planning. This too provides an opportunity for requiring a finer resolution of the bathymetric conditions of these resources.

The value of these efforts will be enhanced if the shoal resources are described using consistent terminology and information is obtained on their dimensions. For low relief, long wavelength features, this will require high-resolution bathymetry. For maximum usefulness, resulting data should be archived in a readily accessible database, such as the Marine Cadastre developed jointly by BOEM and NOAA (http://marinecadastre.gov/) or the USGS databases.

### 5.1.3 Applicability of Physical Processes Data from Inner Continental Shelf to OCS Sand Shoals

- *Most information is specific to the inner continental shelf; does it translate to OCS?*
    - *Need for improved understanding of sediment transport mechanisms on the shelf*

Analyses by Dibajna and Nairn 2011 suggest that, at least for the Atlantic OCS, mechanisms controlling the shape of sand shoals can be estimated reasonably well based on water depth, wave climate, and bottom currents. Data on wave climate can be readily obtained from the 90 NOAA weather buoys that are located both on the inner and the outer continental shelf (locations of buoys can be found at http://www.ndbc.noaa.gov/stndesc.shtml). Wave energy spectra transmitted from these buoys can be used to derive significant wave height, dominant wave period, average wave period, and direction of wave propagation that can be compared to bathymetric conditions to determine the likelihood of wave impacts to the shoal in question. Data on bottom currents are somewhat limited; oceanographic buoys that include current meters only measure surface currents. If a particular shoal were of great interest, however, this gap could be readily filled by installing a current meter or series of current meters at appropriate depths such as within a meter of the seafloor and within a meter of the crest of the shoal.

### 5.1.4 Physical Recovery of OCS Shoals from Disturbance

Understanding the likelihood that a shoal from which sand has been removed will return to its pre-disturbance dimensions is critical to determining the frequency at which a particular shoal can be mined. It also feeds into understanding the significance of any biological impacts. As described in Section 2.2, physical dynamics of the three types of shoals differ, with time scales of change ranging from daily/annually (e.g., bedforms) to decadal or longer (e.g., cape-associated shoals) to geologic (e.g., Holocene deposits). These differences factor strongly into three important, and closely-linked, questions regarding how much material can be removed from a particular shoal:

- *How does regional/site-specific variability among shoals control sediment dynamics and the likelihood that sand removed from a shoal will be replaced through natural processes?*
- *What is the basis for determining how much material can be removed and still maintain physical features sufficient to allow ecological function?*
- *What data are needed to predict how much material can be removed from a shoal complex without disrupting the physical processes controlling its dimensions?*

Two studies supported by BOEM have investigated the questions of physical effects to, and recovery of, sand borrow areas. Dibajna and Nairn (2011) focused on modeling the time sequence of infilling of sand following extraction from bedform shoals in the Mid-Atlantic OCS.

Using various extraction scenarios, they demonstrated that these dynamic shoals are likely to return to their pre-disturbance dimensions. This study was used to support the proposed post-Hurricane Sandy repairs at Wallops Island, VA using sand from an offshore shoal (Unnamed Shoal A). BOEM has required that post-dredging bathymetric surveys be conducted immediately after dredging and over the following 1 to 3 years (Bennett 2013). Comparison of these surveys to the pre-dredging survey will be valuable in validating Dibajna and Nairn's (2011) modeling predictions.

A second study entitled "Best Practices for Physical Processes and Impact Assessment in Support of Dredging Operations on the U.S. Outer Continental Shelf" (BOEM Contract Number M10PC00118) is currently underway. Although this study focuses more on borrow pits, an important objective is to "test, tailor and apply existing numerical morphological modeling tools and methods in order to provide robust and defensible predictions of morphological behavior in OCS sand extraction pits/areas, as well as the associated nearfield and far-field impacts." Thus, the results may be relevant to a greater understanding of physical processes determining sand distribution and shoal formation/maintenance on the OCS.

Physical recovery of sorted bedform shoals appears to be more fully understood and while there may be regional variation in the elapsed time required for recovery, in general it can be expected that physical recovery will take place.

Similar analyses appear to be missing for other types of shoals. It is recommended, therefore, that modeling efforts be applied to stranded Holocene and cape-associated shoals to generate predictions of recovery time from disturbances at various levels of impact.

## 5.2 Biology

Preparation of the draft synthesis and the workshop discussions identified a number of knowledge gaps related to fish use of offshore sand shoals and shoal complexes that were grouped into six broad categories:

- Species occurrence and utilization
- Functional uses
- Temporal patterns
- Sampling methods
- Impact assessment
- Mitigation or resource management approaches

### 5.2.1 Species Occurrence and Utilization

- *Do useful indicator species exist?*
    - *What fishes commonly use shoal habitats?*
    - *Are there species common to most/all shoal habitats in a region?*
    - *Can impacts to certain species on individual shoals be extended to other members of the fish community and to other shoals?*
- *Are shoal habitats limiting (i.e., is there competition for space among fish species on shoals)?*

- *Given patchy and temporally variable use of shoals by fishes, can we identify important microhabitats?*
    - *Measurements of habitat use at fine scales and linkages to microhabitats within a shoal or shoal complex*
    - *Information on the use of shoals and shoal complexes by different life stages*
- *Are certain habitats used in exclusion of other habitats within a shoal complex?*
- *Are fish communities (assemblage structure) on shoal habitats unique and distinct from non-shoal habitats?*
- *Do certain life stages and species exclusively use shoal areas such that repeated disturbance to one shoal could lead to chronic biological impacts?*

Review of the research conducted on shoals and shoal complexes indicates that a variety of fishes (over 350 species) that are common members of shallow continental shelf fish communities utilize these habitats in both the Atlantic and GOM OCS. Some of these species have been documented on multiple shoals within a region (e.g., sand lance, spotted hake), and sixteen species (including, e.g., striped anchovy, smallmouth flounder, lined seahorse, striped cusk-eel, and inshore lizardfish) were found to occur on shoals and shoal complexes over a large geographic range that included multiple regions. Several species documented as using OCS shoals and shoal complexes have been identified as keystone species due to their important ecosystem roles in linking habitats and trophic biomass (i.e. forage fishes or apex predators) or as habitat engineers; these include river herring, sand lances, Atlantic herring, Atlantic menhaden, red grouper, several Atlantic highly migratory species, and blue crab. Shoal areas have also been designated as EFH for several Atlantic highly migratory species (e.g., tunas, sharks, swordfish, and billfishes), although direct links to shoal habitats for these species are not well defined.

Many studies have been restricted to investigating a single shoal or ridge area within a complex, so it is often unknown whether individual shoals or ridges within a complex contain the same fish communities. The research conducted by Slacum et al. (2006) and Brooks et al. (2005) suggests that individual shoals within a complex or region may have varying habitat values due to environmental and microscale factors.

Additionally, the importance of specific habitat features for fish communities within the continental shelf system is not well understood. Outside of a small number of studies completed in the Mid-Atlantic and for some focused on individual species, we have limited information on how fish are using specific meso- and micro-habitats within shoals and shoal complexes. The studies completed in the Mid-Atlantic indicate that a few species such as sand lances, northern stargazers, and snakefish have a preference for the tops of shoals or ridges that consist of coarse sand and large bedforms, habitats conducive to burrowing (Diaz et al. 2003, Vasslides and Able 2008a). Smallmouth flounder and spotted hake instead showed a preference for daytime use of complex biogenic trough habitats (Diaz et al. 2003). In the GOM, dwarf sand perch and least puffers were present in higher numbers on the shoal crest, while other species (e.g., shoal flounder, large-scale lizardfish, silver seatrout) were more abundant in areas adjacent to the crest (Wells et al. 2009). Blue crabs have also shown a preference for the tops of shoals in this region, which have been hypothesized to provide a refuge from hypoxic conditions that occur in deeper waters (Condrey and Gelpi 2010, Gelpi 2012). Information on the fish species using only the shoal and ridge top areas in these complexes, which represent the areas of highest interest for sediment extraction and offshore energy development, appears to be currently unavailable for much of the South Atlantic, Florida Straits, and GOM regions.

The majority of the studies conducted on shoals and shoal complex habitats have used trawls to obtain data on fish diversity, abundance, and seasonality of occurrence. Due to some of the specific limitations of trawl gear sampling (e.g., gear selectivity, habitat effects on catchability, meso-geographic scale of sampling) that are outlined below in Section 5.2.1.3 on Sampling Methods, selection for specific microhabitats by individual fish species on a shoal or within a complex cannot be determined definitively. Ichthyoplankton sampling provides information on the fish eggs and larvae present in an area; however, due to the pelagic nature of early life stages for many taxa, direct links to spawning locations and bottom habitat preferences of spawning adults are difficult to make and, in all likelihood, require multi-year data sets. Stomach content analyses have shown that fishes commonly forage on the benthic invertebrate communities present on a shoal or within a complex, and strong connections between the local benthic invertebrate assemblages and the demersal fish community have been documented (Diaz et al. 2006, Vasslides and Able 2008b, Zarillo et al. 2008, Zarillo et al. 2009). Unfortunately, these analyses cannot delineate specific microhabitats on the shoal or in the complex where specific fish species are foraging, nor can they determine the role that habitat-forming non-prey invertebrate species may have on the fish community structure. Data are currently unavailable to determine if fish species are using shoal areas selectively, whether fish species compete for meso- or micro- habitats on an individual shoal or within a complex, or the meso- and micro-habitats that must be present in order for the shoal or complex to maintain functional fish habitat value. Identifying the species utilizing the shoal and ridge top areas is also necessary to determine useful indicator species for each region of the OCS. An improved understanding of microhabitats used within a shoal or shoal complex habitats is required to fully understand the potential chronic impacts of sediment extractions from an individual shoal or extraction from multiple shoals within a complex on regional fish populations and habitat connectivity.

#### 5.2.1.1 Functional Uses

- *Is the use of shoal habitats or microhabitats on shoals or shoal complexes life-stage dependent?*
- *Are shoals important habitats for migratory fish species?*
- *Are these habitats primarily foraging or refuge areas?*
- *Do shoal and shoal complex habitats function as nurseries for marine fishes?*
    - *Occurrence of specific life-stages*
    - *Measurement of vital rates*
        - *Growth*
        - *Condition*
        - *Mortality*
    - *Contribution of recruits from shoal habitats to regional fish populations*
- *Does the usage of shoal and shoal complex habitats by fishes differ depending on the shoal size, complexity, distance from shore, or from major currents?*

- *Within a region, which shoals and shoal complexes are most valuable and why?*
- *Does a change in the composition of benthic invertebrate species significantly impact habitat value for fishes using shoals?*
- *At the landscape scale is there a significant functional difference between impacted versus non-impacted areas in these habitats?*
- *What is the certainty of our knowledge of the use of shoal habitats and microhabitats specifically? Can available sampling methods provide confident predictions?*

Shoals and shoal complexes represent unique habitats in OCS waters that may enhance biological productivity. Shoals and shoal complexes can serve as fish habitat and provide ecological services including foraging areas, refuges from predation, spawning sites, and nursery areas (Diaz et al. 2006, Geary et al. 2007, Gilmore 2008, Mikulas and Rooker 2008, Vasslides and Able 2008b, Zarillo et al. 2009). Shoal areas have been designated as EFH and HAPC for some members of the Atlantic highly migratory species complex, although the evidence for this connection is limited (NMFS 2009). Shoal and shoal habitats appear to function as nursery areas for marine fishes given that younger life stages predominate (Rooker et al. 2004, Mikulas and Rooker 2008). Determining the use of these habitats as nursery areas has been complicated by many factors including the spatial scale of fish movements (meters, kilometers, to hundreds of kilometers), the duration of a species early life stages, species-specific ontogenetic and spawning cohort habitat shifts, and the lack of species-specific growth and mortality information. Measurements of species-specific vital rates for the species present on shoals and shoal complexes are necessary in helping to understand shoal and shoal complex habitat value and the role these habitats might play in regional fish population dynamics.

The studies conducted by Byrnes et al. (1999), Brooks et al. (2005), Slacum et al. (2006), and Zarillo et al. (2009) collectively indicate that individual shoals within a complex and/or region can have different habitat values due to macroscale environmental factors (e.g., hypoxia zones) as well as differences in microscale factors (e.g., shoal relief and presence of biogenic structures). The lack of shoal-specific biological characterization at broad spatial scales makes it difficult to determine which shoals and shoal complexes within a region are the most valuable, contributing the greatest fish habitat value or ecological function. The location of the shoal or shoal complex in relation to other important features (e.g., shore, hard bottom areas, coral reefs, and major currents) may also contribute to the habitat value of a particular shoal or shoal complex. For example, in the South Atlantic, Florida Straits, and the GOM, reef-associated fish species have been found on shoals and shoal complexes adjacent to or containing hard-bottom areas, indicating that these hard-bottom features likely influenced the local shoal fish assemblage and may have contributed to increased species diversity in these shoal areas (SAFMC 1998, Zarillo 2009). Studies in the Mid-Atlantic and GOM also suggest that shoals and shoal complexes may act as migration corridors between estuarine and ocean habitats, linking early life stage and adult habitats for many fish species as well as providing macroscale guides for spawning and seasonal migrations (Able 2005, Well et al. 2009, CSA International Inc. et al. 2010).

#### 5.2.1.2 Temporal Patterns

- *Do diel patterns in the use of shoals exist that can inform optimum times for disturbance to minimize acute impacts (e.g., mortality directly associated with the disturbance activity)?*
- *Can we identify seasonal patterns in the use of shoal habitats that can inform decision making on time-of-year windows for disturbance activities?*

Diel patterns of shoal use have been documented during Mid-Atlantic studies and may be related to multiple factors, including species-specific foraging behavior and shoal relief (Diaz et al. 2003, Slacum et al. 2006). The spatial scale and daytime sampling used in past studies conducted in the South Atlantic, Florida Straits, and GOM did not allow for the discernment of diel patterns of shoal use in these regions. Therefore, data are not currently available to recommend optimum times for disturbance to shoals and shoal complexes to minimize acute impacts associated with disturbance activities. Observations in the Mid-Atlantic indicate that diel patterns of shoal use may be species-specific. Due to the varying fish assemblages found in the shoals and shoal complexes in each of the Atlantic and GOM OCS regions, optimal times for disturbance may need to be determined regionally in order to effectively minimize acute disturbance impacts for the species present in these habitats.

Seasonal patterns of fish occurrence on shoals and shoal complexes have also been documented and are generally similar to the regional-specific seasonal migratory and recruitment patterns in the Mid-Atlantic, South Atlantic and GOM regions (Cutter and Diaz 2000, Brooks et al. 2005, Gilmore 2008, Slacum et al. 2010, Wells et al. 2009). In the Mid-Atlantic, the majority of the species observed were seasonal residents on shoals and/or shoal complexes, with only a small percentage present in the winter or year-round (Cutter and Diaz 2000, Slacum et al. 2006, Slacum et al. 2010, Vasslides and Able 2008a). Slacum et al. (2010) suggested that restricting sediment extraction to winter may minimize adverse impacts to shoal and shoal complex communities in the Mid-Atlantic, as it would avoid periods of peak benthic invertebrate recruitment (spring and summer) and demersal finfish use of the continental shelf as nursery grounds.

Wintertime sediment extraction may not be ideal for all locations. For example, along the eastern Florida coast in the South Atlantic region, the subtropical to tropical environment allows for protracted occurrence and spawning periods that extend throughout the year for many species, as several finfish species spawn on the continental shelf during the fall, winter, and spring (Gilmore 2008). As a result, a winter restriction for sediment extraction may not be appropriate for this region and for the finfish species that are utilizing OCS shoals and shoal complexes in the South Atlantic.

In the GOM, the hypoxia zone that can occur from late February through early October, with the most severe hypoxic conditions occurring in June through August, may affect species richness and abundance in the shoal areas within this zone (Brooks et al. 2005). The occurrence of the hypoxic zone and the impacts it may have on species occurrence, interactions with disturbance activity, and the potential to lengthen recovery times should be considered in determining an appropriate temporal window for shoals and shoal complex disturbance in the specific area of the hypoxic zone and in the larger GOM region.

Time-of-year windows for shoals and shoal complex disturbance activities need to be determined for each region based on the species present and the periods of peak recruitment and nursery ground use for both benthic invertebrate and finfish communities, in conjunction with any other large-scale seasonal environmental factors (e.g., hypoxic zones) that could influence the local fish assemblages. The data needed to determine time-of-year windows for disturbance activities appear to be incomplete for the South Atlantic, Florida Straits, and the GOM regions.

#### *5.2.1.3 Sampling Methods*

- *Are standard fishery sampling methods (e.g., trawls, traps, etc.) sufficient?*
- *Can we effectively sample shoal/ridge habitats to determine their value to fishes at various spatial scales?*
    - *Are there biases in estimates generated by traditional sampling gears?*
    - *Potential alternative approaches*
        - *Remotely operated vehicles [ROVs]*
        - *Gear-mounted or drop cameras*
        - *Tagging studies*
        - *Data storage tags to determine details of movements and potential environmental cues*
        - *Active and passive acoustics*
    - *Before-After Control-Impact (BACI) studies to provide baseline information*
- *What are the appropriate research methods to improve our understanding of the ecological value and function of shoal habitats for fishes?*

There are a variety of sampling techniques available to collect fisheries biological data. Many articles and books have been written to describe fisheries sampling techniques and protocols (e.g., Zale et al. 2012). Recommendations for physical and biological monitoring programs to evaluate the long-term impacts from sediment extraction on the OCS have been discussed by Research Planning Inc. et al (2001), Nairn et al (2004), and Diaz et al. (2006). Effective sampling of shoals and shoal complex habitats to better understand their value to fishes and fisheries will be accomplished by using a variety of sampling methods over multiple spatial and time scales to target specific knowledge gaps. The sampling techniques selected will be dependent on the data needed to address the specific knowledge gap, the target organism, and the time of year (Zale et al. 2012). Sampling approaches used to study these habitats should be fully integrated to collect and report data in the most efficient and cost-effective ways.

All fishing gears have a degree of selectivity (e.g., size or species of fishes collected) that is often dependent on habitat. As a result, the catches in fishing gears are often biased compared to the actual unknown size and species composition of the ecosystem being sampled. Due to this selectivity, a single sampling gear provides only limited representation of the characteristics of a fish population or community (Zale et al. 2012).

### ***Trawls***

Trawls have been the most commonly used gear to study the fish communities on shoals or in shoal complexes. Trawls are often used because they provide a direct assessment of the fish community (as opposed to indirect assessments from e.g., acoustic surveys) and sample a discrete area or volume of habitat. Because the unit of effort is well defined, trawl surveys generate quantitative indices of fish population abundance (Zale et al. 2012).

However, trawls have several limitations, including that they cannot be effectively fished where vertical obstructions are present on the substrate, they generally are not suitable for sampling in very shallow habitats, they sample at a fairly broad or meso-scale, there is no direct observation of the benthic habitat, and fast-swimming fishes or older life stages may avoid collection (Zale et al. 2012). In addition, they are typically selective in terms of the size classes caught.

While trawls have provided useful information on fish diversity, abundance, and sizes occurring in shoals and shoal complex habitats, their continued use should be coupled with additional sampling gears, along with the routine collection of fish tissue samples to determine diet (e.g., stomach contents or stable isotope analysis), age (e.g. scales or otoliths) and genetics. Trawl surveys can be effectively combined with other sampling methods to provide finer spatial scale information on habitat use, such as methods that provide direct observations of habitat utilization and species interactions (e.g., ROV surveys).

The knowledge gaps in meso- and micro-scale habitat utilization can be investigated using remote direct observation, tagging, and biotelemetry techniques. Tagging and biotelemetry studies can also help to fill knowledge gaps related to fish movement, foraging, growth, and survival for species that use shoals and shoal complexes.

### ***Direct Observation***

Direct observation techniques are most effective at obtaining accurate information on marine organisms in their ecological surroundings to supplement studies that include broad-scale inventories of distribution and abundance. Specifically, *in situ* observational techniques can record observations on fish behavior, evaluate habitat use, quantify species interactions, and aid in the performance assessment of traditional gears. The advantages of direct observation methods are the ability to obtain *in situ* behavioral information in a nonintrusive and nondestructive way that is recorded for later examination and verification. Direct observations are most appropriate when the effectiveness of other sampling methods are compromised by environmental conditions (e.g., habitat complexity and depth; Zale et al. 2012). ROVs and gear-mounted cameras are examples of remote direct observation equipment that can be used in shoals and shoal complexes to investigate utilization of the invertebrate benthic community as the fish forage base and for biogenic shelters, species- and life stage-specific microhabitat utilization, and species interactions. Direct observation techniques can be limited by local environmental conditions (e.g., water clarity, currents, waves, and depth) and the inability to measure many important biological characteristics (e.g., weight, sex, age, and reproductive status) of the fish.

### ***VIE Tagging***

Tagging studies are used to examine fish movement patterns and to estimate growth rates, demographic traits, and abundance of fish populations. If well planned, tagging programs can address multiple characteristics of interest (e.g., movements, vital rates, and connectivity) in the same study. A wide variety of tags and marking techniques can be used. Tag selection should consider visibility, non-impairment to tagged fish growth and survival, tag retention rates, and cost (Zale et al. 2012). Tags that may be useful in studying shoals and shoal complexes include visible implant elastomer (VIE) tags and electronic tags including both data storage tags and acoustic tags.

VIE tags are colored elastomer mixed with a clear catalyst that are injected with a hypodermic needle into transparent or translucent fish tissues and are visible as a colored dot or stripe. They are widely utilized because they can be applied to small individuals; have little effect on fish behavior, growth, and survival; can create unique identifications; have long retention times depending on tag location, species and color; and are available at a low cost (Zale et al. 2012). VIE tags could be used to study short term (i.e., weeks and months) growth and movement of young-of-the-year juvenile fish on shoals and shoal complexes. A drawback to VIE tags is that the tagged individuals must be recaptured in order to obtain any data so their application would require simultaneous trawl and/or ROV studies.

### *Electronic Tagging*

Electronic tags remotely monitor behavioral, physiological, and environmental data from an individual free-swimming fish moving through the marine environment to determine habitat use, aspects of migrations, survival rates, and home ranges. The advantages of electronic tags are the ability to assess differences among individuals, to link behavior and physiology, to work across different spatial and temporal scales, and to collect data from remote or inaccessible habitats. Limitations of these tags include: high cost, difficulty obtaining adequate sample sizes for robust statistical power and population level inference on a limited budget, expensive sensor calibration or upload fees, and some limitations associated with fish size. It can also be difficult and time consuming to interpret large volumes of data for multiple biological parameters that may or may not be independent of one another (Zale et al. 2012).

There are two primary types of electronic tags that would be useful for investigations around shoals: data storage tags and acoustic tags.

Data storage tags contain sensors with long battery life (up to 7 years) and large data storage capacity, and can be programmed to record a variety of parameters (e.g., location, depth, temperature, salinity, pressure, and swimming dynamics) from a fish moving through the marine environment. Data storage tags usually need to be recovered from the fish to acquire recorded data; although satellite transmitters can provide real-time uplinks to orbiting satellites on large surface swimming fishes and pop-up satellite tags are designed to be released from the fish and float to the surface where they transmit the recorded data. The disadvantages of these tags include tag cost, the expenses associated with initial fish capture and tag application, and the dependence on voluntary recovery and reporting by fishermen and processors for tag returns and data retrieval. To maximize tag recovery, tags and contact information should be highly visible, a monetary reward should be offered for tag returns, and the study should be widely publicized (Zale et al. 2012; www.fishmarking.com/electronic_data_storage_tag.php). Data storage tags could be useful in filling the knowledge gaps in migratory patterns and routes, the time of year and length of use of shoals and shoal complexes, determination of selective use of these features, and preferred environmental features, particularly for Atlantic highly migratory species and other large commercially and recreationally important fish species that may only use shoals and shoal complexes sporadically.

Another type of electronic tags is the acoustic tag. Broadly referred to as acoustic telemetry, acoustic tags produce an acoustic transmission ranging from 24 to 200 kHz with an internal battery that is detected by one or more fixed-position acoustic receivers that the investigator deploys within a study area. In addition, active telemetry involves the use of a mobile tracking receiver to locate fish. Data are stored in the receivers in the form of detections of specific fish, with each detection defined by a date and time. Acoustic tag longevity ranges from 5 days to 2.5 years depending on battery size and transmission frequency. Fish size (>12 cm) and morphology, water depth, temperature, study duration, and attachment method are important considerations in selecting the type of transmitter used in a study. It is recommend that the transmitter weigh less than 2% (in air) of the body mass of a fish to prevent negative impacts on swimming behavior. There is currently no evidence that acoustic transmitters alter fish behavior or increase predation risk although alosine species are known to show aversion to 110-140 kHz high-intensity ultrasound. The propagated sound signal produced by each transmitter is detected by either a mobile tracking receiver, submerged hydrophone, or two-and three- dimensional positioning hydrophones arrays. Detection range is influenced by depth, transmitter output, and environmental noise. Wireless systems can send data collected from hydrophones on buoys to nearby receivers and data loggers to provide fish location data in near-real time (Zale et al. 2012). Acoustic telemetry is receiving increased attention and has been used to describe broad-scale movements of several species of marine and freshwater fishes. However information on fine-scale habitat use has been limited with conventional acoustic telemetry because geolocation estimates from single receiver detections are relatively coarse (± 100's of meters), and are restricted by the detection range of the receiver. Recently developed technology (e.g., Vemco VR2W Positioning System) uses multiple, closely spaced hydrophones to triangulate fish positions, which for the first time has provided continuous records of fine-scale movements and habitat linkages within a marine seascape (Espinoza et al. 2011a, b; Furey et al. 2013). Future assessments of habitat use on shoals and shoal complexes can benefit from the inclusion of Vemco VR2W Positioning System's and similar technology.

Active fisheries acoustics (commonly referred to as hydroacoustics) is the process of transmitting sound pulses and analyzing the returning echoes to detect fish. This technique is used to measure the distribution and abundance of organisms in the entire water column for depths ranging from hundreds to thousands of meters during day or night (Zale et al. 2012). Hydroacoustics techniques can be used to investigate fish behaviors (e.g. diel vertical migrations, foraging and migration-related swimming behavior, and schooling structure), year-class formation, prey abundance and distribution, bottom sediment type and submerged vegetation, and other seafloor features. Hydroacoustic methods are hindered by a limited ability to differentiate among similar fish species and to detect fish close to the surface and bottom. For hydroacoustic surveys to provide accurate information, they are often paired with trawl surveys to provide data on species composition and length frequencies that enable the calculation of hydroacoustic target strength (Zale et al. 2012). Newly developed imaging sonars (e.g., DIDSON or ARIS from Sound Metrics) transmit sound pulses and convert the echoes into digital images that can be used to differentiate individuals to the family or even species level. A spilt-beam bioacoustics system could be used to study short-and long-term pelagic fish density and distribution, diel vertical migrations, and zooplankton abundance and distribution in shoals and shoal complexes. Side-scan sonar could be used to study shoal and ridge features, shoal bedforms, and for assessing the physical impacts of sediment extraction and offshore development on shoals and shoal complexes. Complementary traditional gear (e.g., trawl) surveys would be necessary for at least a subset of stations to validate hydroacoustic information.

#### *5.1.2.4 Impact Assessment*

- *Can fishes compensate for disturbance to shoal habitats?*
  - *Determine whether essential habitats are limiting*
  - *Determine connectivity of shoal habitats*
  - *Density-dependent competition for refuge space, prey resources, spawning sites*
- *How do we extrapolate localized disturbance effects to population-level responses at a regional scale?*
  - *Measurement of presence/absence or abundance at multiple spatial scales*
  - *Assessing disturbance*
    - *Do disturbance thresholds exist? Do temporal thresholds exist for local or regional habitat disturbance within a large marine ecosystem that translate to chronic impacts on fish populations?*
    - *Relate magnitude and time of anthropogenic disturbances to natural or other (e.g., fishing) disturbances*
  - *Application of new approaches to measure:*
    - *Genetic diversity*
    - *Regional contribution to adult stocks (e.g., chemical tracers in hard parts)*
- *Cumulative impacts – regional management*
- *Is there a threshold of limited habitat that can be predetermined for a given region?*
- *Are there any habitat benefits from dredging-related disturbances to shoals (i.e., do these activities create any new habitats)?*

A variety of methods have been used to investigate the movements and habitat use of fishes across marine seascapes (defined here as areas with a mix of habitat types) such as shoals and shoal complexes. Traditional methods described above (active sampling with net gears, conventional tags) provide a snapshot of an organism's distribution within a seascape; however, they provided very little information on movements or the linkages of species across different habitat types. As a result, information on the habitat value and function of offshore shoals and shoal complex habitats for fishes and fisheries is incomplete at this time and it is unknown if fishes can compensate for large-scale disturbances to these habitats. Disturbances can affect the behavior and physiology of marine organisms which in turn could lead to changes in survivability and demographic rates. Population level effects of disturbance could also cascade among species if keystone forage or predator species are impacted. Identifying and modeling mechanisms through which individual level responses to disturbances could propagate to a population level effect is difficult. Part of this difficulty comes from a lack of quantitative understanding of marine ecosystem connectivity, marine fish use of various habitats, important species interactions within these habitats, and how different frequencies and magnitudes of anthropogenic disturbances impact habitats, as compared to natural disturbances such as storms.

Extrapolating the impacts of local disturbance at shoal and shoal complex habitats to the population level is currently not feasible given the nature of previous sampling efforts. Concurrent sampling with similar experimental design and gear is needed across multiple shoals and shoal complexes in the South Atlantic and GOM to better characterize spatial and temporal patterns of habitat use. These data can then be linked to environmental data (e.g., areal coverage of substrate types, water quality, and depth) to develop habitat suitability models (e.g. generalized additive models), which can then be used to determine the influence of environmental conditions on the occurrence of each species of interest. Explanatory variables in these models, which often include both physicochemical and biological parameters, can be used to predict the probability of occurrence (including defining "high quality" habitat) for each species at large regional scales. The spatial extent of impacted shoal areas for each species can then be viewed in relation to the total available area and the spatial distribution of "high quality" habitat of each species to assess potential impacts due to disturbance (e.g. Rooker et al. 2013).

Mobile species and life-stages are expected to emigrate, at least temporarily, during shoal habitat disturbances; however, the specific meso- and micro- habitats that are being utilized by many of the species present in shoal habitats are unknown and as such it cannot be determined if they are limiting to regional populations or species. As discussed previously, further research is necessary to more fully understand the use of fine-scale habitats within these features and the function they provide as nursery areas and/or spawning locations. Further research is also necessary to understand the function that shoals and shoal complexes may have in estuarine-offshore migrations and habitat connectivity. Species that use specific shoals as spawning locations (e.g. red ear sardine, scaled sardine, and Atlantic thread herring) may be more sensitive and less resilient to disturbances to these habitats than other species. Species and populations that are already stressed due to large-scale factors limiting the amount of quality habitat available (e.g., hypoxia zones) may also be less resilient to disturbances to shoal and shoal complex habitats compared to species or populations in another region.

We currently do not know if disturbance thresholds exist for sediment extraction from marine ecosystems, at what habitat disturbance frequencies or magnitudes could translate into cumulative or chronic impacts on fish populations, or how multiple anthropogenic disturbances or stressors will interact to impact large marine ecosystem fish populations or assemblages. The data necessary to determine disturbance thresholds can be collected through baseline surveys and fish stock assessments, and long-term (five years or more) BACI studies. Size structure and conditions indices can be integrated to document changes in fish populations over time especially in conjunction with relative abundance, recruitment, growth, and mortality data (Zale et al 2012). Genetic analysis of fish populations and chemical analysis of hard structures (e.g., otoliths) can help determine natal origins and fish movement patterns over broad spatial scales that can be used to develop spatial management programs. Additionally, approaches like potential biological removal levels that are used to evaluate anthropogenic disturbances to marine mammal, sea turtle, and seabird populations could be adapted to evaluate disturbances to fish populations.

Natural disturbances are important to soft-substrate communities and can positively affect biodiversity by generating patchiness and heterogeneity which maintain diversity and stability at community, population, and ecosystem levels (Thrush and Dayton 2002). Sediment extraction in soft-substrate habitats results in the direct removal of infaunal and epifaunal organisms with reductions in the number of individuals, species, and biomass. OCS macrobenthic communities usually recover total abundance and biomass within 3 months to 2.5 years, however post-disturbance taxonomic composition and species diversity can remain different from pre-disturbance conditions for more than 3-5 years (Michel et al. 2013).

The fact that natural disturbances can have some positive effects on soft-substrate communities has led to the suggestion that anthropogenic disturbances can positively influence biodiversity. However, this has not been tested over the broad spatial scale relevant to anthropogenic disturbances. As a result, its application across species, benthic communities, and various scales of disturbance and recovery time may not be appropriate (Thrush and Dayton 2002).

Significant threats to the integrity and resilience of marine benthic communities occur when the rate of anthropogenic disturbance exceeds the rate at which ecosystems can respond. This is likely to occur where habitat structure and heterogeneity are reduced and large areas of habitat have been disturbed. Benthic organisms with slow growth and reproductive rates will often experience the greatest negative effects and will have a reduced potential to reestablish or colonize new areas compared to faster growing, short-lived species. The loss of ecological function and habitat value could result if habitat homogenization and loss of small-scale patchiness occurs (Thrush and Dayton 2002). Michel et al. (2103) suggests that applications of ecological disturbance theory and resilience as achieved by benthic community recovery could guide the predictions of OCS sediment extraction impacts. The scientific literature discusses the potential impacts, minimization and mitigation methods, and recovery times to OCS borrow areas; the literature has not discussed the benefits of sediment extraction to these OCS borrow locations.

#### 5.2.1.5 Mitigation or Resource Management Approaches

- *How do we avoid or minimize disturbances to ecologically valuable shoal habitats? What resource conservation methods are appropriate?*
    - *Which Best Management Practices (BMPs) have substantiated results?*
    - *Can we develop uniform mitigation approaches that can be applied to multiple projects with similar resources?*
- *How can we mitigate disturbance to shoal habitats?*
    - *Scheduling of activities (time of day, season)*
    - *Minimize physical impact to shoal*
        - *Restrict depth of sand mining*
        - *Uniform removal along shoal length*
        - *Avoid regions of shoal containing important microhabitats*
        - *Large scale open and closed areas (rotational disturbance)*
- *Develop the idea of adaptive mitigation measures depending on geological and physical conditions and how to apply this concept*

A large amount of literature exists on the impacts of anthropogenic benthic habitat disturbance in estuarine and nearshore areas. The known effects of these disturbances has led to BMPs that are often required to be used when project activities will disturb benthic habitats. Some of these practices may be applicable to activities being conducted on the OCS, for example seasonal or time-of-year restrictions, whereas other mitigation methods may be specific to or necessary for shoals and shoal complex habitats. Michel et al. (2013) provides a recent review of the impacts of sediment extraction on OCS sand borrow areas which includes mitigation measures and their potential effectiveness. The effectiveness of many of the mitigation measures is unknown at this time since monitoring data has not been able to fully substantiate the results.

***Conduct Long-Term Morphological Evaluations***

Mitigation of disturbances to shoals and shoal complexes and their ecologically valuable habitats should begin during the shoal or sand resource area selection process. Long-term and short-term studies of shoal morphology evolution to investigate shoal self-sustainability mechanisms should be completed for the offshore shoals in each region through a detailed morphologic evaluation that includes morphometric analysis, field measurements, and numerical modeling of extraction scenarios. These detailed regional evaluations are necessary to determine specific features that maintain shoal integrity in the region and to determine which shoals are likely to retain shoal integrity and related ecological functions after disturbance. A detailed morphologic evaluation with guidelines for sediment extraction has been performed for the Mid-Atlantic region based on local storm wave height, direction, and related subtidal currents (Dibajnia and Nairn 2011). Similar evaluations should be performed for the South Atlantic, Florida Straits, and GOM regions.

For sorted bedform and ridge/trogh shoals in the Mid-Atlantic region, the evaluation by Dibajnia and Nairn (2011) found that shoal height (relief) was the most important factor representing shoal integrity. Their guidelines for sediment extraction practices result in a reformed shoal with the same height as the pre-extracted shoal, maintaining and protecting offshore shoal and ridge integrity. The modeling indicated that the reformed shoal contained a smaller sediment volume compared to the pre-extracted shoal because extracted volume was not fully compensated by the transport of material from outside of the shoal. It is unlikely that these results are applicable to other shoal types. Ecological studies in the Mid-Atlantic (e.g. Diaz et al. 2003, Slacum et al. 2006, and Slacum et al. 2010) suggest that shoal relief (height) is an important feature that contributes to fish habitat value.

***Use Shoal Integrity Guidelines***

As a result of shoal morphology studies, the following guidelines were recommended to maintain shoal integrity and related ecological function of sorted bedform and ridge/trough shoals in the Mid-Atlantic region:

1) sediment extraction should be conducted from shoals that have reached their maximum relative shoal height;

2) sediment extraction should be conducted from the southwest side of the shoal and longitudinal extraction should be avoided;

3) relative shoal height (shoal height to base depth) should not be reduced to less than 0.65 after sediment extraction, therefore directly removing sediment from the shoal crest is not recommended for this area; and
4) shoals with the base depth greater than 30 m and shoals with relative shoal height ratio (height above substrate/base depth) of less than 0.5 should not be dredged (Dibajnia and Nairn 2011).

Recommendations for borrow site selection and extraction methods suggested by CSA International Inc. et al. (2010) for sorted bedform and ridge/trough type shoals include:
1) extraction should occur from depocenter or leading (downdrift) margin of the shoal to avoid interrupting natural shoal migration;
2) extraction should occur over large areas in a striped pattern to leave sediment sources interspersed throughout and adjacent to the borrow area in order to avoid deep pits and promote more uniformly distributed infilling processes; and
3) limit total sediment removed from an individual shoal so that only a portion of a shoal is removed.

***Use Numerical Modeling***
As many of the large shoals in the northwest GOM are stranded Holocene sedimentary deposits that will not regrow or rebuild, numerical modeling of extraction scenarios for this shoal type is extremely important in order to select the best extraction scenarios that will maintain shoal integrity and related ecological functions (e.g., hypoxia refuges).

***Account for Extenuating Environmental Conditions***
Prior to selecting a particular shoal for sand removal, extenuating environmental conditions need to be identified and taken into account.Special consideration must be paid to shoals that offer or could offer unique functions. For example, shoals with substantial relative relief in the GOM can act as hypoxia refuges. In the Mid-Atlantic, some studies suggest that fishes may be using individual shoals within a shoal complex differently or to a greater or lesser degree. Shoals for which fishes show affinity should be afforded more protection from disturbance or, at a minimum, be disturbed less frequently.

***Apply Time-of-Year Restrictions***
Common practices used in sediment extraction of nearshore habitats that may be applicable to activities being conducted on OCS shoals and shoal complexes include time-of-year restrictions as well as maintenance of undisturbed patches of benthic habitat (*sensu* habitat reserves). Seasonal or time-of-year restrictions which are BMPsin estuarine and nearshore habitats may be applicable mitigation for disturbance to the benthic invertebrate and fish communities in offshore shoals and shoal complexes, since seasonal patterns of fish occurrence have been documented in these habitats and were generally similar to the regional-specific seasonal migratory and recruitment patterns. Slacum et al. (2010) suggested adverse impacts to shoal and shoal complex communities from sediment extraction may be minimized by avoiding seasons of peak recruitment and times of the year when the shoals function as nursery grounds. Time-of-year windows for disturbances to shoals and shoal complexes need to be determined for each region based on the species present, the periods of peak recruitment and nursery ground use of both the benthic invertebrate and finfish communities, and any other large seasonal environmental factors that could influence the local assemblages (e.g. hypoxic zones). Areas in subtropical to tropical

environments that have protracted fish occurrence and spawning periods throughout the year for many species may need to determine time-of-year restrictions based on the species and local environmental conditions present on the specific shoal selected for disturbance in these areas in order to minimize adverse impacts. For the Mid-Atlantic region which has a high percentage of summer seasonal residents, Slacum et al. (2010) suggested a winter time-of-year window for sediment extraction to avoid periods of peak fish and invertebrate recruitment (spring and summer). The data needed to determine time-of-year windows for disturbance activities on OCS shoals and shoal complexes is incomplete for the North and South Atlantic, Florida Straits, and the GOM regions.

***Leave Undisturbed Patches***

The second mitigation measure that is often recommended for sediment extraction in nearshore waters that may be applicable mitigation for the benthic invertebrate and fish communities in OCS areas is the practice of leaving undisturbed patches of benthic habitat (Slacum et al. 2010, Michel et al. 2013). The undisturbed patches would provide some refuge for mobile species during extraction activities and would provide habitat from which benthic fauna could recolonize the disturbed areas. If arranged into a network of undisturbed areas, fish could readily migrate between areas to avoid localized disturbances. Telemetry approaches would be a fruitful technique to determine the effectiveness of such a design.

## 5.3 Biophysical Coupling

- *What are the key physical or biological features of shoal habitats that provide ecological function and value to fishes?*
- *Connectivity between shoal and non-shoal habitats; how do the habitat characteristics of adjacent non-shoal habitat affect shoal fish assemblages and their ability to move among shoals?*
- *How do species-specific life history traits and/or behaviors impact the value and connectivity of shoal/ridge habitats?*
- *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?*
- *Are microhabitats within shoals used differentially and does this reflect different habitat value?*
- *Is there sufficient information to understand cumulative effects of repetitive use of the same feature or multiple features in the same geographic area?*

The physical features of shoals that provide important ecological value depend on what function is of concern. In the example of blue crabs in the GOM, better water quality conditions in terms of dissolved oxygen levels on the crest of the shoal appeared to be the primary factor that influenced their distribution. It is reasonable to postulate that other demersal species could also benefit from a bathymetric high to avoid low oxygen levels. As a result, preservation of ecological function could be achieved by restricting removal of sand from these shoals to the slopes and prohibiting removal from the crest. Some shoal-dredging projects in the eastern GOM have followed this practice under the assumption that it would preserve nursery habitat for species like cobia, although Wells et al. (2009) found that habitat preference varied among species.

Relationships between the benthic infaunal community and the physical environment are well understood with sediment grain size and amount of exposure to waves and currents being two of the most important factors. In principle, this knowledge can be applied to shoal ecology, but research specifically addressing these relationships is limited. Demersal fishes are typically found to have substrate (hard versus unconsolidated; general grain size) preferences for feeding and perhaps spawning but conclusive data relating to use of microhabitats (as defined by sediment structure) on shoals are not available. Logically, it would seem that static shoals would have greater ecological value as nursery areas than would more dynamic shoals.

Recommendations for biological studies are discussed in the Section 5.4. Greater understanding of the relationships between biota and the microhabitats of shoals and adjacent non-shoal habitats would be attainable through these multi-technique efforts.

## 5.4 Recommendations for Next Steps

In order to enable BOEM to move forward with its mandate of managing offshore sand resources, including dredging for habitat restoration, beach nourishment, and shoreline protection, it is important to identify the most important research to accomplish. As described in Sections 5.1 through 5.3, there are several gaps in our understanding of both physical and biological features that are key to shoal function, including some very basic facets. This section provides recommendations for research that will have broad applications to assessment of individual shoals for sand removal. The most basic questions identified in the literature survey and workshop are:

- How dynamic are offshore shoals and how resilient are they to disturbance (e.g., dredging, storms)?
- What organisms use the offshore shoals preferentially and why?

The answers to these questions are likely to vary by region and by type of shoal but will provide the basic information to guide additional research. While these initial research questions will not necessarily provide the answers to all of the questions that arose during the literature survey and workshop, it is expected that they will supply BOEM with sufficient data to make informed decisions on the future use of shoals.

Prior to initiating extensive research programs, it would be advisable to convene a working group composed of resource and regulatory agency staff and research scientists to solidify plans. At a minimum this should include BOEM, NOAA-Fisheries, and the Corps representatives from the eastern and western GOM, South Atlantic, Mid-Atlantic, and North Atlantic. Primary goals of these meetings would be to develop research approaches for sediment dynamics and biological investigations and to identify shoals where research should take place. The group must operate under the premise that the research will be targeted to obtain the necessary information to evaluate the feasibility of harvesting sand from offshore shoals. They must identify shoals that are representative of each particular type that occurs in each region (Table 5-1).

**Table 5-1. Distribution of shoals in US OCS in the Gulf of Mexico and Atlantic**

| Region | Stranded Holocene/Pleistocene | Cape-Associated | Sorted Bedform |
|---|---|---|---|
| Western GOM | x | | |
| Eastern GOM | x | | x |
| South Atlantic | x | x | x |
| Mid-Atlantic | | x | x |
| North Atlantic | | x | x |

### 5.4.1 Geological and Physical Research

Physical condition, whether it is the bathymetric expression, the heterogeneity of the substrate, or availability of shelter, has a great deal of influence on the biota that use the shoals. Expanding our understanding of shoal dynamics in particular will help elucidate the factors that cause some species to make use of the shoals.

Evidence was presented in Section 2.2.4 showing that the physical dynamics of shoals could be quite variable even within one type of shoal. For example, some sorted bedform shoals have been observed to migrate quite rapidly while others have not moved in several years. Does this migratory behavior also reflect local sediment transport conditions such that the actively migrating shoals are likely to refill more readily than the more stationary shoals?

Modeling predicts that ridge and trough shoals in the Mid-Atlantic can refill after sand removal but post-dredging recovery of other types of shoals has not been modeled. Understanding the time frame and relative completeness of physical recovery of a shoal or type of shoal is key to evaluating the potential biological impacts with shoal dredging. It is recommended that modeling similar to that conducted by Dibajna and Nairn (2011) be completed for each type of shoal in each region.

It is also important to test model predictions with empirical studies. As discussed in Section 5.4.2 on biological research recommendations, at least a few study shoals should be identified for a full range of survey techniques. In terms of geology and dynamics, the study parameters should include detailed bathymetric and grain size mapping of the feature prior to any human disturbance and follow-up mapping after either a major storm or a dredging event. Deployment of current meters at appropriate depths would also be beneficial.

### 5.4.2 Biological Research

Most biological research that has been conducted on offshore shoals has been targeted at answering one or several specific questions, but the studies have lacked a holistic approach that examines multiple facets of the communities that are using the shoals. As discussed in Section 5.2, the fisheries sampling methods that have been used by most past projects have limitations either in terms of the life stages vulnerable to the sampling gear or in the ability to document exactly where the captured organisms were at the time of capture. A holistic approach would include both benthos and finfish sampling and use sampling equipment appropriate for each of the life stages that could be present.

It is recommended that a similar study design be applied to each of the shoals identified by the shoal research working group in order to address these questions:

- What species, if any, use shoal habitats extensively or exclusively?
- Are there specific life stages dependent on shoals?
- How are different parts of the shoal used?
- How is the adjacent habitat used?
- Are all the shoals within a shoal complex used the same way?

A solid baseline study would consist of multiple survey techniques for both benthos and finfish, including such methods as:

- Benthos
  - Sediment profile imaging
  - Grab sampling
  - Epibenthic sled
  - Remotely operated video
- Finfish
  - Trawl, potentially of different mesh sizes
  - Gear-mounted video
  - Remotely operated video
  - Acoustic telemetry
  - Ichthyoplankton sampling

Sampling should be conducted at intervals appropriate to the specific resources of interest. Annual benthic sampling might be sufficient whereas fisheries and ichthyoplankton sampling must be much more frequent, potentially monthly or twice monthly.

BACI studies are used to evaluate physical changes to habitats resulting from anthropogenic disturbances (Stewart-Oaten et al. 1986; Underwood 1994). In a BACI study design, time is used as the replicate with biological or habitat variables measured before and after disturbance at both the disturbed site and an undisturbed reference site. The reference or control site is used to obtain an unbiased evaluation of the disturbance effects. BACI designs need to consider both sampling frequency and potential collinear changes (Zale et al. 2012). Long-term BACI studies should be conducted for representative offshore shoals in areas proposed for (or likely to be proposed for) sediment extraction and development. In shoal complexes, it would be important to examine more than one individual shoal as studies in these habitats have indicated that habitat value may vary within the complex. Asymmetrical multiple control BACI design may be more appropriate to use when evaluating impacts from multiple disturbances to a single shoal and disturbances to multiple shoals in a complex or region. BACI studies should be long term (five years or more), ideally include as many baseline period surveys as post-impact surveys, and include monitoring of surface, mid, and bottom water quality; sediment bedform and grain size; the benthic invertebrate community; and the fish community.

Use of the BACI study design will provide a strong basis for understanding data collected from a shoal following a dredging event. The BACI design compares both baseline and post-impact conditions at a site targeted for some type of human intervention to a similar control area. Having sufficient baseline data to understand the level of natural variability in biological activity is very useful, but the presence of a carefully selected control area allows interpretation of post-impact conditions within a broader spatial context.

### 5.4.3 Best Management Practices (BMPs)

Various mitigative actions have been factored into some shoal dredging projects and include restrictions on the time of year, portion of the shoal where sand can be removed, and volume of sand that can be removed. The efficacy of these practices has not been confirmed, however. It will be important to include consideration of these mitigative actions into the study design for the recommended biological research program.

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# 7.0 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 terrains 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.

Bedform Shoal- a shoal found within the morpho-sedimentary bedform continuum. The continuum consists of large scale bedforms on the shelf, controlled by amount of sediment flux. These bedforms range from sorted bedforms on the sediment starved end of the continuum to shore attached and linear shelf sand ridges on the sediment rich end of the continuum.

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

Cape-associated shoals – Capes are triangular shaped promontories that formed due to the convergence of longshore drift. Because of this convergence, there is a net offshore transport of sediment that form shoals. With sea level rise, the capes retreat landward, leaving behind a series of progressively older shoals in the offshore direction.

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 (Finfish 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.

Isolated inner shelf shoals – A shoal, typically comprising a relict Holocene deposit of sediment on the shelf, that is isolated from other shoals.

Linear shelf sand shoals - A series of shoals that are typically shore normal or shore oblique, on the shelf. They are one end of the morpho-sedimentary bedform continuum, occupying the high sediment flux end member. These shoals were typically originally formed as shore-attached ridges, but are found offshore in deeper water due to sea level rise.

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

Morpho-sedimentary bedform continuum - a continuum of large scale bedforms exist on the shelf, controlled by amount of sediment flux. These bedforms range from sorted bedforms on the sediment starved end of the continuum to shore attached and linear shelf sand ridges on the sediment rich end of the continuum.

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.

Ravinement – An irregular junction that marks a break in sedimentation such as an erosion line occurring where shallow-water marine deposits have cut down slightly into eroded underlying beds; associated with sea-level rise.

Relict cape-associated shoals – Cape associated shoals that exist along a section of the coast that has become re-configured such that there is no longer a cape, but the shoals remain.

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. Synonymous with ridge and swale. Both are terms used extensively in the literature to refer to abundant sediment flux end of the continuum of Bedform Shoals.

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.

Shelf (or shoal) retreat massif – An older term for one of two types of shoals, either a relict cape-associated shoal or a relict Holocene/Pleistocene deposit shoal.

Shoal – *Noun* - 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. *Verb* - to cause to become shallow or less deep.

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

Shoal fields – A region on the shelf where there are a series of shoals rather than an isolated shoal.

Shore-attached ridge (or shoal) – A large beach ridge (or shoal) attached to the shore and extending in a shore oblique direction offshore. These are the high sediment longshore drift sediment flux end member of the Morpho-sedimentary bedform continuum.

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.

Sorted Bedforms - also called rippled scour depressions) are bathymetrically subtle, large-scale bed features that are characterized by alternating bands of coarse and fine grained sediment with wavelengths of hundreds of meters, and negative relief of ~1m that trend obliquely to the coast.

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 A: Workshop Agenda and Presentations

BOEM
Bureau of Ocean Energy Management

# BOEM Working Group on the Habitat Values of Offshore Shoal Systems

*Held in conjunction with the Southern Division of the American Fisheries Society winter 2014 meeting*
January 24, 2014 Charleston, South Carolina

| Time | Topic | Speaker |
|---|---|---|
| 8:30- 8:40 | Welcome and Introduction | Ann Pembroke<br>Normandeau Associates |
| 8:40-9:00 | Why Offshore Shoals Systems are a Priority to BOEM | Dr. Jennifer Culbertson<br>BOEM |
| 9:00- 9:30 | Geological/Physical Processes Governing Shoals | Dr. Timothy Dellapenna<br>Texas A & M |
| 9:30-10:00 | Panel Discussion on Geological/Physical Processes Governing Shoals | Panel discussion facilitated by<br>Dr. Christopher Glass<br>Univ. New Hampshire |
| **10:00-10:30** | **BREAK** | |
| 10:30-11:00 | Panel discussion on Geological/Physical Processes Governing Shoals, continued | Panel discussion facilitated by<br>Dr. Christopher Glass |
| 11:00-11:30 | Benthic and Fish Resources of Shoal Complexes in the Gulf of Mexico OCS | Dr. Jay Rooker<br>Texas A & M, Galveston |
| 11:30-12:00 | Benthic and Fish Resources of Shoal Complexes in the Gulf of Mexico OCS, White Paper Summary | Dr. Fred Scharf<br>University of North Carolina, Wilmington |
| **12:00- 1:00** | **LUNCH** | |
| 1:00- 1:20 | Monitoring Fish on Shoals | Joseph Iafrate,<br>Navy/Kennedy Space Center |
| 1:20- 3:00 | Panel Discussion on Biological Resource Issues Associated with Use of Shoal Complexes | Panel discussion facilitated by<br>Dr. Christopher Glass |
| **3:00-3:30** | **BREAK** | |
| 3:30- 4:00 | Panel Discussion on Biological Resource Issues Associated with Use of Shoal Complexes, continued | Panel discussion facilitated by<br>Dr. Christopher Glass |
| 4:00-4:30 | Conclusions and Wrap Up | Ann Pembroke |

- Working group conducted and white paper prepared by Normandeau Associates, Inc.
- Webinar coordinated by Kearns and West, Inc.

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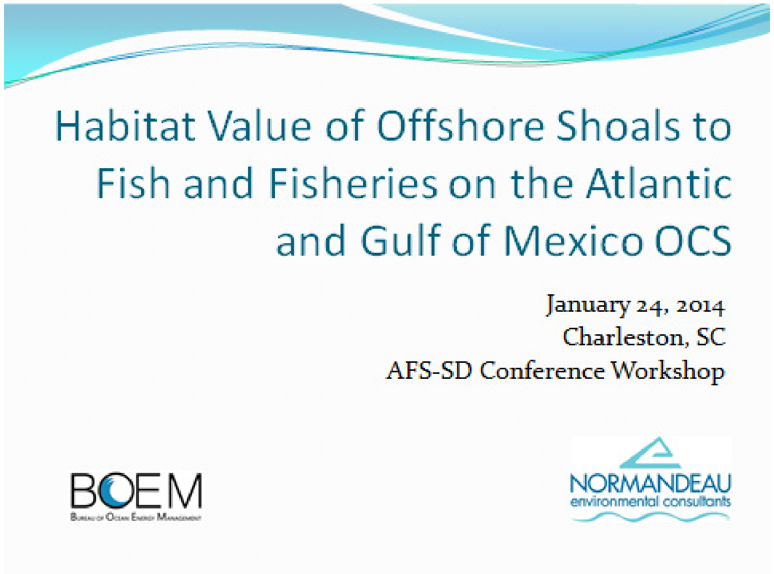

# Habitat Value of Offshore Shoals to Fish and Fisheries on the Atlantic and Gulf of Mexico OCS

January 24, 2014
Charleston, SC
AFS-SD Conference Workshop

BOEM

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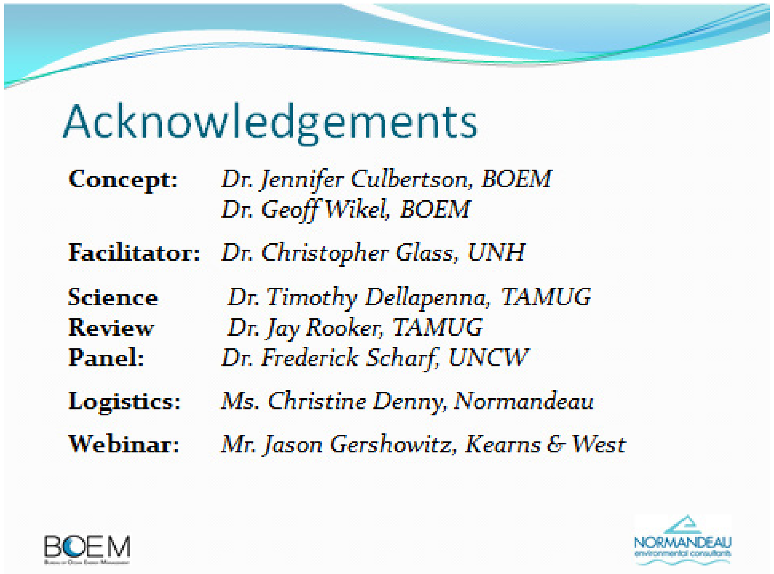

## Acknowledgements

| | |
|---|---|
| **Concept:** | *Dr. Jennifer Culbertson, BOEM*<br>*Dr. Geoff Wikel, BOEM* |
| **Facilitator:** | *Dr. Christopher Glass, UNH* |
| **Science Review Panel:** | *Dr. Timothy Dellapenna, TAMUG*<br>*Dr. Jay Rooker, TAMUG*<br>*Dr. Frederick Scharf, UNCW* |
| **Logistics:** | *Ms. Christine Denny, Normandeau* |
| **Webinar:** | *Mr. Jason Gershowitz, Kearns & West* |

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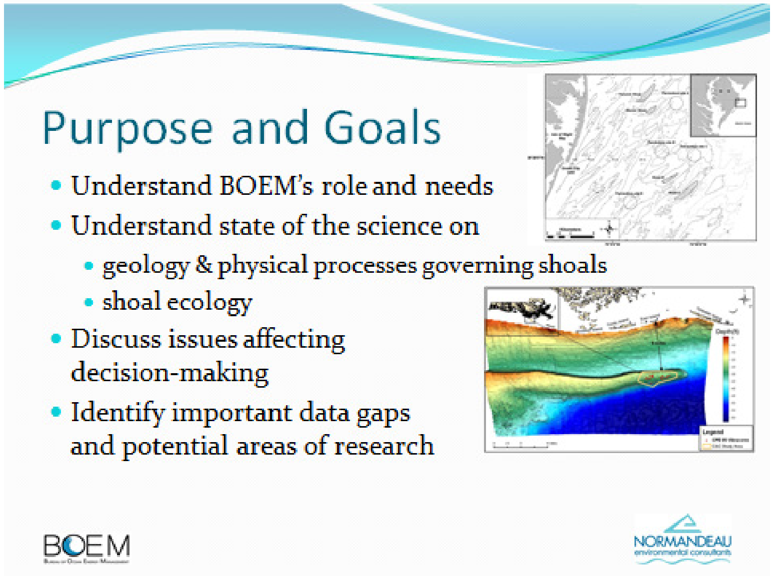

## Purpose and Goals

- Understand BOEM's role and needs
- Understand state of the science on
  - geology & physical processes governing shoals
  - shoal ecology
- Discuss issues affecting decision-making
- Identify important data gaps and potential areas of research

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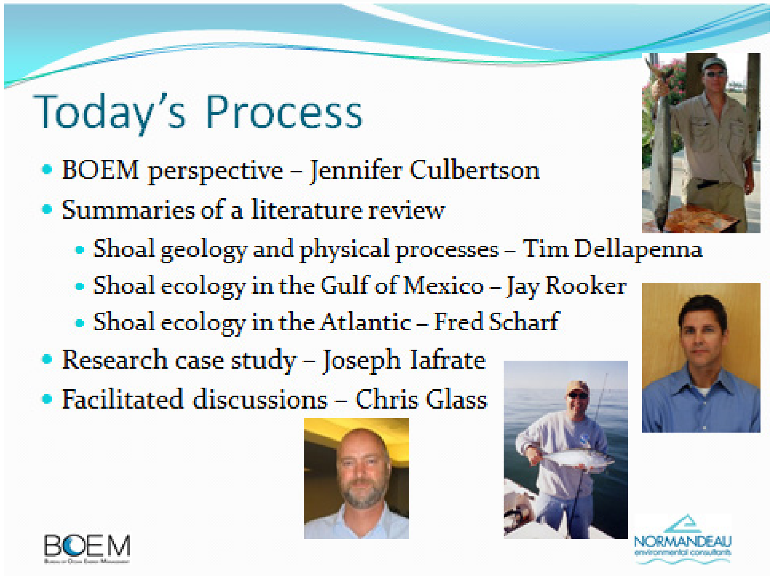

## Today's Process

- BOEM perspective – Jennifer Culbertson
- Summaries of a literature review
  - Shoal geology and physical processes – Tim Dellapenna
  - Shoal ecology in the Gulf of Mexico – Jay Rooker
  - Shoal ecology in the Atlantic – Fred Scharf
- Research case study – Joseph Iafrate
- Facilitated discussions – Chris Glass

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## Panelists

| | |
|---|---|
| BOEM | *Geoff Wikel* |
| USACE | *Jesse McNinch*, Alan Shirey* |
| NOAA | *David O'Brien, Pace Wilber* |
| SCDNR | *Denise Sanger* |
| TAMUG | *Tim Dellapenna, Jay Rooker* |
| UNCW | *Fred Scharf* |
| Coastal Tech Corp. | *Michael Walther** |
| Great Lakes Dredging | *Bill Hanson* |
| Versar | *Ward Slacum* |

**via webinar*

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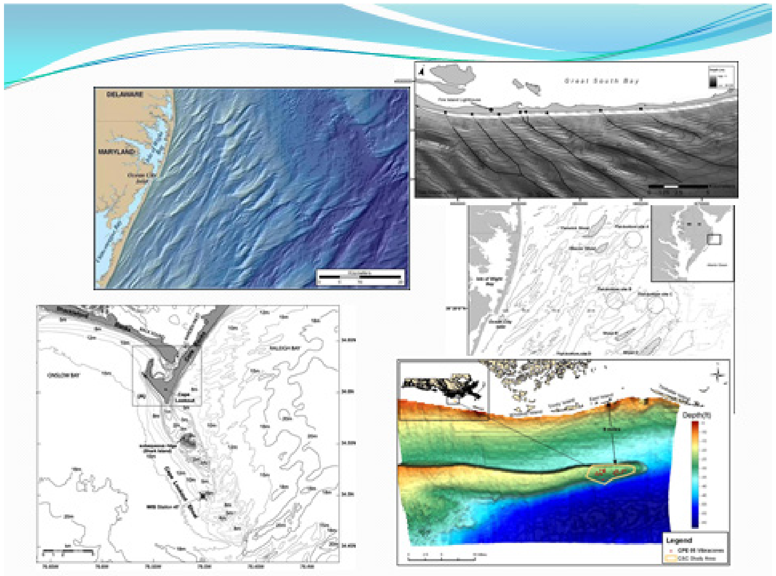
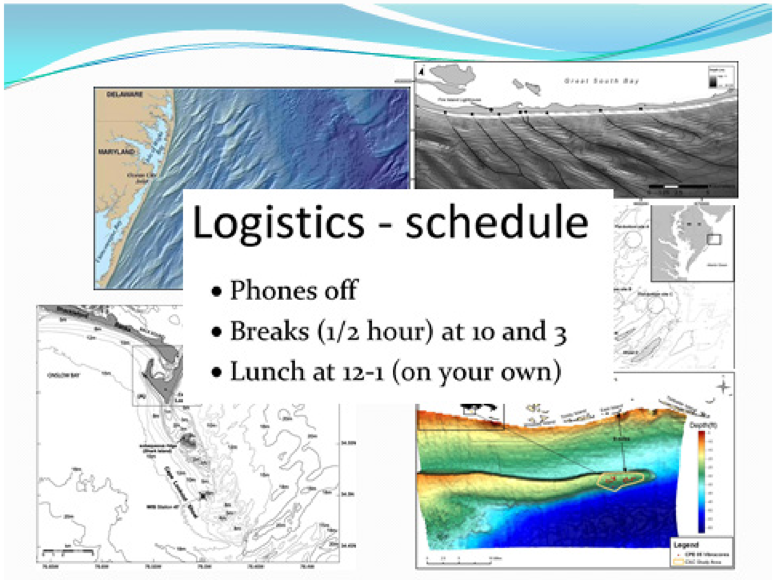


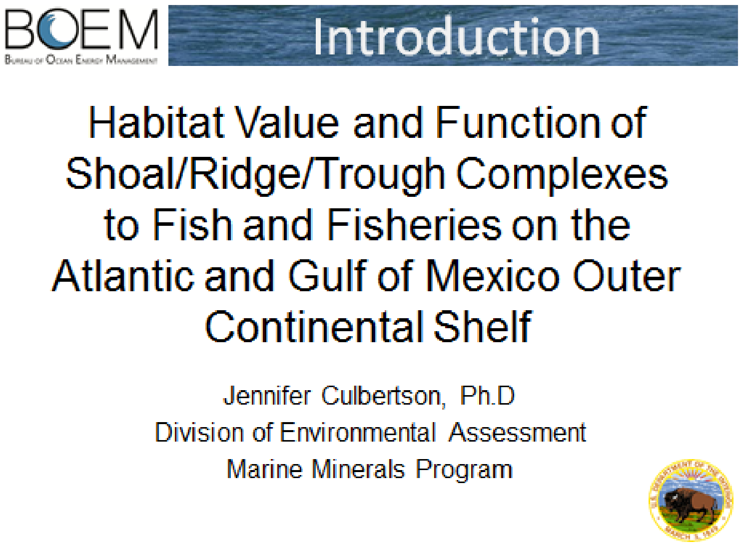


## Logistics - schedule

- Phones off
- Breaks (1/2 hour) at 10 and 3
- Lunch at 12-1 (on your own)

## Logistics – discussions

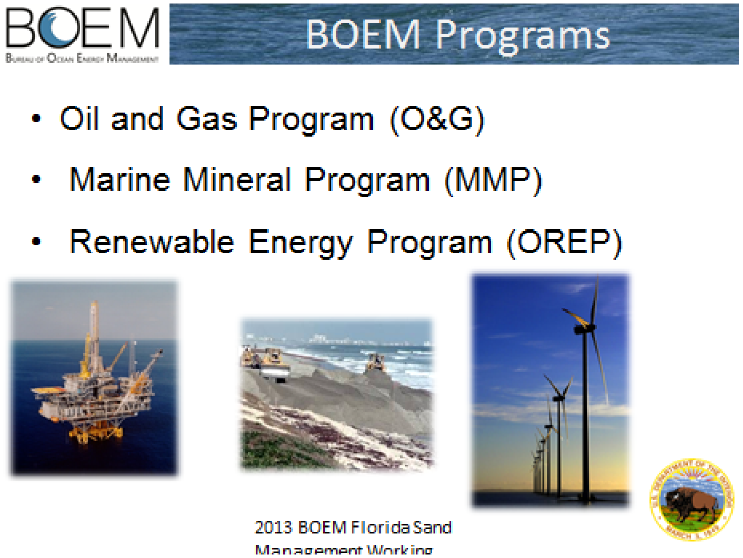
- Facilitated discussions, panelists prioritized
- Meeting being recorded
- Phone-in participants on mute
- In-room commenters use mikes
- Written comments welcome through February 21, 2014 (apembroke@normandeau.com)



## Introduction

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

Jennifer Culbertson, Ph.D
Division of Environmental Assessment
Marine Minerals Program



## BOEM Programs

- Oil and Gas Program (O&G)
- Marine Mineral Program (MMP)
- Renewable Energy Program (OREP)

2013 BOEM Florida Sand
Management Working

## Marine Minerals Program

Cameron Parish Shoreline Restoration Project
10/4/2013 Louisiana CPRA

BOEM is responsible for managing development of OCS marine mineral resources.

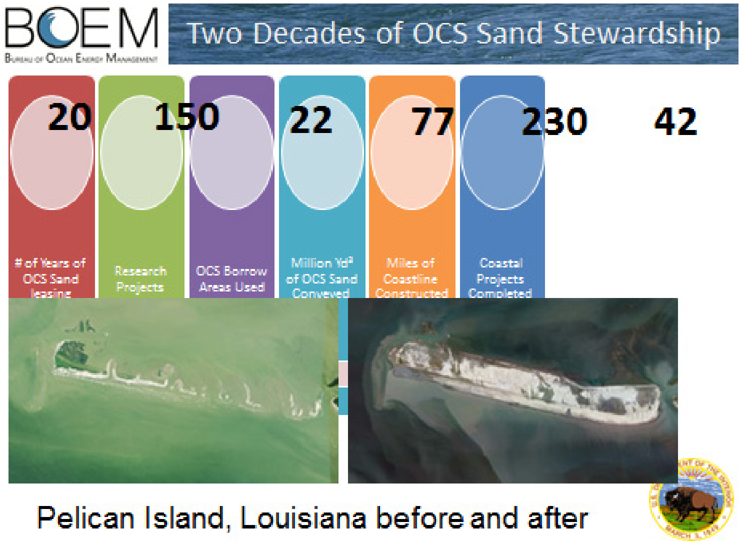
- Hard Mineral Competitive Leasing
  - Gold, Rare Earth Minerals, Copper, Zinc, Silver
- Competitive Sand Leasing (aggregate industry)
- Noncompetitive Negotiated Agreement for Public Works Sand Conveyance

## Noncompetitive OCS Sand

"The Secretary may negotiate with any person an agreement for the use of Outer Continental Shelf sand, gravel and shell resources—

(i) for use in a program of, or project for, shore protection, beach restoration, or coastal wetlands restoration undertaken by a Federal, State, or local government agency; or

(ii) for use in a construction project, that is funded in whole or in part by or authorized by the Federal Government." (Outer Continental Shelf Lands Act)

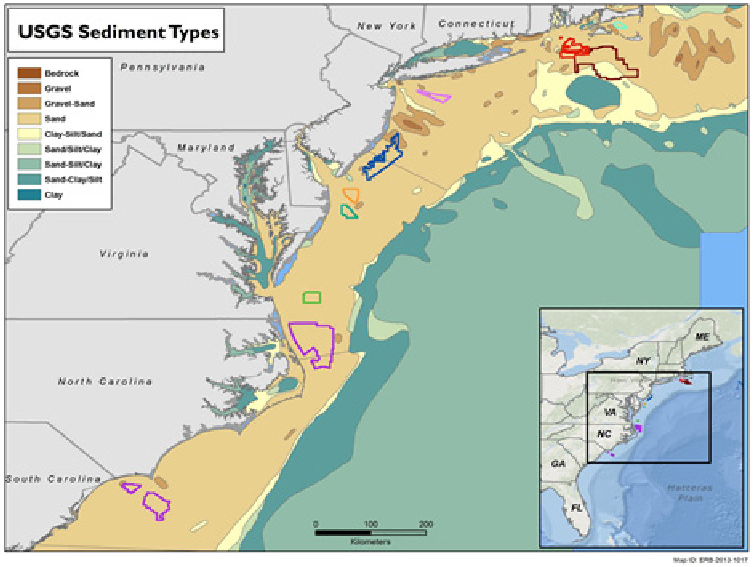


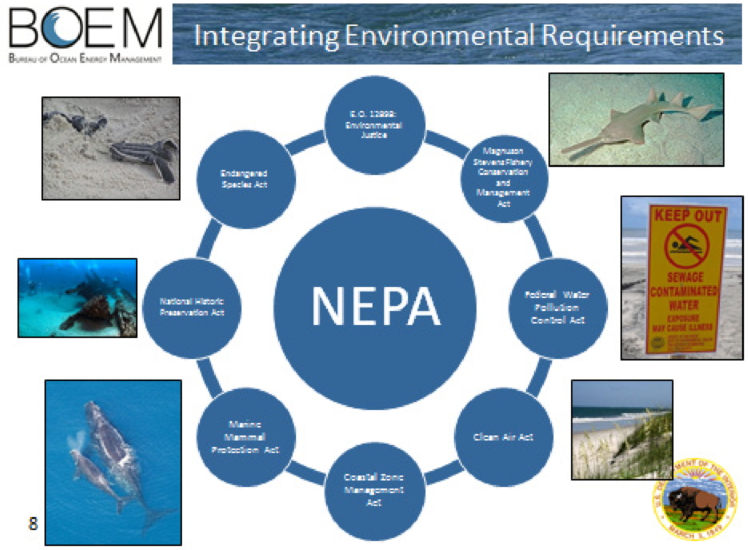
## Two Decades of OCS Sand Stewardship

Pelican Island, Louisiana before and after

## OCS Renewable Energy

- BOEM has statutory obligations to "protect the environment." – Energy Policy Act of 2005
- BOEM thus requires geophysical and biological data in order to approve a lessee's plan (see 30 CFR Part 585). Including:
  - Identification of sensitive bottom habitats, and
  - Fish and shellfish populations.

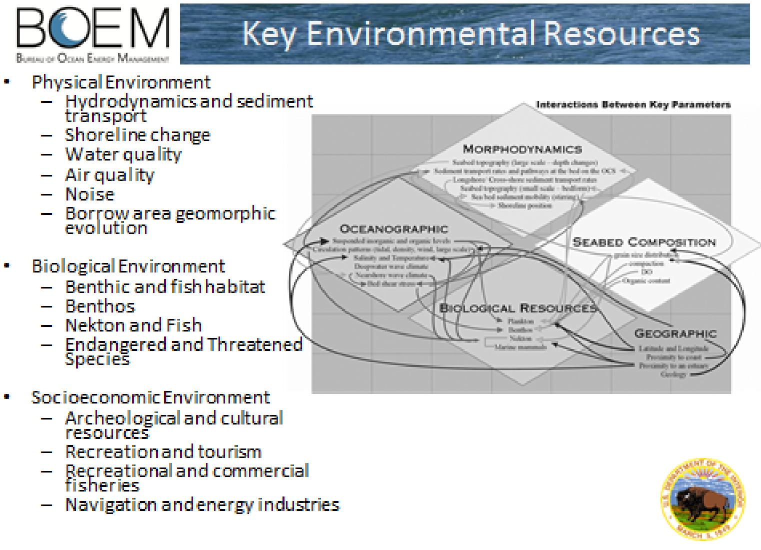




## Integrating Environmental Requirements

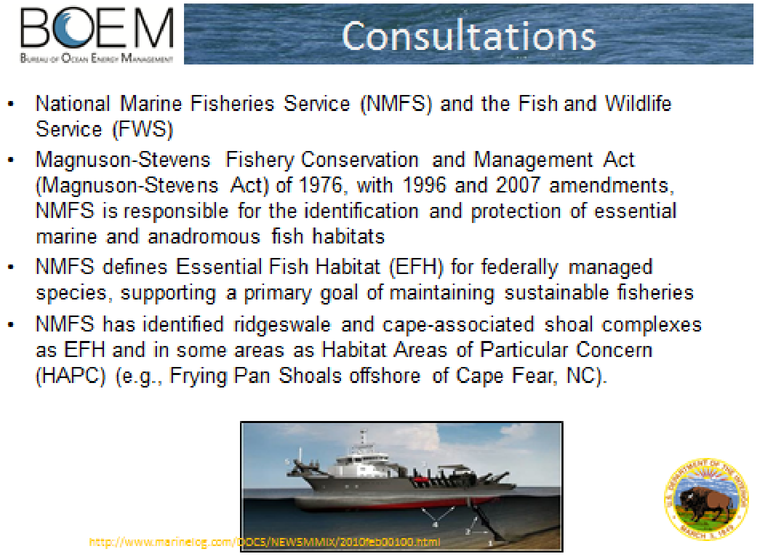
NEPA

- E.O. 12898: Environmental Justice
- Magnuson Stevens Fishery Conservation and Management Act
- Federal Water Pollution Control Act
- Clean Air Act
- Coastal Zone Management Act
- Marine Mammal Protection Act
- National Historic Preservation Act
- Endangered Species Act



## Key Environmental Resources

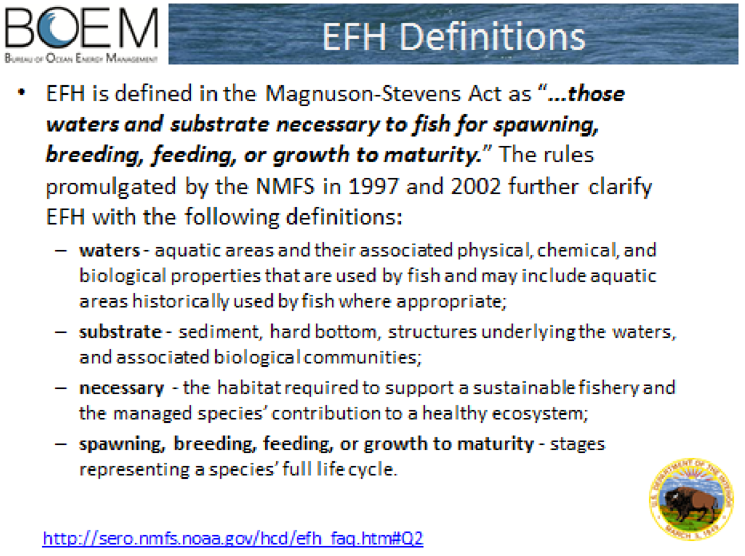
- Physical Environment
  - Hydrodynamics and sediment transport
  - Shoreline change
  - Water quality
  - Air quality
  - Noise
  - Borrow area geomorphic evolution
- Biological Environment
  - Benthic and fish habitat
  - Benthos
  - Nekton and Fish
  - Endangered and Threatened Species
- Socioeconomic Environment
  - Archeological and cultural resources
  - Recreation and tourism
  - Recreational and commercial fisheries
  - Navigation and energy industries



## Consultations

- National Marine Fisheries Service (NMFS) and the Fish and Wildlife Service (FWS)
- 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).

http://www.marinelog.com/DOCS/NEWSMMIX/2010feb00100.html



## EFH Definitions

- EFH is defined in the Magnuson-Stevens Act as "***...those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity.***" The rules promulgated by the NMFS in 1997 and 2002 further clarify EFH with the following definitions:
  - **waters** - aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate;
  - **substrate** - sediment, hard bottom, structures underlying the waters, and associated biological communities;
  - **necessary** - the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem;
  - **spawning, breeding, feeding, or growth to maturity** - stages representing a species' full life cycle.

http://sero.nmfs.noaa.gov/hcd/efh_faq.htm#Q2

## EFH Definitions

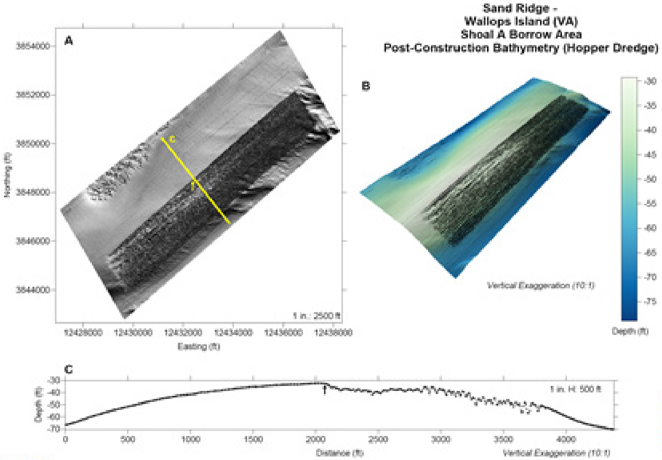
- The EFH rules define an adverse affect as “***any impact which reduces quality and/or quantity of EFH . . . [and] may include direct (e.g., contamination or physical disruption), indirect (e.g., loss of prey, reduction in species’ fecundity), site-specific or habitat wide impacts, including individual, cumulative, or synergistic consequences of actions.***”

http://sero.nmfs.noaa.gov/hcd/efh_faq.htm#Q2

## Environmental Impacts and Mitigation

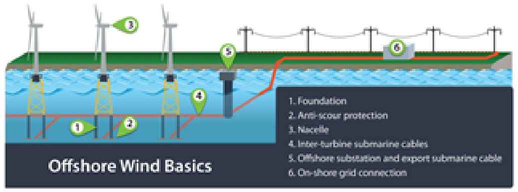
- Potential impacts (direct, indirect, cumulative) vary with resources present in affected environment
- Duration and intensity of impacts determined by location, volume, timing, dredging technology, etc.
- Objective: minimize deleterious impacts through the implementation of impact-reducing mitigation
  - Location avoidance: buffers to archaeological targets, EFH, nesting, protecting species, infrastructure, ordnance
  - Environmental windows: hopper dredging, larval fishes
  - Impact minimization: observers, dredging equipment, rotational/single use dredge areas
  - Monitoring: dredge position/production, benthic recovery, bathymetric recovery

## Wallops Island, VA



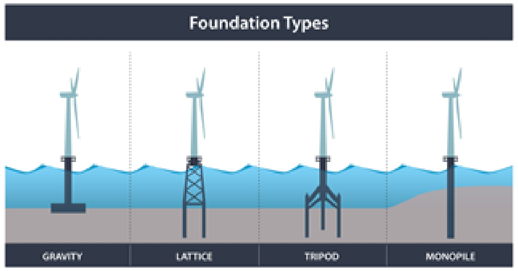
RPI 2013

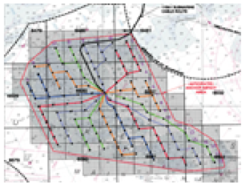
## Renewable Energy Construction

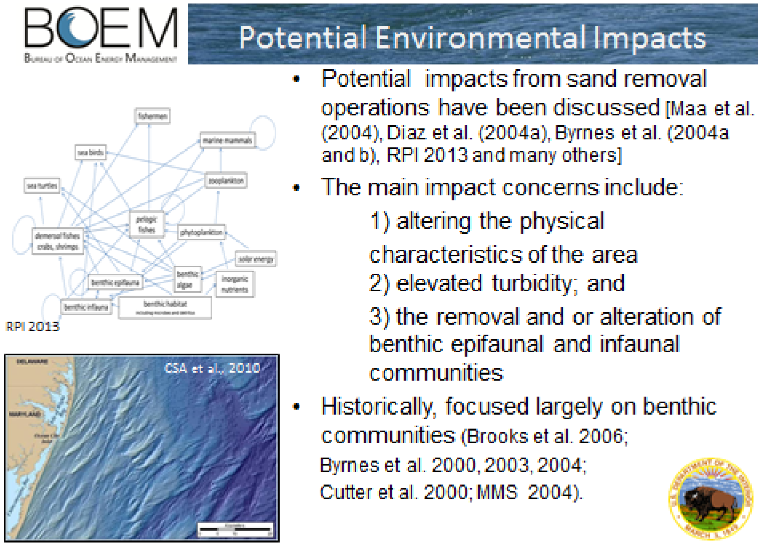


1. Foundation
2. Anti-scour protection
3. Nacelle
4. Inter-turbine submarine cables
5. Offshore substation and export submarine cable
6. On-shore grid connection

Principal impacts to offshore shoals from renewable energy include cable burial and foundation impacts (footprint and scour).





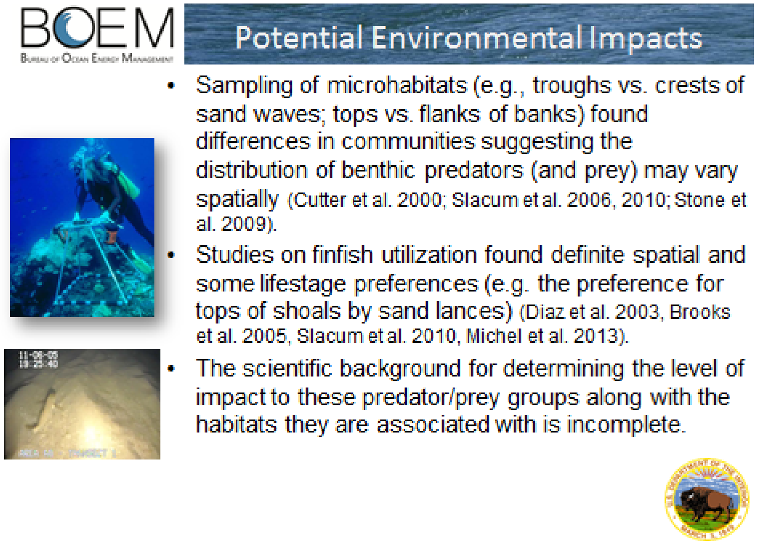


## Potential Environmental Impacts

- Potential impacts from sand removal operations have been discussed [Maa et al. (2004), Diaz et al. (2004a), Byrnes et al. (2004a and b), RPI 2013 and many others]
- The main impact concerns include:
  - 1) altering the physical characteristics of the area
  - 2) elevated turbidity; and
  - 3) the removal and or alteration of benthic epifaunal and infaunal communities
- Historically, focused largely on benthic communities (Brooks et al. 2006; Byrnes et al. 2000, 2003, 2004; Cutter et al. 2000; MMS 2004).

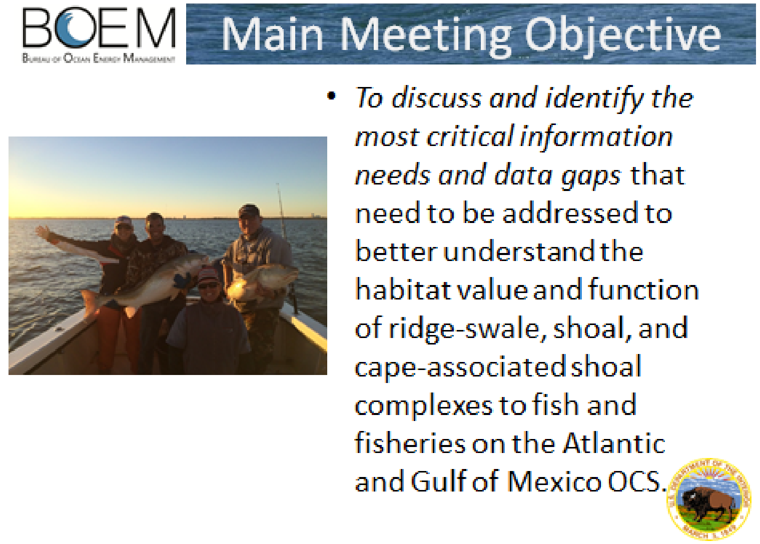
RPI 2013

CSA et al., 2010



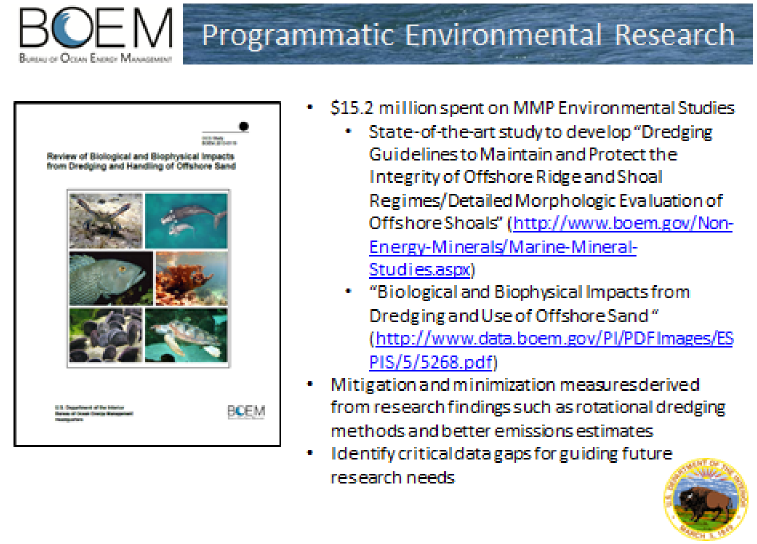
## Potential Environmental Impacts

- Sampling of microhabitats (e.g., troughs vs. crests of sand waves; tops vs. flanks of banks) found differences in communities suggesting the distribution of benthic predators (and prey) may vary spatially (Cutter et al. 2000; Slacum et al. 2006, 2010; Stone et al. 2009).
- Studies on finfish utilization found definite spatial and some lifestage preferences (e.g. the preference for tops of shoals by sand lances) (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.



## Main Meeting Objective

- *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.



## Programmatic Environmental Research

Review of Biological and Biophysical Impacts from Dredging and Handling of Offshore Sand

- $15.2 million spent on MMP Environmental Studies
  - State-of-the-art study to develop "Dredging Guidelines to Maintain and Protect the Integrity of Offshore Ridge and Shoal Regimes/Detailed Morphologic Evaluation of Offshore Shoals" (http://www.boem.gov/Non-Energy-Minerals/Marine-Mineral-Studies.aspx)
  - "Biological and Biophysical Impacts from Dredging and Use of Offshore Sand" (http://www.data.boem.gov/PI/PDFImages/ESPIS/5/5268.pdf)
- Mitigation and minimization measures derived from research findings such as rotational dredging methods and better emissions estimates
- Identify critical data gaps for guiding future research needs

## Contacts

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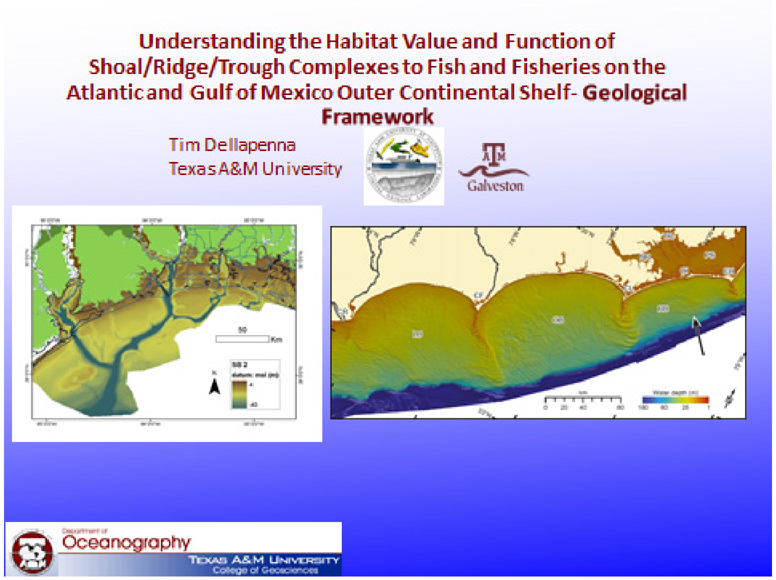
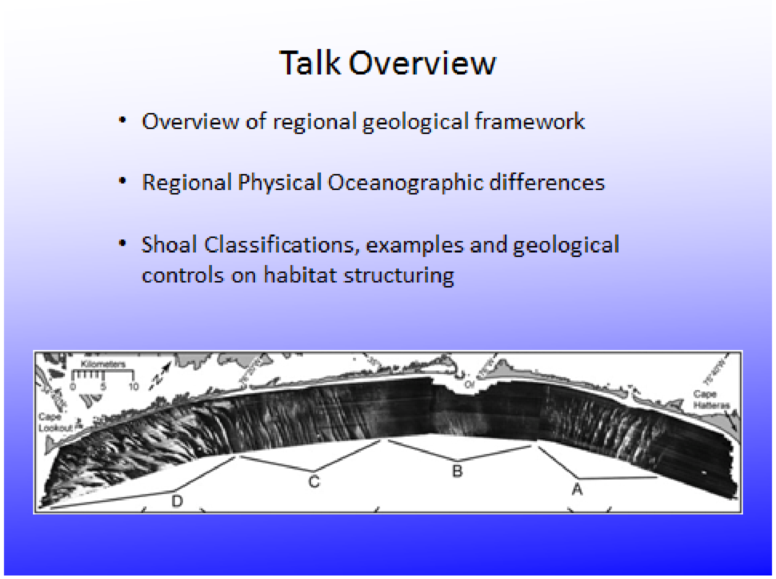
703-787-1833

Visit our website at:
http://www.boem.gov/marinemineralsprogram



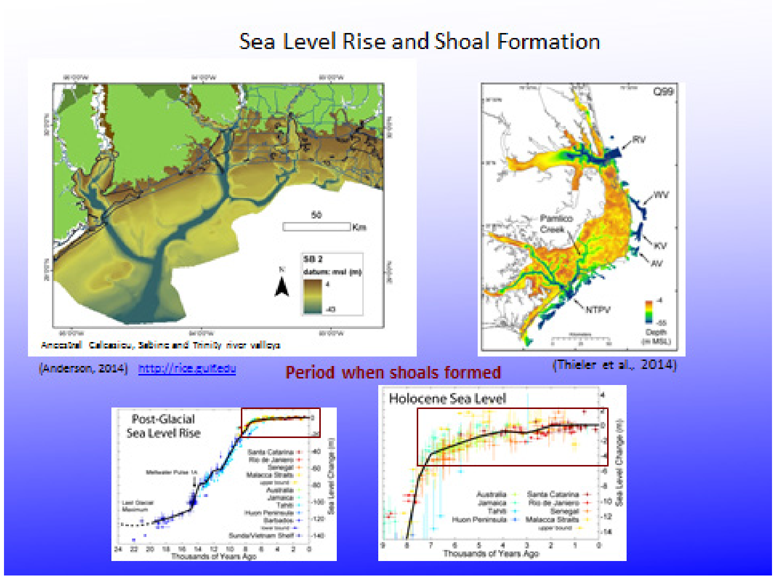
## Understanding the Habitat Value and Function of Shoal/Ridge/Trough Complexes to Fish and Fisheries on the Atlantic and Gulf of Mexico Outer Continental Shelf- **Geological Framework**

Tim Dellapenna
Texas A&M University



## Talk Overview

- Overview of regional geological framework
- Regional Physical Oceanographic differences
- Shoal Classifications, examples and geological controls on habitat structuring



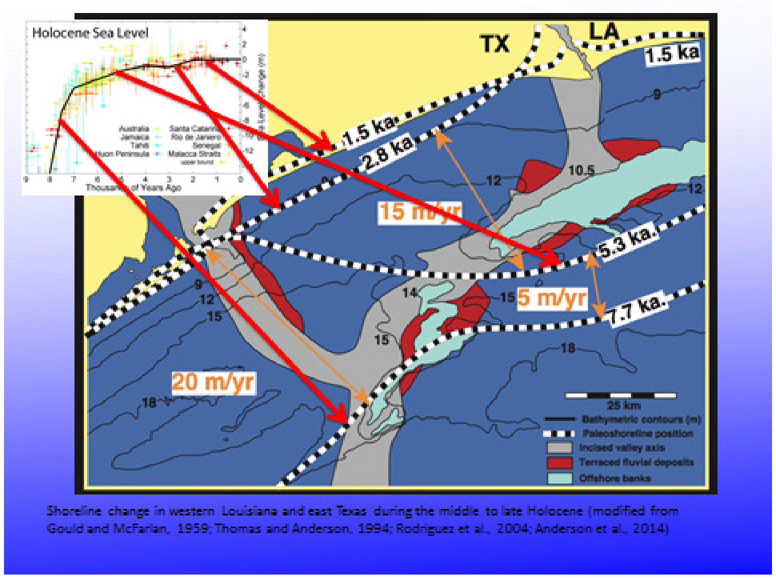
## Sea Level Rise and Shoal Formation

Ancestral Calcasieu, Sabine and Trinity river valleys

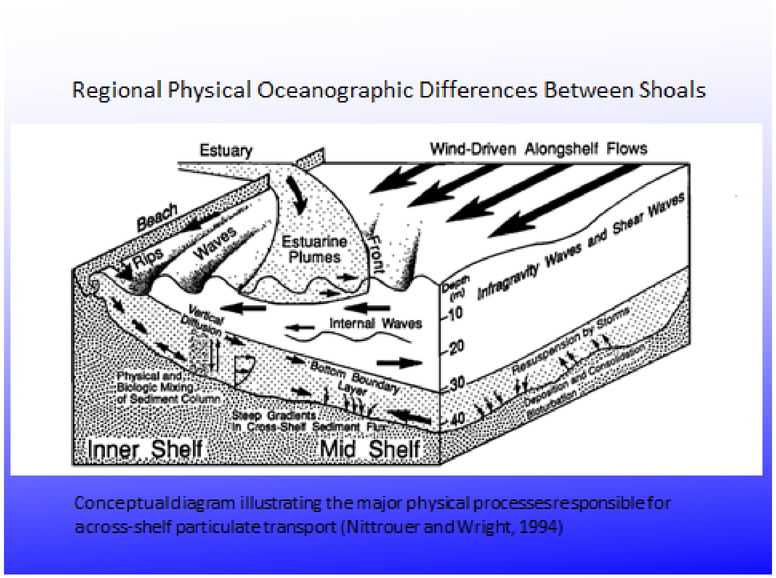
(Anderson, 2014) http://rice.gulf.edu

(Thieler et al., 2014)

Period when shoals formed

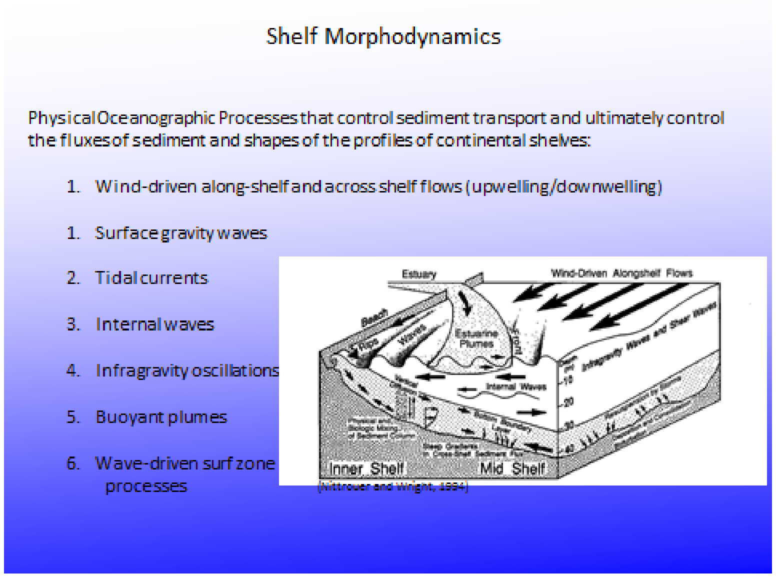


Shoreline change in western Louisiana and east Texas during the middle to late Holocene (modified from Gould and McFarlan, 1959; Thomas and Anderson, 1994; Rodriguez et al., 2004; Anderson et al., 2014)



## Regional Physical Oceanographic Differences Between Shoals

Conceptual diagram illustrating the major physical processes responsible for across-shelf particulate transport (Nittrouer and Wright, 1994)

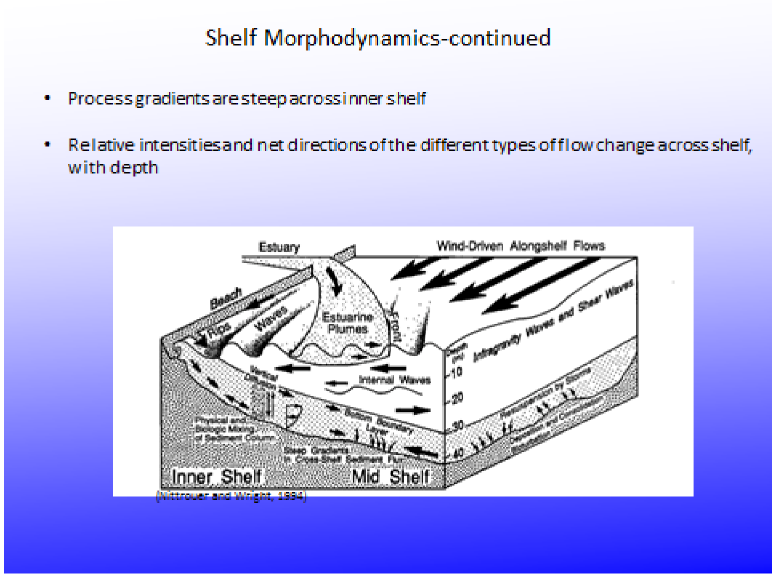


## Shelf Morphodynamics

Physical Oceanographic Processes that control sediment transport and ultimately control the fluxes of sediment and shapes of the profiles of continental shelves:

1. Wind-driven along-shelf and across shelf flows (upwelling/downwelling)
1. Surface gravity waves
2. Tidal currents
3. Internal waves
4. Infragravity oscillations
5. Buoyant plumes
6. Wave-driven surf zone processes

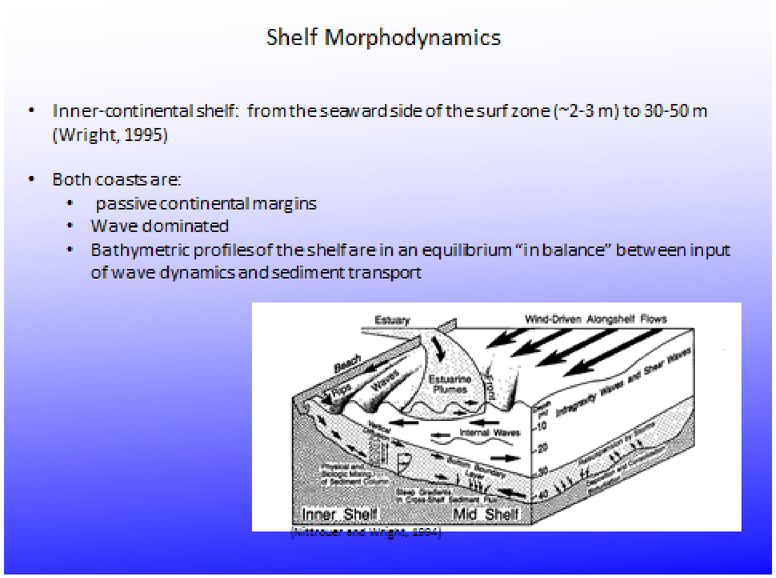
(Nittrouer and Wright, 1994)



## Shelf Morphodynamics-continued

- Process gradients are steep across inner shelf
- Relative intensities and net directions of the different types of flow change across shelf, with depth

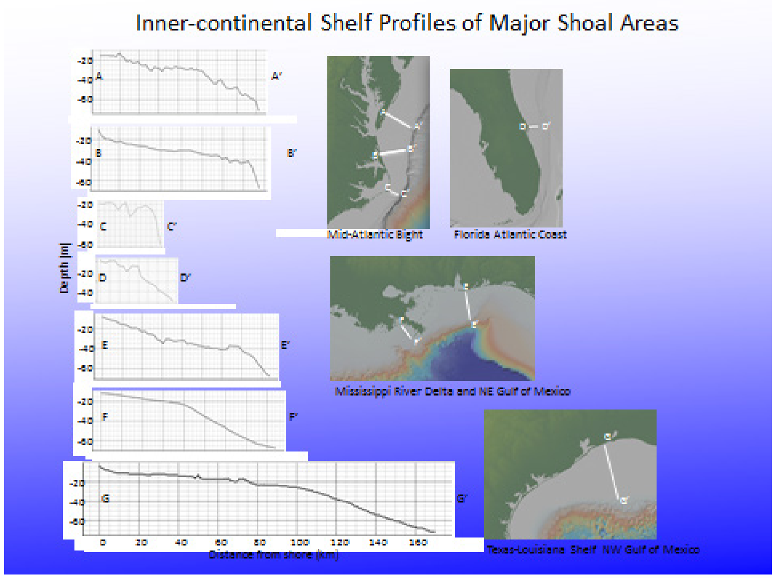
(Nittrouer and Wright, 1994)



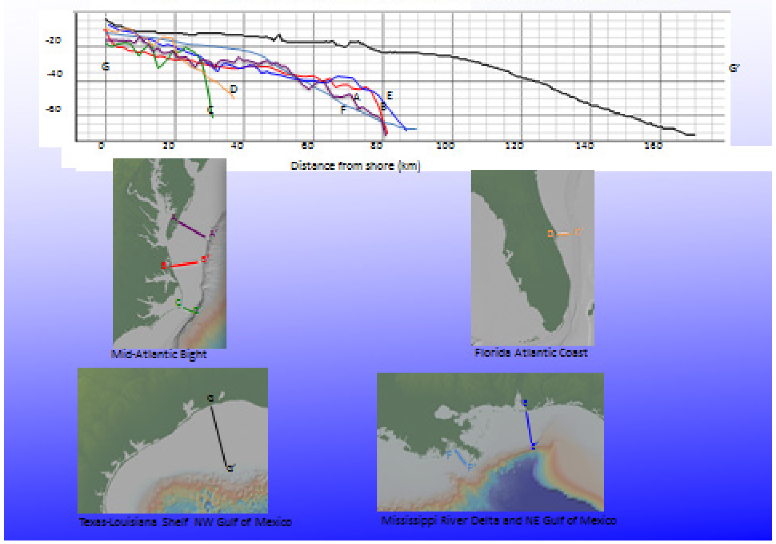
## Shelf Morphodynamics

- Inner-continental shelf: from the seaward side of the surf zone (~2-3 m) to 30-50 m (Wright, 1995)
- Both coasts are:
  - passive continental margins
  - Wave dominated
  - Bathymetric profiles of the shelf are in an equilibrium "in balance" between input of wave dynamics and sediment transport

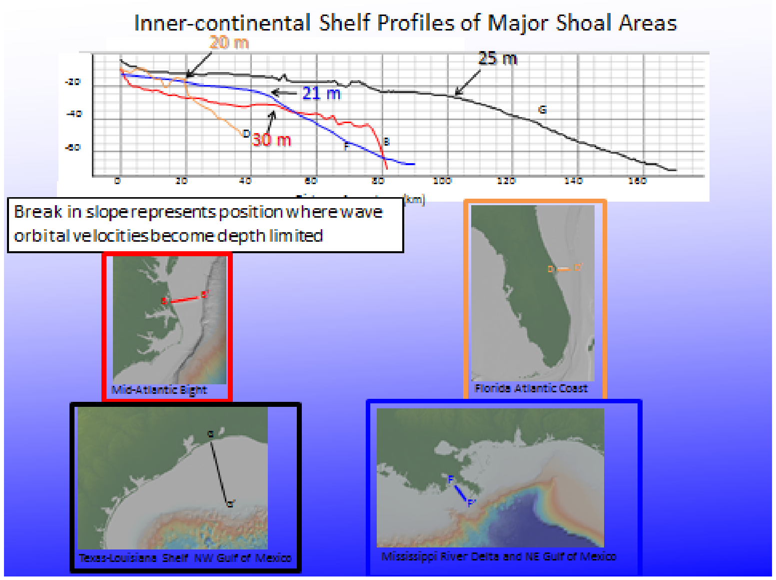
(Nittrouer and Wright, 1994)



## Inner-continental Shelf Profiles of Major Shoal Areas

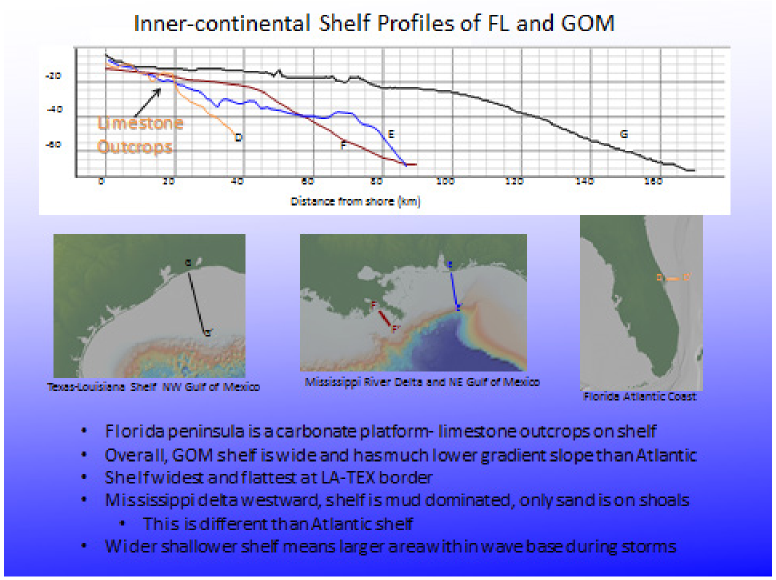


## Inner-continental Shelf Profiles of Major Shoal Areas



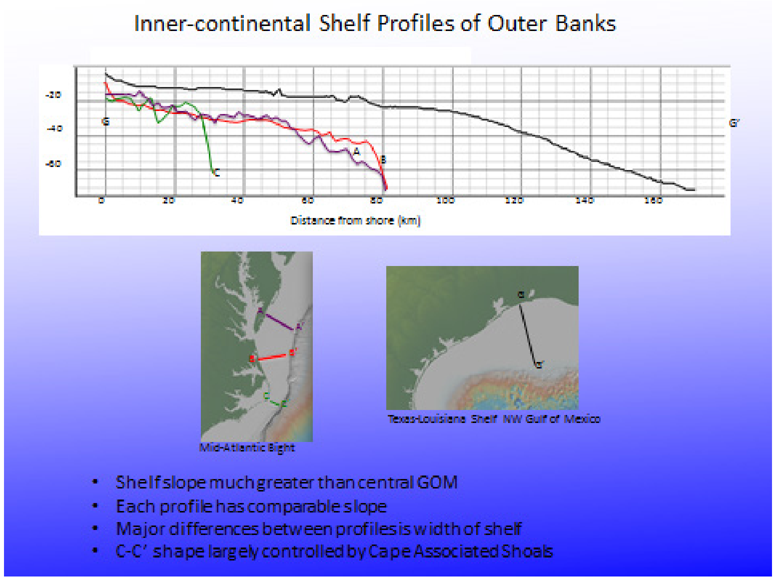
## Inner-continental Shelf Profiles of Major Shoal Areas

Break in slope represents position where wave orbital velocities become depth limited



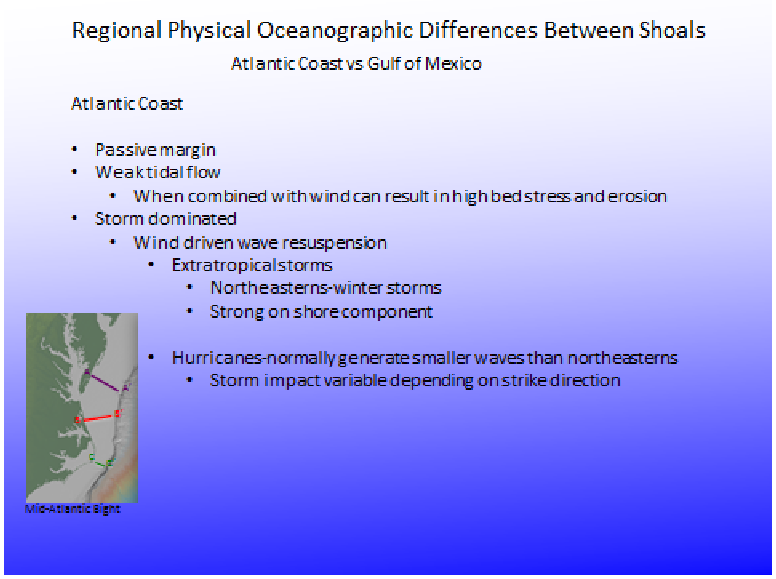
### Inner-continental Shelf Profiles of FL and GOM

- Florida peninsula is a carbonate platform- limestone outcrops on shelf
- Overall, GOM shelf is wide and has much lower gradient slope than Atlantic
- Shelf widest and flattest at LA-TEX border
- Mississippi delta westward, shelf is mud dominated, only sand is on shoals
  - This is different than Atlantic shelf
- Wider shallower shelf means larger area within wave base during storms



### Inner-continental Shelf Profiles of Outer Banks

- Shelf slope much greater than central GOM
- Each profile has comparable slope
- Major differences between profiles is width of shelf
- C-C' shape largely controlled by Cape Associated Shoals

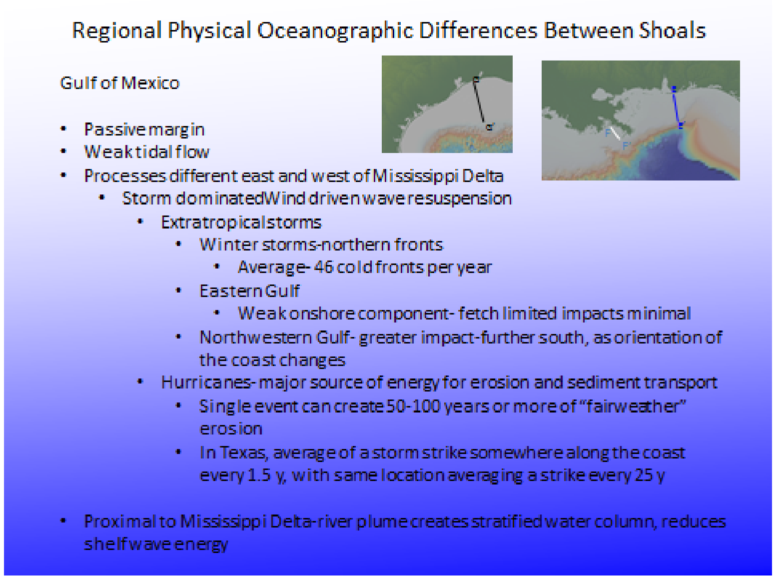


### Regional Physical Oceanographic Differences Between Shoals

Atlantic Coast vs Gulf of Mexico

Atlantic Coast

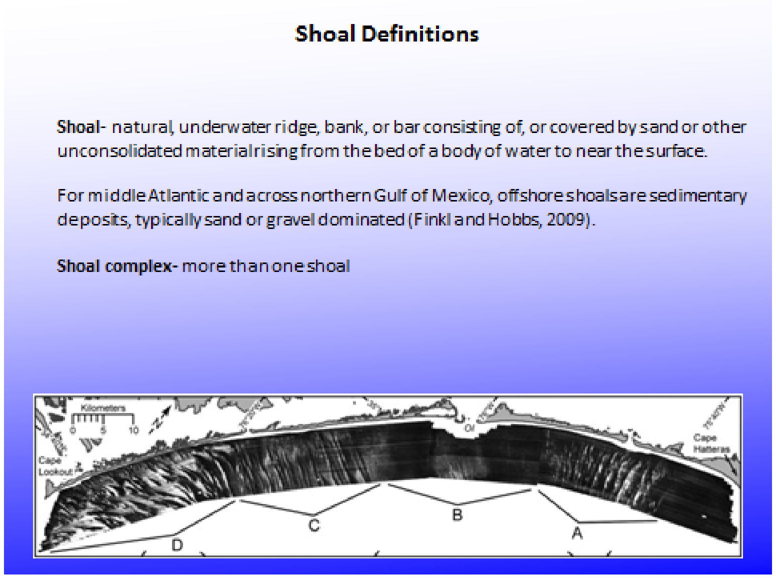
- Passive margin
- Weak tidal flow
  - When combined with wind can result in high bed stress and erosion
- Storm dominated
  - Wind driven wave resuspension
    - Extratropical storms
      - Northeasterns-winter storms
      - Strong on shore component
    - Hurricanes-normally generate smaller waves than northeasterns
      - Storm impact variable depending on strike direction



### Regional Physical Oceanographic Differences Between Shoals

Gulf of Mexico

- Passive margin
- Weak tidal flow
- Processes different east and west of Mississippi Delta
  - Storm dominated Wind driven wave resuspension
    - Extratropical storms
      - Winter storms-northern fronts
        - Average- 46 cold fronts per year
      - Eastern Gulf
        - Weak onshore component- fetch limited impacts minimal
      - Northwestern Gulf- greater impact-further south, as orientation of the coast changes
    - Hurricanes- major source of energy for erosion and sediment transport
      - Single event can create 50-100 years or more of "fairweather" erosion
      - In Texas, average of a storm strike somewhere along the coast every 1.5 y, with same location averaging a strike every 25 y
- Proximal to Mississippi Delta-river plume creates stratified water column, reduces shelf wave energy

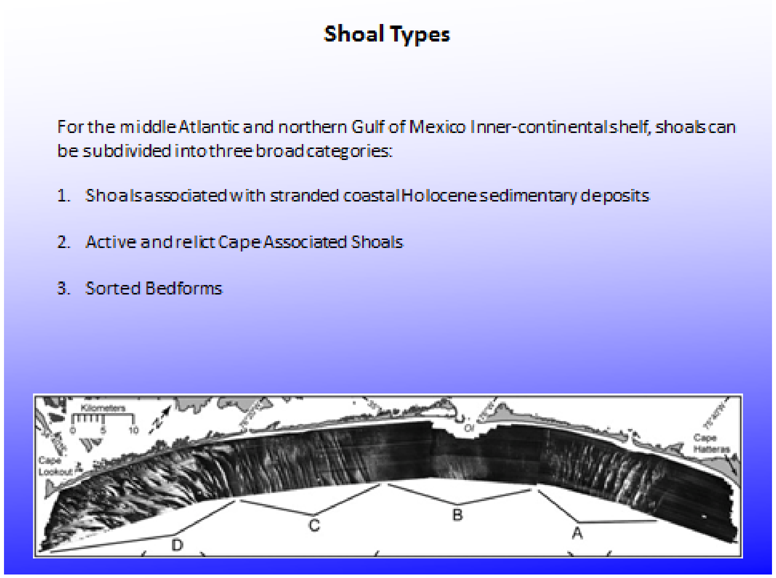


## Shoal Definitions

**Shoal**- 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.

For middle Atlantic and across northern Gulf of Mexico, offshore shoals are sedimentary deposits, typically sand or gravel dominated (Finkl and Hobbs, 2009).

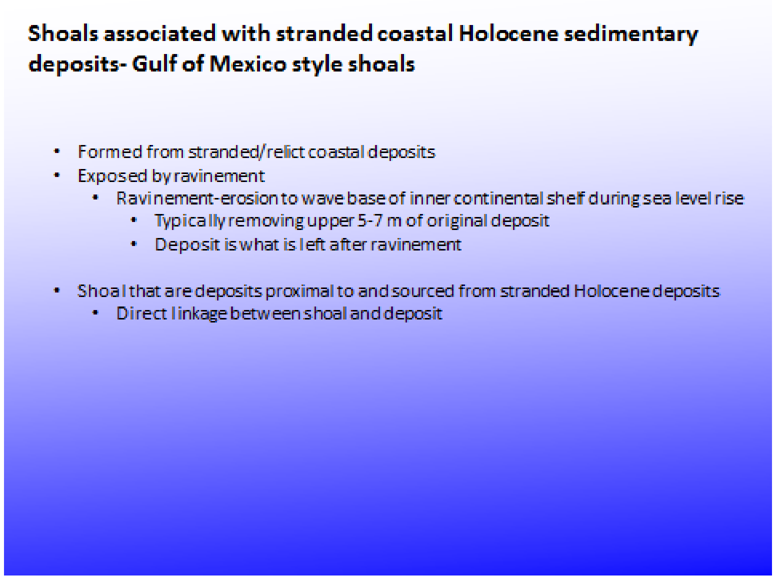
**Shoal complex**- more than one shoal



## Shoal Types

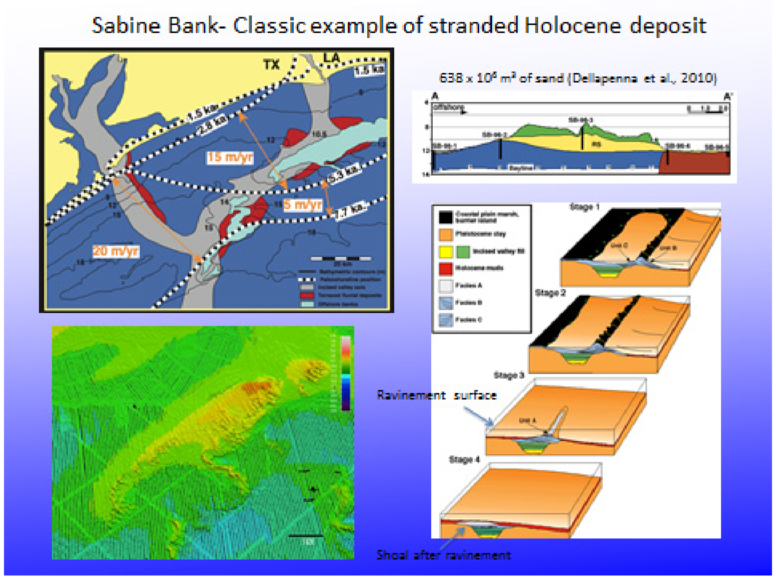
For the middle Atlantic and northern Gulf of Mexico Inner-continental shelf, shoals can be subdivided into three broad categories:

1. Shoals associated with stranded coastal Holocene sedimentary deposits
2. Active and relict Cape Associated Shoals
3. Sorted Bedforms



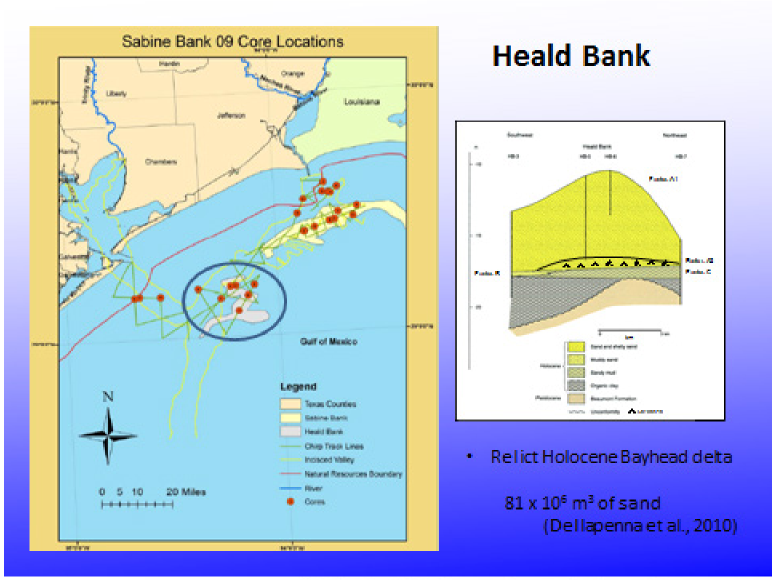
## Shoals associated with stranded coastal Holocene sedimentary deposits- Gulf of Mexico style shoals

- Formed from stranded/relict coastal deposits
- Exposed by ravinement
  - Ravinement-erosion to wave base of inner continental shelf during sea level rise
    - Typically removing upper 5-7 m of original deposit
    - Deposit is what is left after ravinement
- Shoal that are deposits proximal to and sourced from stranded Holocene deposits
  - Direct linkage between shoal and deposit



## Sabine Bank- Classic example of stranded Holocene deposit

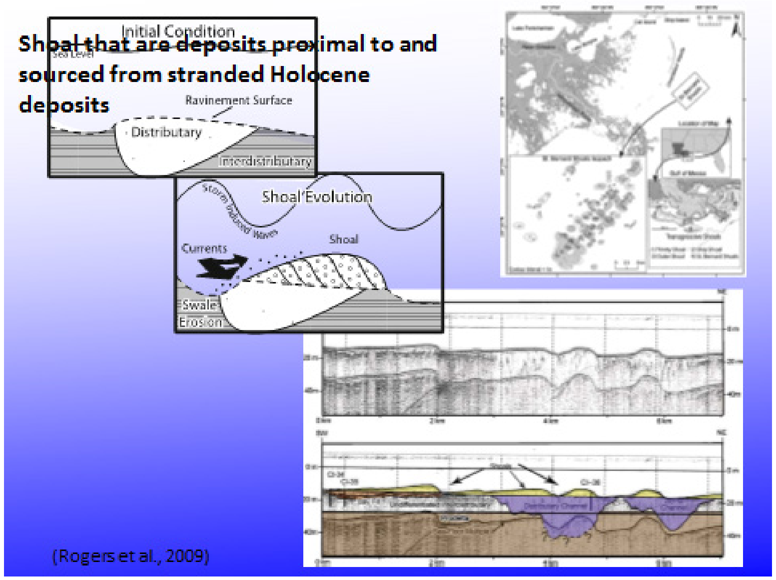
638 x $10^6$ $m^3$ of sand (Dellapenna et al., 2010)



## Heald Bank

- Relict Holocene Bayhead delta

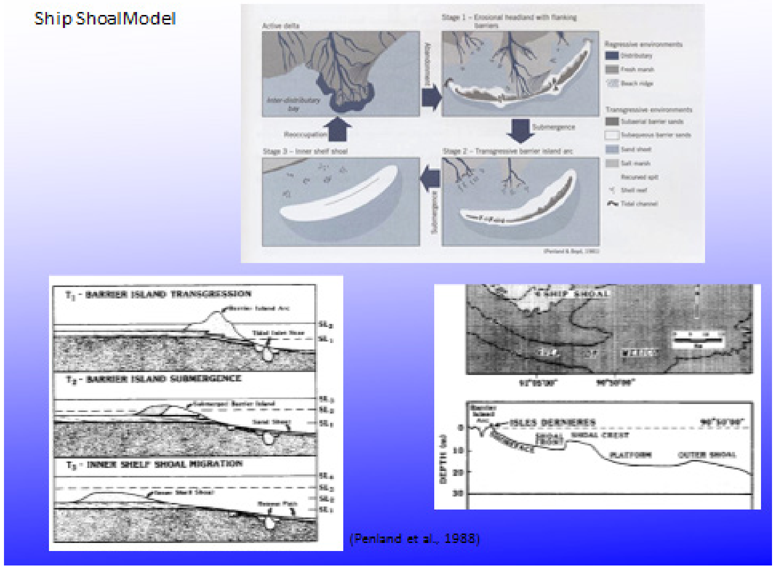
81 x 10$^6$ m$^3$ of sand (Dellapenna et al., 2010)



**Shoal that are deposits proximal to and sourced from stranded Holocene deposits**

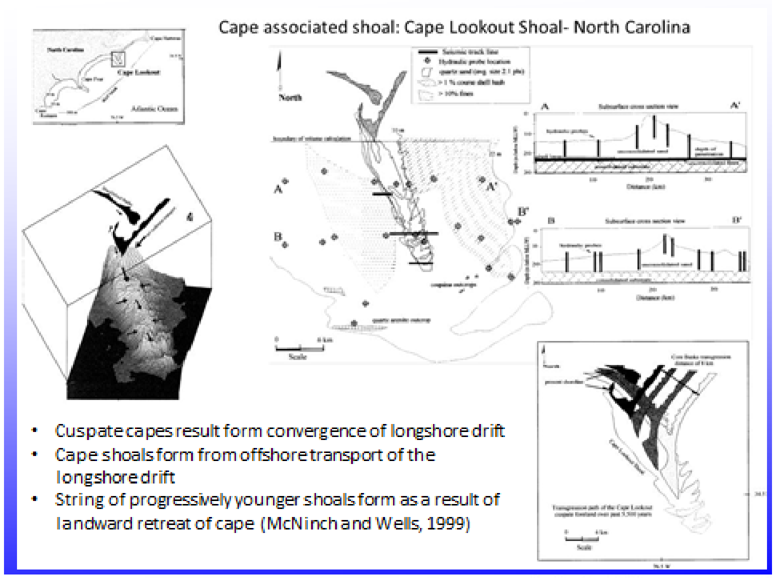
(Rogers et al., 2009)

(Penland et al., 1988)



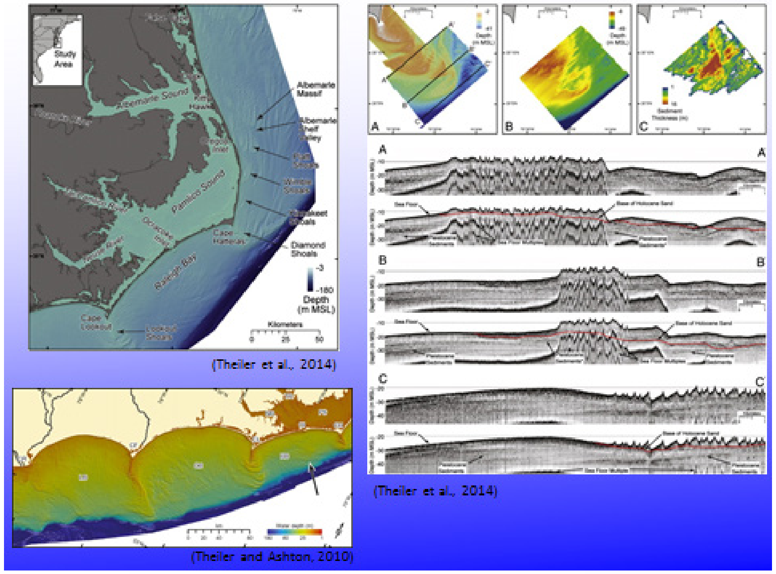
Ship Shoal Model

(Penland et al., 1988)



Cape associated shoal: Cape Lookout Shoal- North Carolina

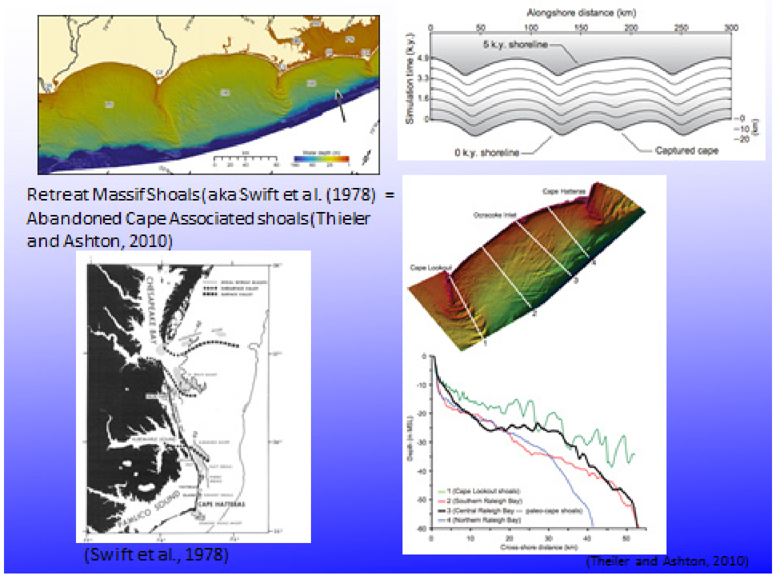
- Cuspate capes result form convergence of longshore drift
- Cape shoals form from offshore transport of the longshore drift
- String of progressively younger shoals form as a result of landward retreat of cape (McNinch and Wells, 1999)



(Theiler et al., 2014)

(Theiler et al., 2014)

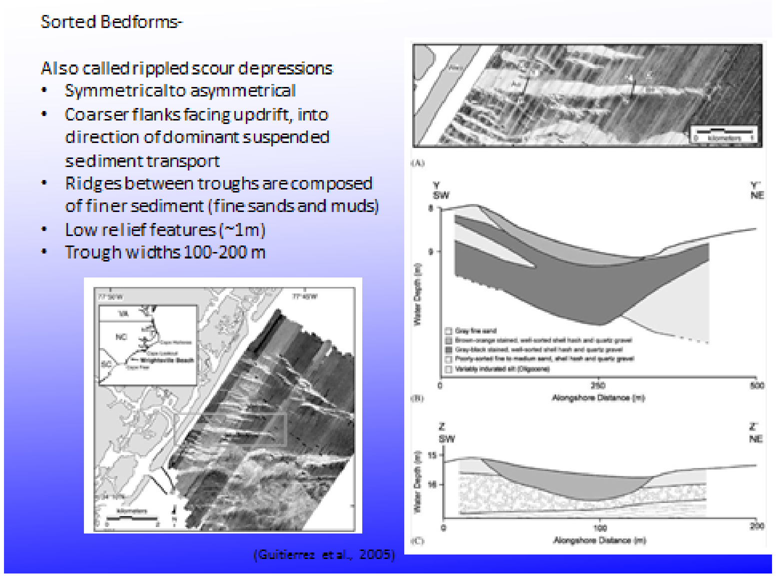
(Theiler and Ashton, 2010)



Retreat Massif Shoals (aka Swift et al. (1978) = Abandoned Cape Associated shoals (Thieler and Ashton, 2010)

(Swift et al., 1978)

(Theiler and Ashton, 2010)

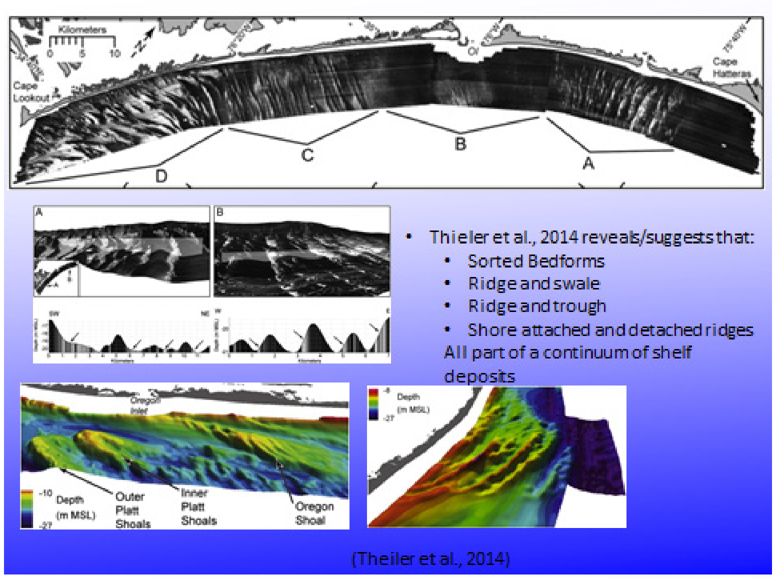


Sorted Bedforms-

Also called rippled scour depressions

- Symmetrical to asymmetrical
- Coarser flanks facing updrift, into direction of dominant suspended sediment transport
- Ridges between troughs are composed of finer sediment (fine sands and muds)
- Low relief features (~1m)
- Trough widths 100-200 m

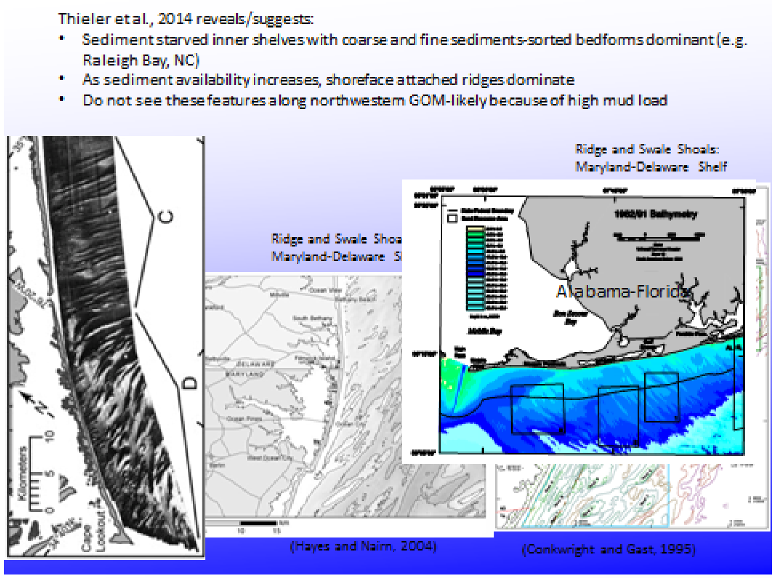
(Gutierrez et al., 2005)



- Thieler et al., 2014 reveals/suggests that:
  - Sorted Bedforms
  - Ridge and swale
  - Ridge and trough
  - Shore attached and detached ridges

  All part of a continuum of shelf deposits

(Theiler et al., 2014)

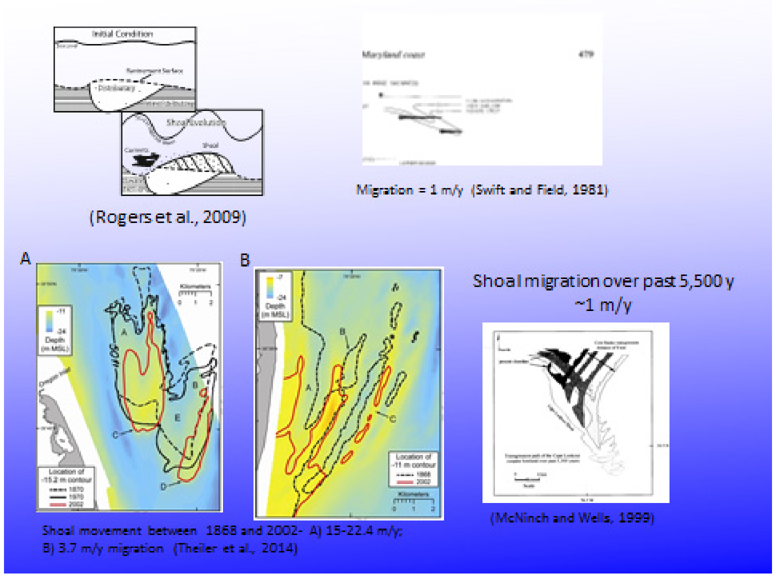

Thieler et al., 2014 reveals/suggests:

- Sediment starved inner shelves with coarse and fine sediments-sorted bedforms dominant (e.g. Raleigh Bay, NC)
- As sediment availability increases, shoreface attached ridges dominate
- Do not see these features along northwestern GOM-likely because of high mud load

Ridge and Swale Shoals:
Maryland-Delaware Shelf

(Hayes and Nairn, 2004)

(Conkwright and Gast, 1995)



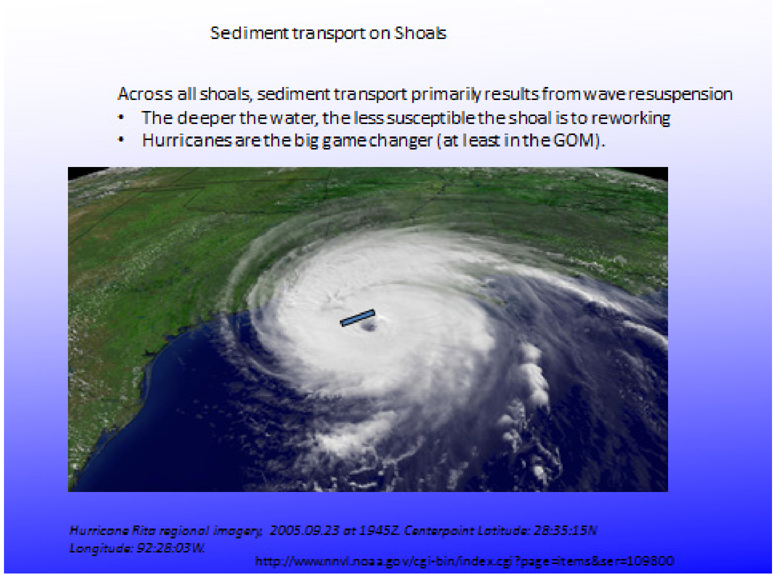
(Rogers et al., 2009)

Migration = 1 m/y (Swift and Field, 1981)

Shoal migration over past 5,500 y
~1 m/y

(McNinch and Wells, 1999)

Shoal movement between 1868 and 2002- A) 15-22.4 m/y; B) 3.7 m/y migration (Theiler et al., 2014)

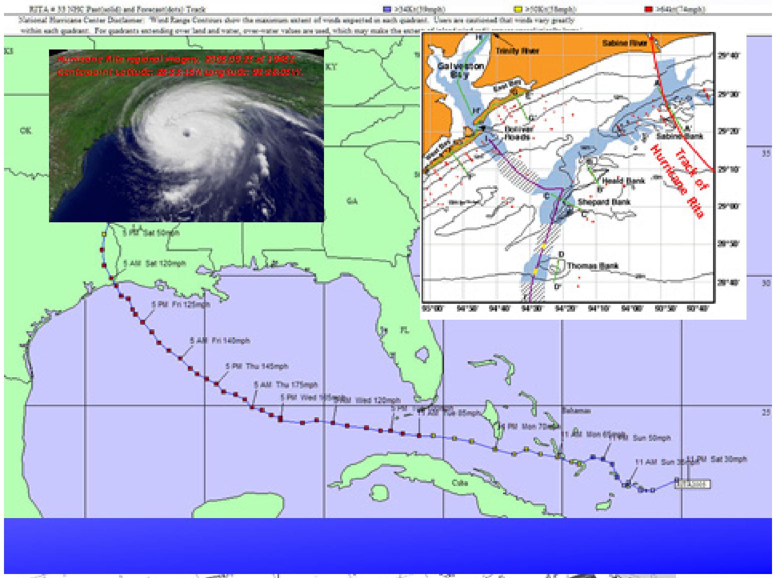

Sediment transport on Shoals

Across all shoals, sediment transport primarily results from wave resuspension

- The deeper the water, the less susceptible the shoal is to reworking
- Hurricanes are the big game changer (at least in the GOM).

*Hurricane Rita regional imagery, 2005.09.23 at 1945Z. Centerpoint Latitude: 28:35:15N Longitude: 92:28:03W.*

http://www.nnvl.noaa.gov/cgi-bin/index.cgi?page=items&ser=109800



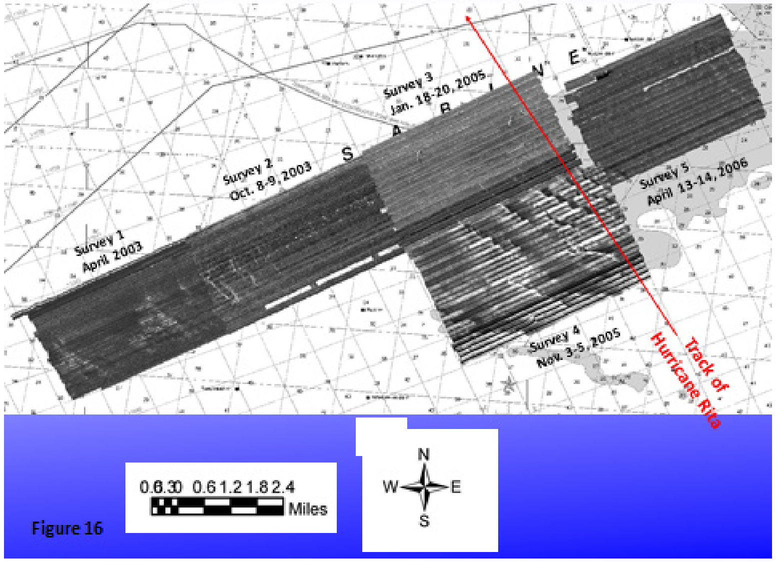
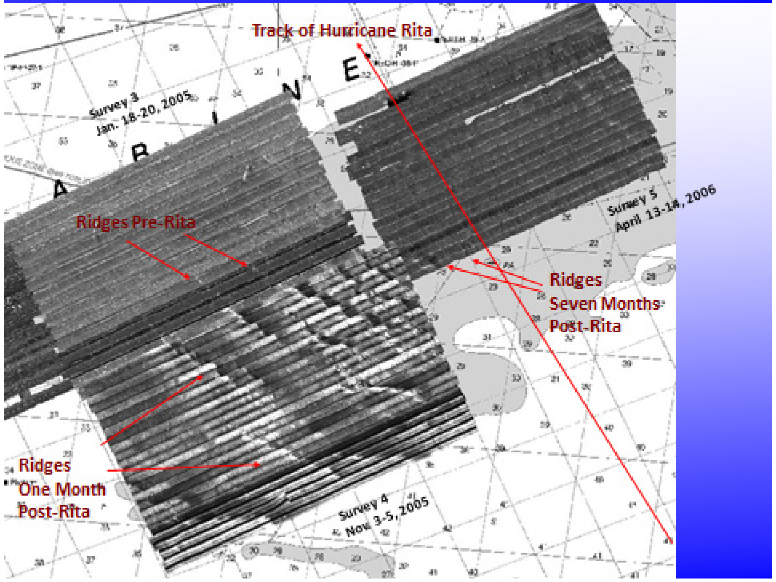
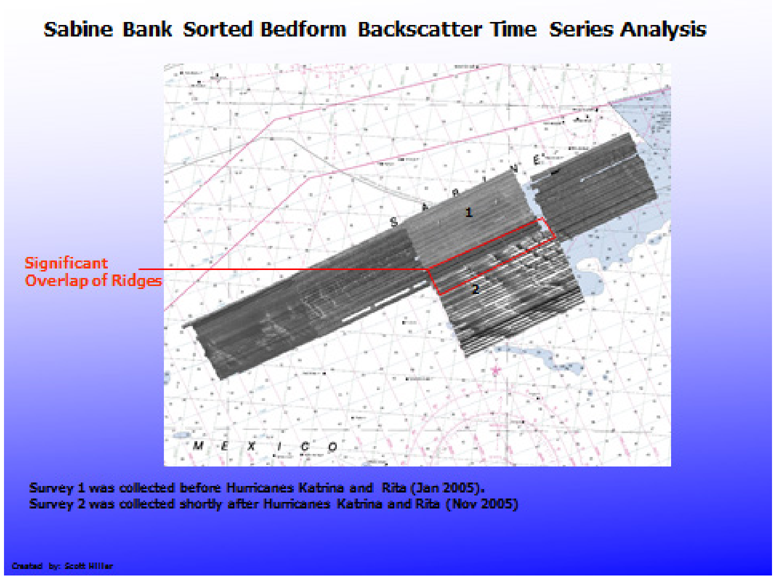


Figure 16

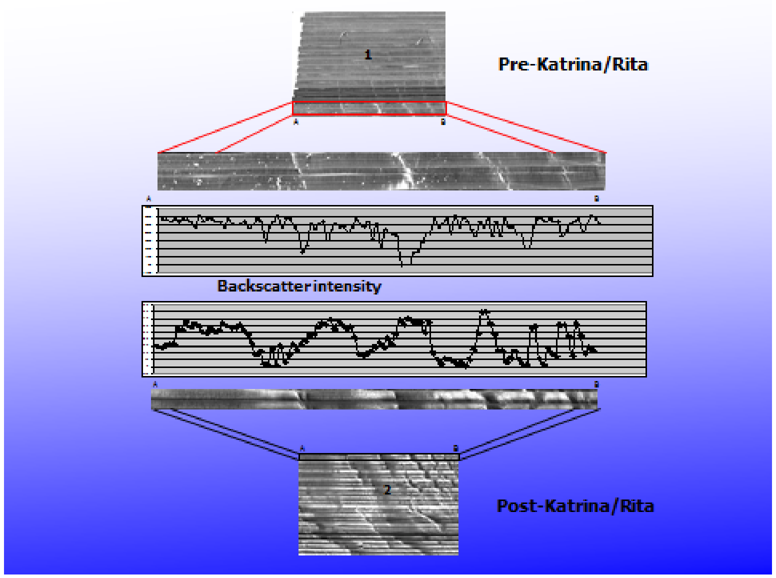


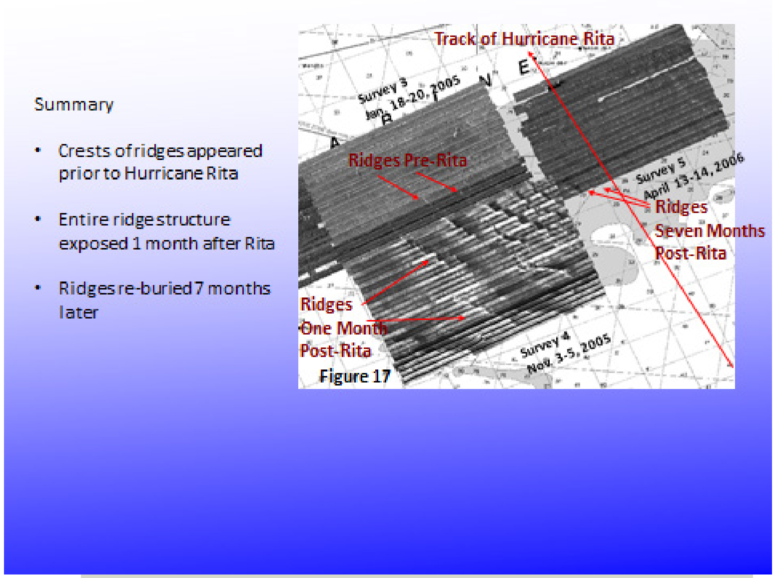


## Sabine Bank Sorted Bedform Backscatter Time Series Analysis

Survey 1 was collected before Hurricanes Katrina and Rita (Jan 2005).
Survey 2 was collected shortly after Hurricanes Katrina and Rita (Nov 2005)

Created by: Scott Miller

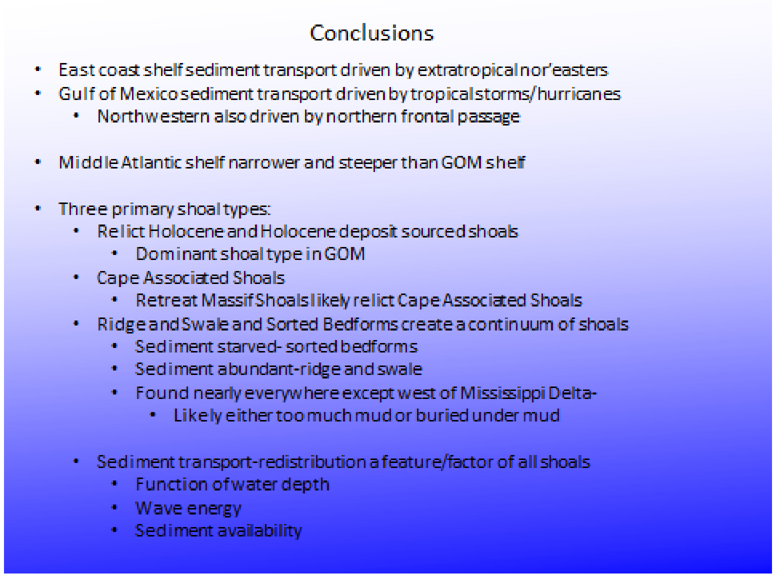




Summary

- Crests of ridges appeared prior to Hurricane Rita
- Entire ridge structure exposed 1 month after Rita
- Ridges re-buried 7 months later

Figure 17



## Conclusions

- East coast shelf sediment transport driven by extratropical nor'easters
- Gulf of Mexico sediment transport driven by tropical storms/hurricanes
  - Northwestern also driven by northern frontal passage

- Middle Atlantic shelf narrower and steeper than GOM shelf

- Three primary shoal types:
  - Relict Holocene and Holocene deposit sourced shoals
    - Dominant shoal type in GOM
  - Cape Associated Shoals
    - Retreat Massif Shoals likely relict Cape Associated Shoals
  - Ridge and Swale and Sorted Bedforms create a continuum of shoals
    - Sediment starved- sorted bedforms
    - Sediment abundant-ridge and swale
    - Found nearly everywhere except west of Mississippi Delta-
      - Likely either too much mud or buried under mud

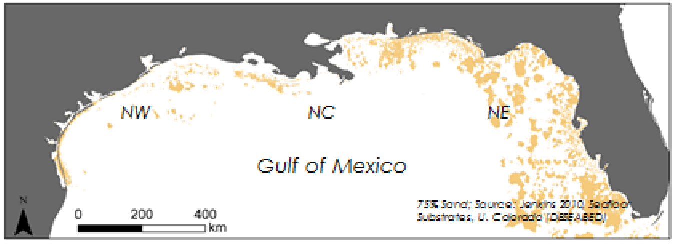
  - Sediment transport-redistribution a feature/factor of all shoals
    - Function of water depth
    - Wave energy
    - Sediment availability

## Ecological function of shoal and ridge/trough complexes in Gulf of Mexico

Jay R. Rooker

Texas A&M University

## Overview of shoal study sites in the Gulf of Mexico



75% Sand; Source: Jenkins 2010, Seafloor Substrates, U. Colorado (DBSEABED)

- Sabine Bank
- Heald Bank
- Freeport Rocks
- Rio Grande Bank
- Ship Shoal
- Tiger & Trinity Shoals
- St. Bernard Shoals
- Perdido Shoals
- West Florida Shelf

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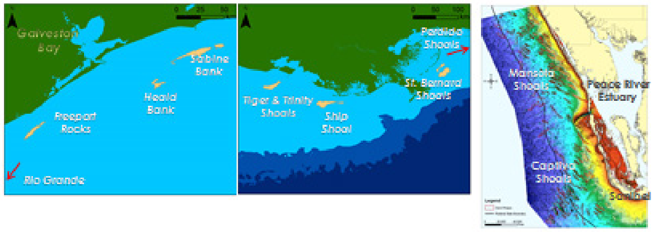

- Sabine Bank
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- Freeport Rocks
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- St. Bernard Shoals
- Perdido Shoals
- West Florida Shelf

## Gears used to assess resources associated with shoals in Gulf of Mexico

Invertebrates

- Box corers (GOM), Box dredge (GOM) vs. Smith-McIntyre grabs (ATL)
- Trawls

Brooks et al. 2004, Zarillo et al. 2008, Dubois et al. 2009

Fishes

- Trawls & gill nets
- Visual surveys (SCUBA, ROV)
- Benthic sleds (w & w/o cameras)
- Active acoustics

Diaz 2003, Rooker et al. 2004, Szedlmayer and Lee 2004, Brooks et al. 2005, Mikulas and Rooker 2008, Wells et al. 2009, Patterson et al. 2012

*Different techniques and gear configurations limit comparisons across studies*

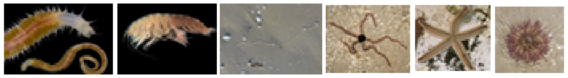
## Overview of invertebrates associated with shoals in Gulf of Mexico

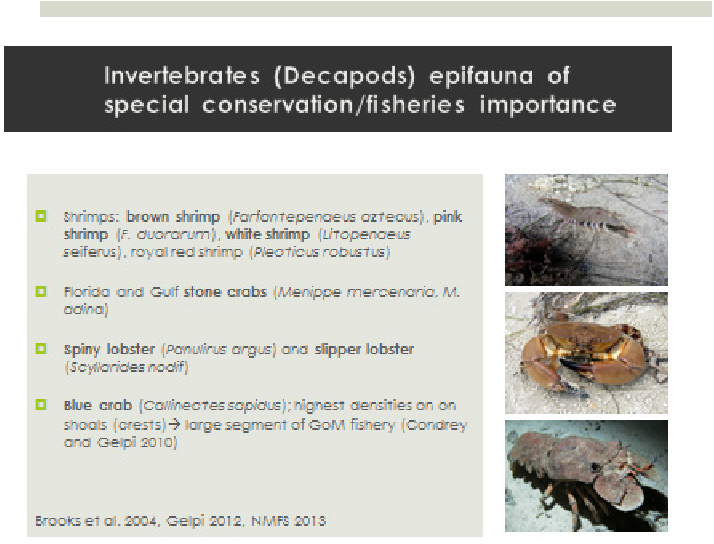
**Common infauna**

- Focus on **benthic megafauna ( > 1 cm)** (Dubois et al. 2009)
- Species composition varies over large spatial scales
- However, certain taxa common across regions/areas: polychaetes and crustaceans; **polychaetes** dominant invertebrate in survey conducted in both GoM and Atlantic (Brooks et al 2006)
- **Spionid polychates** (*Prionspio pinnata*) repeatedly cited numerically the most dominant taxon; other dominant infauna: other polychaetes (80 Spp. FL), amphipods, and bivalve

**Common epifauna**

- Echinoderms (e.g., Ophiolepis sp., *Luidia sp., Arbacia sp.)*

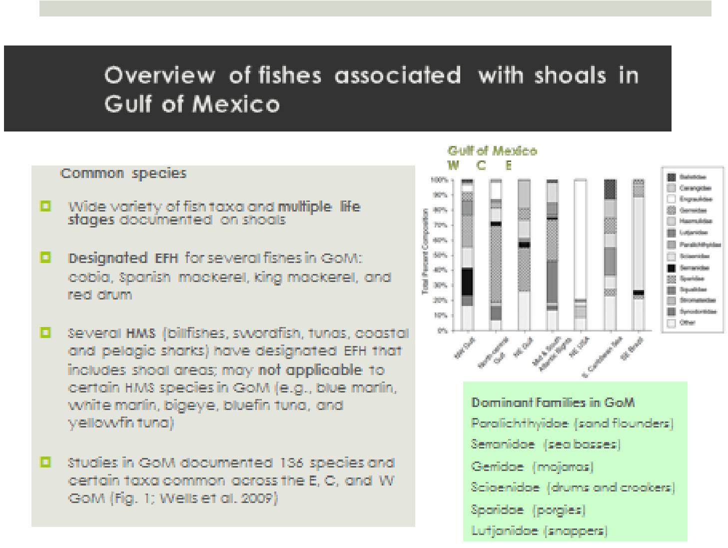




## Invertebrates (Decapods) epifauna of special conservation/fisheries importance

- Shrimps: **brown shrimp** (*Farfantepenaeus aztecus*), **pink shrimp** (*F. duorarum*), **white shrimp** (*Litopenaeus seiferus*), royal red shrimp (*Pleoticus robustus*)
- Florida and Gulf **stone crabs** (*Menippe mercenaria, M. adina*)
- **Spiny lobster** (*Panulirus argus*) and **slipper lobster** (*Scyllarides nodif*)
- **Blue crab** (*Callinectes sapidus*); highest densities on on shoals (crests)→ large segment of GoM fishery (Condrey and Gelpi 2010)

Brooks et al. 2004, Gelpi 2012, NMFS 2013



## Overview of fishes associated with shoals in Gulf of Mexico

Common species

- Wide variety of fish taxa and **multiple life stages** documented on shoals
- **Designated EFH** for several fishes in GoM: cobia, Spanish mackerel, king mackerel, and red drum
- Several **HMS** (billfishes, swordfish, tunas, coastal and pelagic sharks) have designated EFH that includes shoal areas; may **not applicable** to certain HMS species in GoM (e.g., blue marlin, white marlin, bigeye, bluefin tuna, and yellowfin tuna)
- Studies in GoM documented 136 species and certain taxa common across the E, C, and W GoM (Fig. 1; Wells et al. 2009)

**Dominant Families in GoM**
Paralichthyidae (sand flounders)
Serranidae (sea basses)
Gerridae (mojarras)
Sciaenidae (drums and croakers)
Sparidae (porgies)
Lutjanidae (snappers)

## Common species/taxa among trawling studies on shoals in the Gulf of Mexico

**Assemblage composition: common species**

| **NW GoM** | **NC GoM** | **NE GoM** |
|---|---|---|
| *(Wells et al. 2009)* | *(Wells et al. 2008)* | *(Pierce & Mahmoudi 2001)* |
| Shoal flounder | Longspine porgy | Pinfish |
| Dwarf sand perch | Atlantic croaker | Mojarra (spp.) |
| Red snapper | Large-scale lizardfish | Sand perch |
| Least puffer | Shoal Flounder | Inshore lizardfish |
| Silver seatrout | Red snapper | Tomtate |
| Large-scale lizardfish | Inshore lizardfish | Lane snapper |
| Mojarra (spp.) | Dwarf sand perch | Littlehead porgy |
| Sand seatrout | Spot | Scrawled cowfish |

*Common species in both* ***NW and NC****; NE distinctly different by species but* ***ecological equivalents present*** *(same family/different species, e.g., lutjanids, serranids, synodontids)*

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| ➡ Red snapper 🟠 | ➡ Large-scale lizardfish ⚫ | Sand perch 🔵 |
| Least puffer | ➡ Shoal Flounder | Inshore lizardfish ⚫ |
| Silver seatrout | ➡ Red snapper 🟠 | Tomtate |
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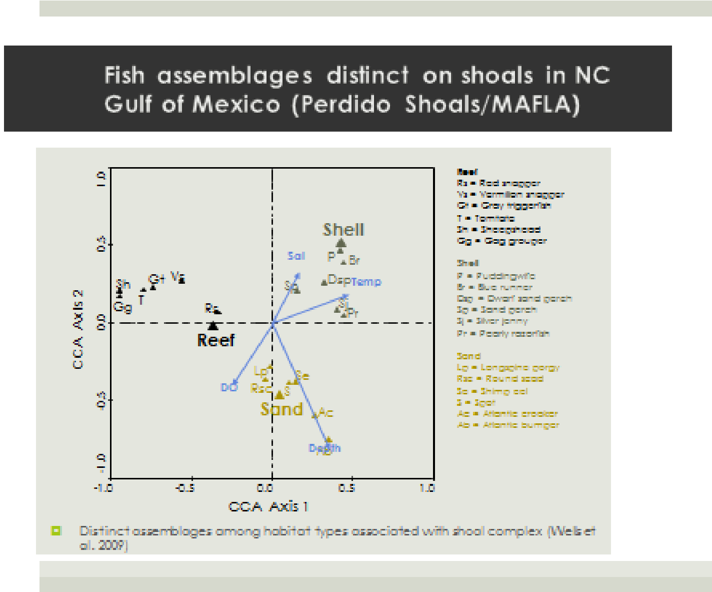


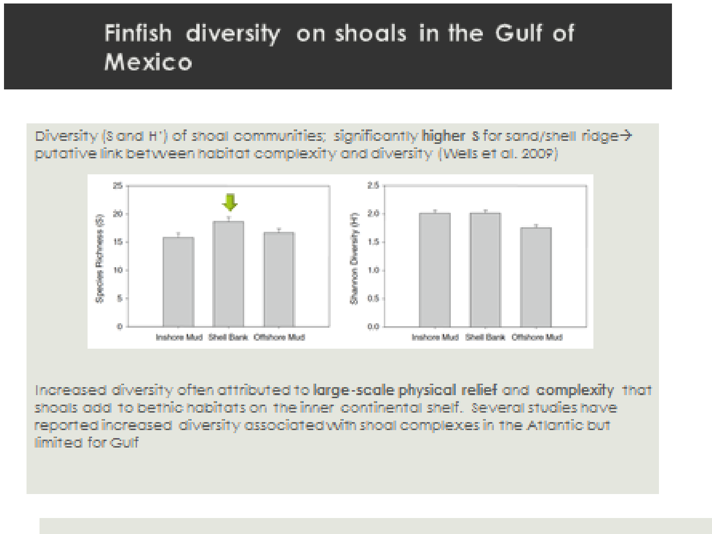
## Fish assemblages distinct on shoals in NC Gulf of Mexico (Perdido Shoals/MAFLA)

**Reef**
Rs = Red snapper
Vs = Vermilion snapper
Gt = Gray triggerfish
T = Tomtate
Sh = Sheepshead
Gg = Gag grouper

**Shell**
P = Puddingwife
Br = Blue runner
Dsp = Dwarf sand perch
Sp = Sand perch
Sj = Silver jenny
Pr = Pearly razorfish

**Sand**
Lp = Longspine porgy
Rsc = Round scad
Se = Shrimp eel
S = Spot
Ac = Atlantic croaker
Ab = Atlantic bumper

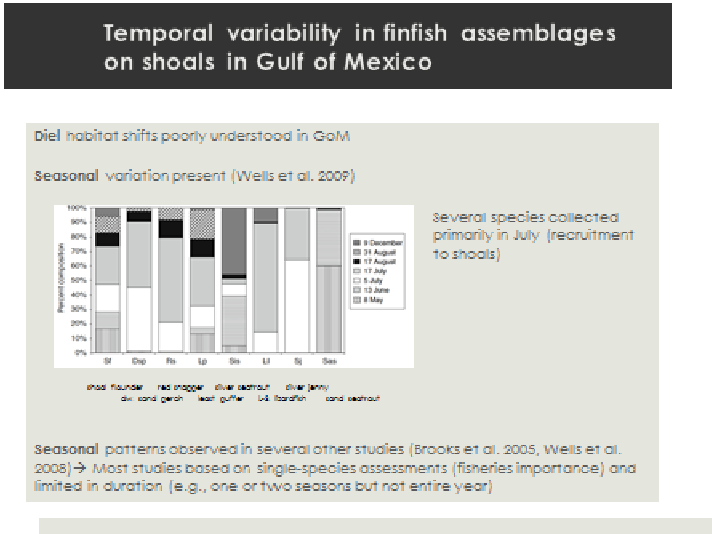
- Distinct assemblages among habitat types associated with shoal complex (Wells et al. 2009)



## Finfish diversity on shoals in the Gulf of Mexico

Diversity (S and H') of shoal communities; significantly **higher** S for sand/shell ridge→ putative link between habitat complexity and diversity (Wells et al. 2009)

Increased diversity often attributed to **large-scale physical relief** and **complexity** that shoals add to bethic habitats on the inner continental shelf. Several studies have reported increased diversity associated with shoal complexes in the Atlantic but limited for Gulf



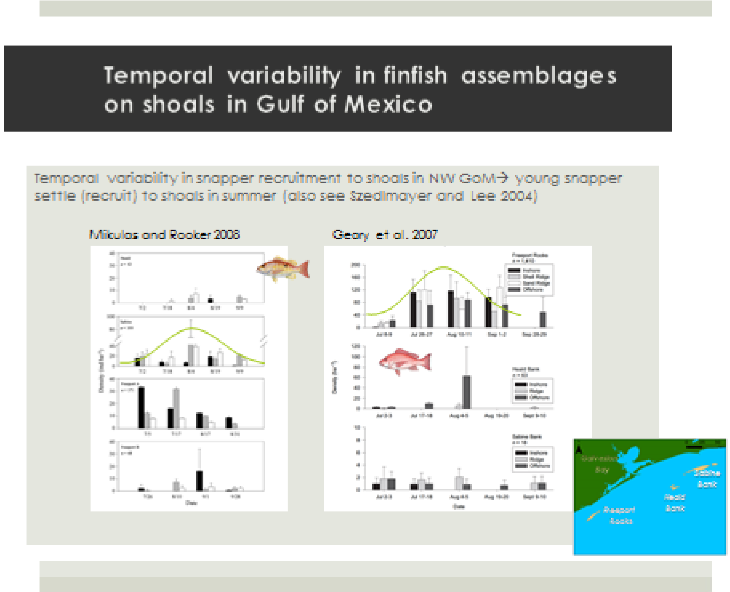
## Temporal variability in finfish assemblages on shoals in Gulf of Mexico

**Diel** habitat shifts poorly understood in GoM

**Seasonal** variation present (Wells et al. 2009)

Several species collected primarily in July (recruitment to shoals)

**Seasonal** patterns observed in several other studies (Brooks et al. 2005, Wells et al. 2008)→ Most studies based on single-species assessments (fisheries importance) and limited in duration (e.g., one or two seasons but not entire year)

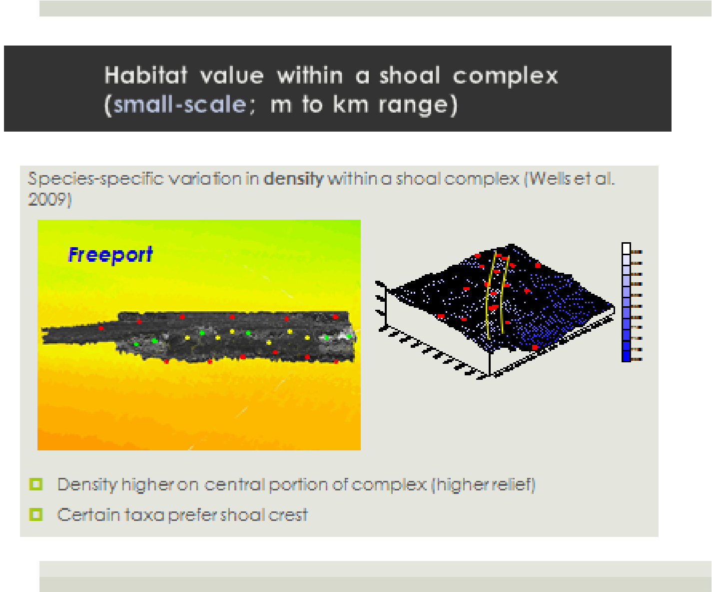


## Temporal variability in finfish assemblages on shoals in Gulf of Mexico

Temporal variability in snapper recruitment to shoals in NW GoM→ young snapper settle (recruit) to shoals in summer (also see Szedlmayer and Lee 2004)

Mikulas and Rooker 2008

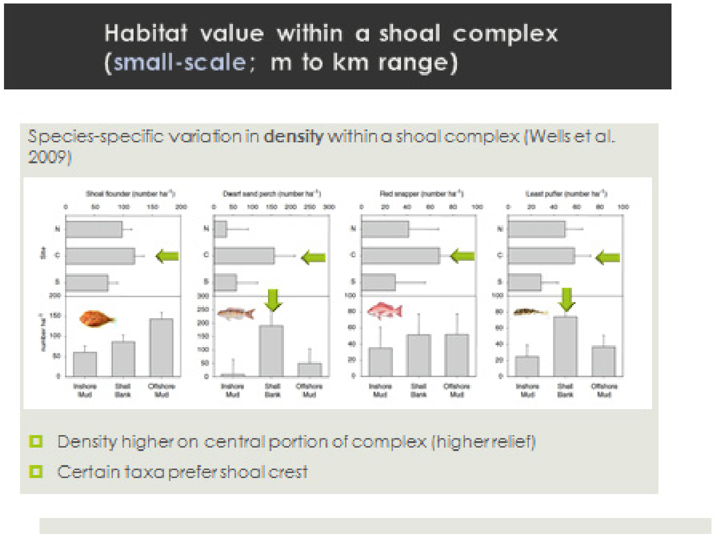
Geary et al. 2007



## Habitat value within a shoal complex (small-scale; m to km range)

Species-specific variation in **density** within a shoal complex (Wells et al. 2009)

- Density higher on central portion of complex (higher relief)
- Certain taxa prefer shoal crest



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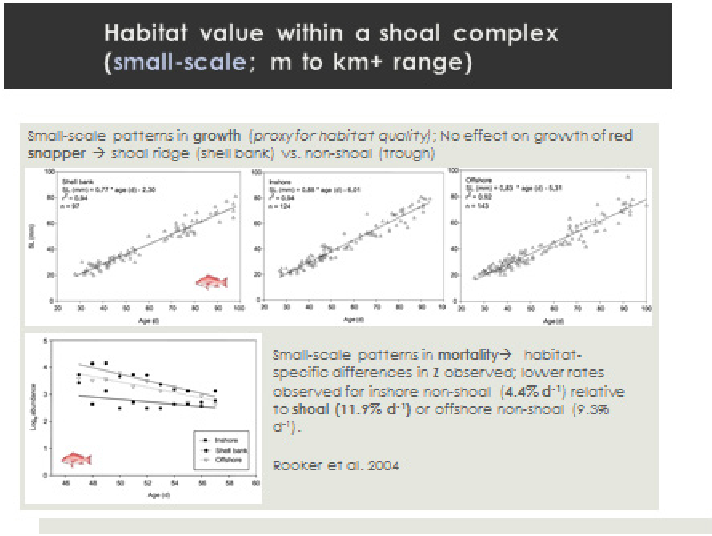
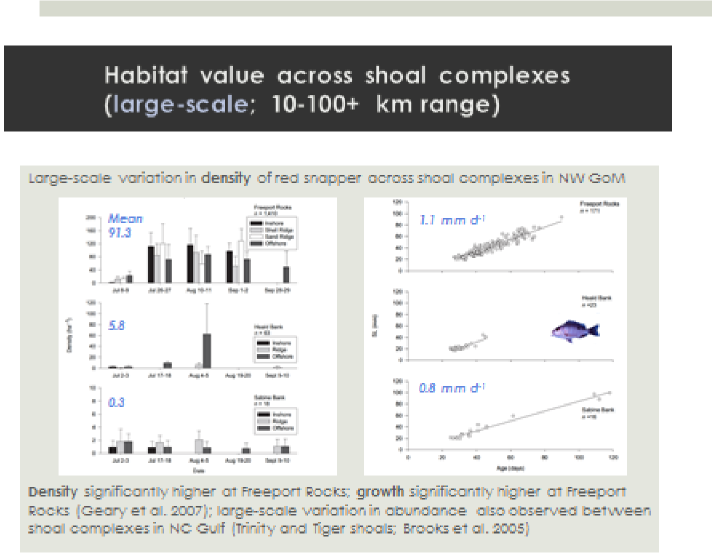


## Habitat value within a shoal complex (small-scale; m to km+ range)

Small-scale patterns in **growth** (*proxy for habitat quality*); No effect on growth of **red snapper** → shoal ridge (shell bank) vs. non-shoal (trough)

Small-scale patterns in **mortality**→ habitat-specific differences in Z observed; lower rates observed for inshore non-shoal (**4.4% d⁻¹**) relative to **shoal (11.9% d⁻¹)** or offshore non-shoal (9.3% d⁻¹).

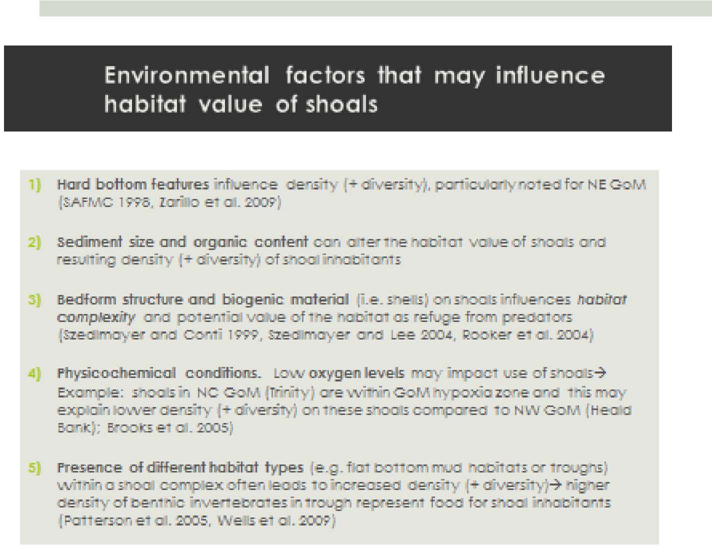
Rooker et al. 2004



## Habitat value across shoal complexes (large-scale; 10-100+ km range)

Large-scale variation in **density** of red snapper across shoal complexes in NW GoM

**Density** significantly higher at Freeport Rocks; **growth** significantly higher at Freeport Rocks (Geary et al. 2007); large-scale variation in abundance also observed between shoal complexes in NC Gulf (Trinity and Tiger shoals; Brooks et al. 2005)



## Environmental factors that may influence habitat value of shoals

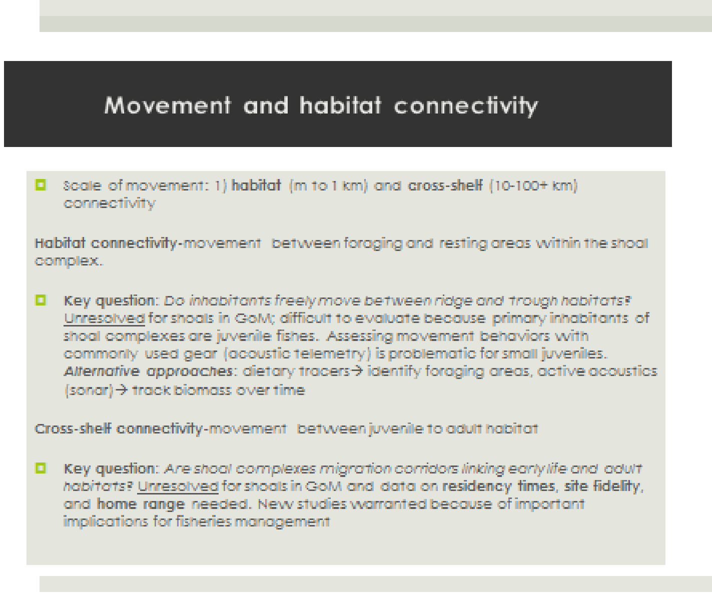
1) **Hard bottom features** influence density (+ diversity), particularly noted for NE GoM (SAFMC 1998, Zarillo et al. 2009)

2) **Sediment size and organic content** can alter the habitat value of shoals and resulting density (+ diversity) of shoal inhabitants

3) **Bedform structure and biogenic material** (i.e. shells) on shoals influences ***habitat complexity*** and potential value of the habitat as refuge from predators (Szedlmayer and Conti 1999, Szedlmayer and Lee 2004, Rooker et al. 2004)

4) **Physicochemical conditions.** Low **oxygen levels** may impact use of shoals→ Example: shoals in NC GoM (Trinity) are within GoM hypoxia zone and this may explain lower density (+ diversity) on these shoals compared to NW GoM (Heald Bank); Brooks et al. 2005)

5) **Presence of different habitat types** (e.g. flat bottom mud habitats or troughs) within a shoal complex often leads to increased density (+ diversity)→ higher density of benthic invertebrates in trough represent food for shoal inhabitants (Patterson et al. 2005, Wells et al. 2009)



## Movement and habitat connectivity

- Scale of movement: 1) **habitat** (m to 1 km) and **cross-shelf** (10-100+ km) connectivity

**Habitat connectivity**-movement between foraging and resting areas within the shoal complex.

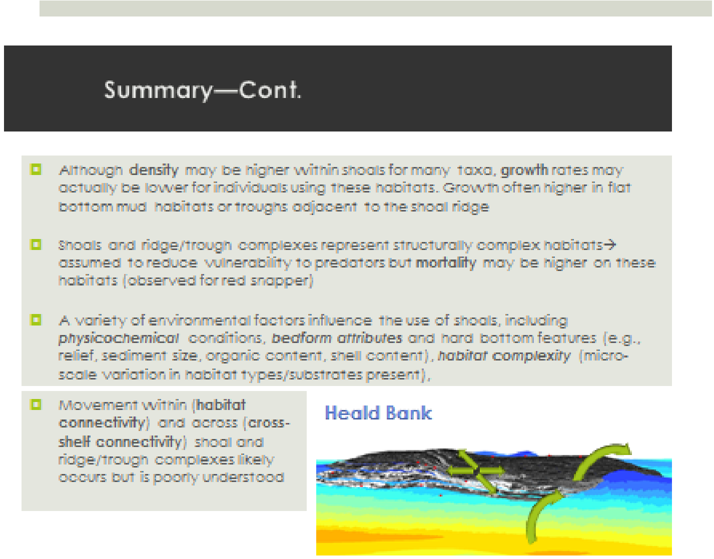
- **Key question:** *Do inhabitants freely move between ridge and trough habitats?* Unresolved for shoals in GoM; difficult to evaluate because primary inhabitants of shoal complexes are juvenile fishes. Assessing movement behaviors with commonly used gear (acoustic telemetry) is problematic for small juveniles. *Alternative approaches*: dietary tracers→ identify foraging areas, active acoustics (sonar)→ track biomass over time

**Cross-shelf connectivity**-movement between juvenile to adult habitat

- **Key question:** *Are shoal complexes migration corridors linking early life and adult habitats?* Unresolved for shoals in GoM and data on **residency times**, **site fidelity**, and **home range** needed. New studies warranted because of important implications for fisheries management

## Summary

- Series of shoal and ridge/trough complexes in NW, NC, and NE GoM
- Several species of fisheries importance use shoals. **Invertebrates:** shrimp, lobster, blue crabs, stone crabs. **Fishes:** lutjanids, sciaenids (particularly during early life) Also, forage fish for higher order predators present on shoals
- Function as shelter sites, forage areas, and spawning sites of several taxa, and designated as EFH and HAPC for benthic and pelagic species
- Assemblage structure varies among region; similar assemblage in **NW and NC** GoM and, although different in NE, **ecological equivalents** on shoals in all regions
- Species-specific pattern of habitat use present and structural complexity of shoals and ridge/trough habitats appears to serve as important early life habitat of several taxa
- Temporal variation (seasonal) is often linked to the **timing of recruitment (settlement)**



## Summary—Cont.

- Although **density** may be higher within shoals for many taxa, **growth** rates may actually be lower for individuals using these habitats. Growth often higher in flat bottom mud habitats or troughs adjacent to the shoal ridge
- Shoals and ridge/trough complexes represent structurally complex habitats→ assumed to reduce vulnerability to predators but **mortality** may be higher on these habitats (observed for red snapper)
- A variety of environmental factors influence the use of shoals, including ***physicochemical*** conditions, ***bedform attributes*** and hard bottom features (e.g., relief, sediment size, organic content, shell content), ***habitat complexity*** (micro-scale variation in habitat types/substrates present),
- Movement within (**habitat connectivity**) and across (**cross-shelf connectivity**) shoal and ridge/trough complexes likely occurs but is poorly understood

## Data gaps

- Lack of **standardized sampling across multiple shoals** within a region (e.g. NW Gulf of Mexico—Heald, Sabine, Freeport, Rio Grande); required to assess the **value** of each shoal, primarily as nursery. Also, incorporation of environmental data into assessments critical
- Data on life history attributes (**condition, growth, mortality**) within shoal habitat types (ridge vs. trough) limited to a few taxa in GoM and findings differ among studies/shoals
- Data on small-scale spatial distribution or **microhabitat use** is extremely limited for fishes in the GoM; majority of published studies on fishes based on trawling surveys, which cannot effectively sample microhabitats. Alternative approaches needed to understand **habitat use** and **movement** within shoal complex
- Value of shoals as **nursery habitat** investigated for a few species (i.e., red snapper); however, data on other species limited. Also, ecological roles as **foraging** and **spawning** habitat is poorly understood
- **Population connectivity** poorly understood for shoal inhabitants at both within and across shoal complexes

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# The ecological function of shoal/ridge habitats for fishes in the Atlantic OCS

Frederick S. Scharf

University of North Carolina - Wilmington

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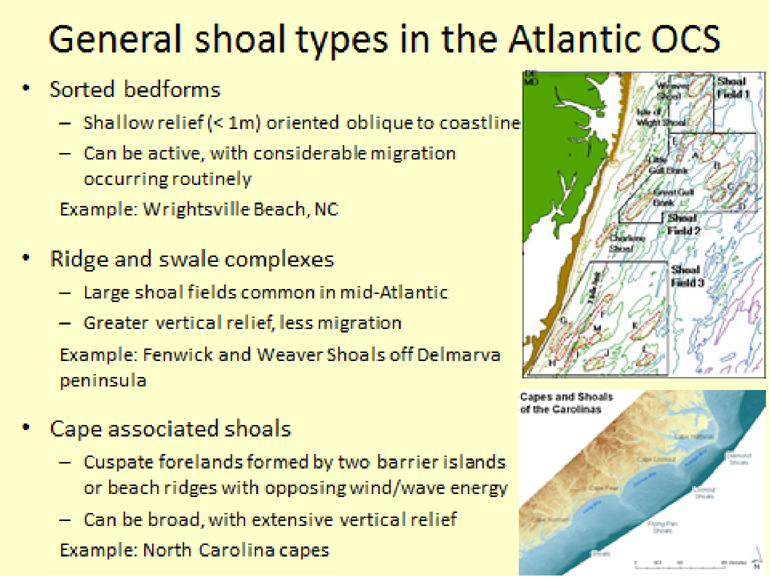


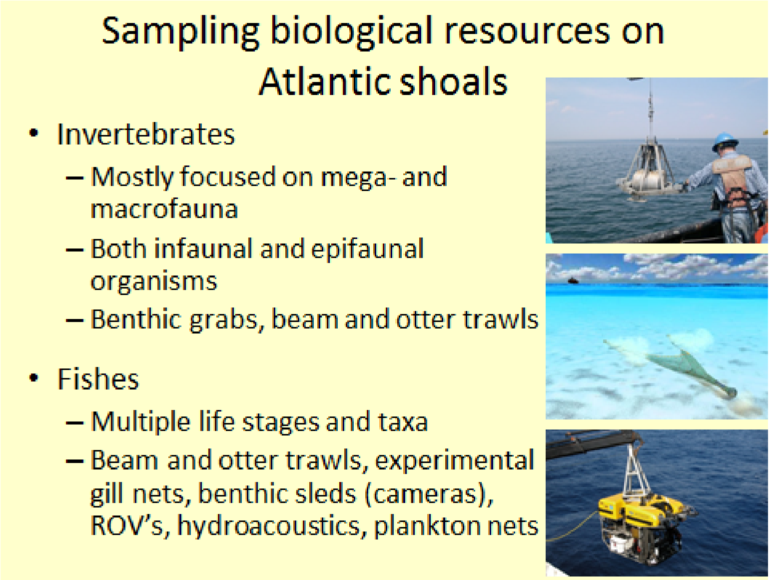
## General shoal types in the Atlantic OCS

- Sorted bedforms
  - Shallow relief (< 1m) oriented oblique to coastline
  - Can be active, with considerable migration occurring routinely

  Example: Wrightsville Beach, NC
- Ridge and swale complexes
  - Large shoal fields common in mid-Atlantic
  - Greater vertical relief, less migration

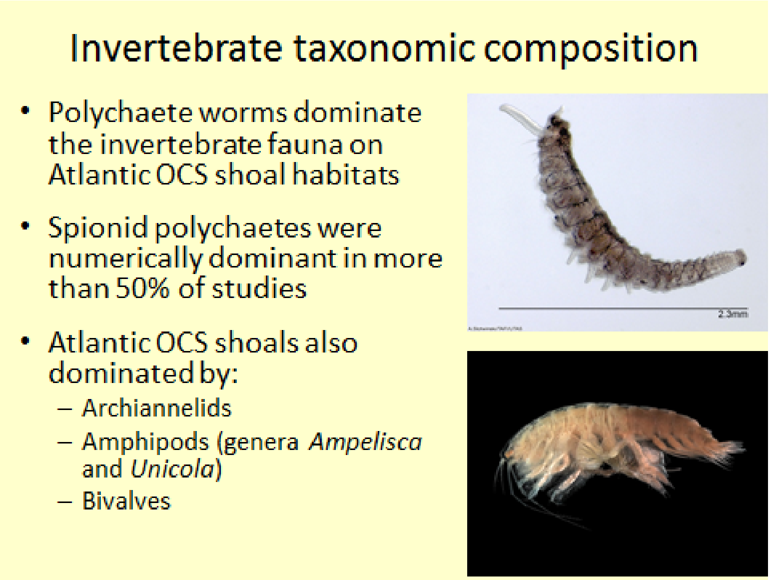
  Example: Fenwick and Weaver Shoals off Delmarva peninsula
- Cape associated shoals
  - Cuspate forelands formed by two barrier islands or beach ridges with opposing wind/wave energy
  - Can be broad, with extensive vertical relief

  Example: North Carolina capes



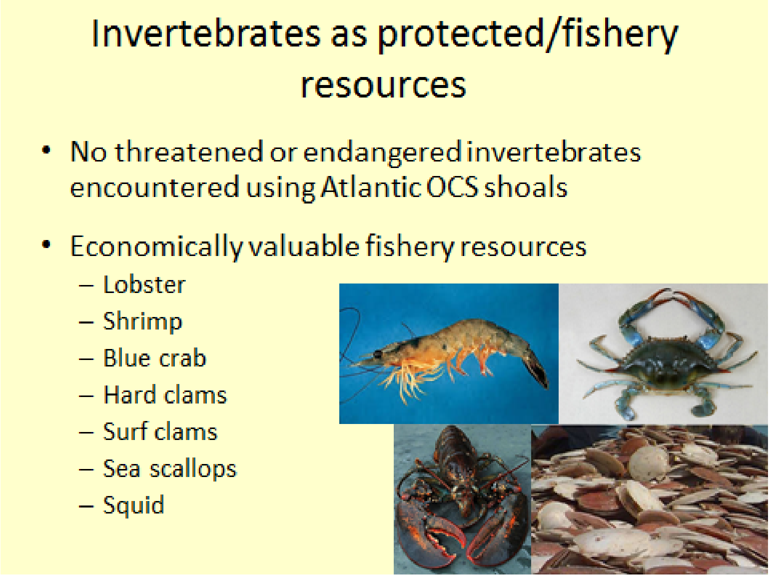
## Sampling biological resources on Atlantic shoals

- Invertebrates
  - Mostly focused on mega- and macrofauna
  - Both infaunal and epifaunal organisms
  - Benthic grabs, beam and otter trawls
- Fishes
  - Multiple life stages and taxa
  - Beam and otter trawls, experimental gill nets, benthic sleds (cameras), ROV's, hydroacoustics, plankton nets



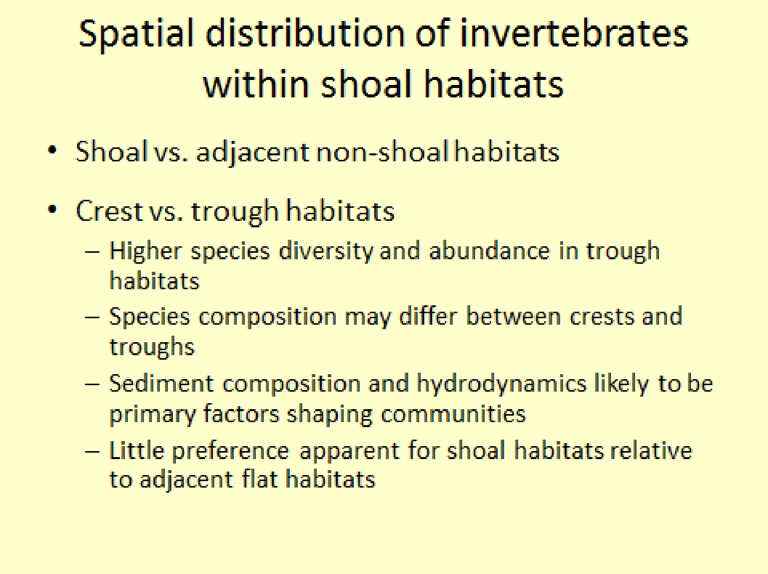
## Invertebrate taxonomic composition

- Polychaete worms dominate the invertebrate fauna on Atlantic OCS shoal habitats
- Spionid polychaetes were numerically dominant in more than 50% of studies
- Atlantic OCS shoals also dominated by:
  - Archiannelids
  - Amphipods (genera *Ampelisca* and *Unicola*)
  - Bivalves



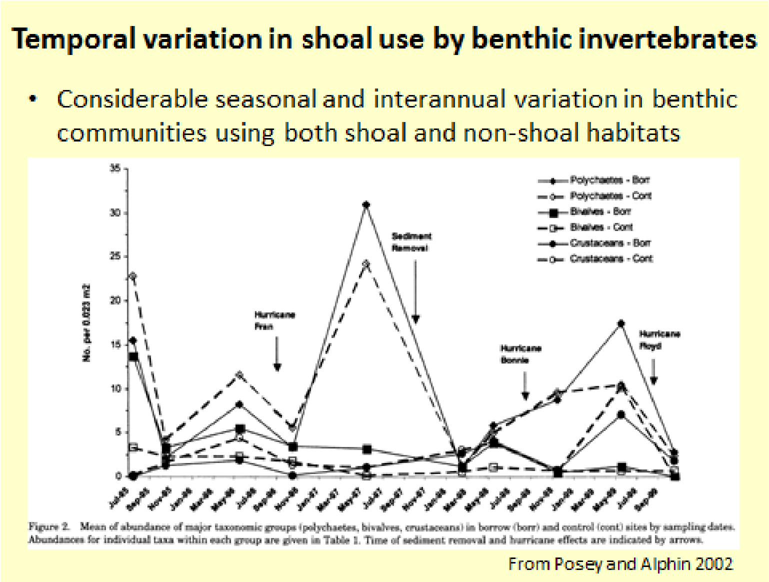
## Invertebrates as protected/fishery resources

- No threatened or endangered invertebrates encountered using Atlantic OCS shoals
- Economically valuable fishery resources
  - Lobster
  - Shrimp
  - Blue crab
  - Hard clams
  - Surf clams
  - Sea scallops
  - Squid



## Spatial distribution of invertebrates within shoal habitats

- Shoal vs. adjacent non-shoal habitats
- Crest vs. trough habitats
  - Higher species diversity and abundance in trough habitats
  - Species composition may differ between crests and troughs
  - Sediment composition and hydrodynamics likely to be primary factors shaping communities
  - Little preference apparent for shoal habitats relative to adjacent flat habitats



## Temporal variation in shoal use by benthic invertebrates

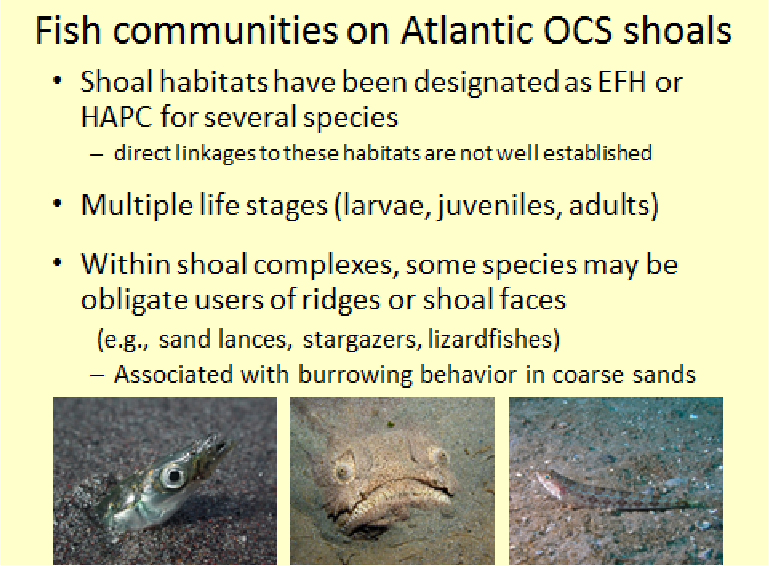
- Considerable seasonal and interannual variation in benthic communities using both shoal and non-shoal habitats

Figure 2. Mean of abundance of major taxonomic groups (polychaetes, bivalves, crustaceans) in borrow (borr) and control (cont) sites by sampling dates. Abundances for individual taxa within each group are given in Table 1. Time of sediment removal and hurricane effects are indicated by arrows.

From Posey and Alphin 2002

## Disturbance impacts on benthic invertebrate communities

- Areas with routine natural disturbance often display high temporal and spatial variability
- Shoals may be recolonized quickly following disturbance
  - Abundance may recover rapidly (months)
  - Diversity and species composition may take longer (years)
- High energy habitats (e.g., crests) subjected to routine natural disturbance = faster recovery
- Taxonomic diversity in recovery time
  - Polychaetes and crustaceans - fast
  - Molluscs – slow
- Timing (e.g., just prior to peak recruitment) and location (e.g., small patches) of disturbance may speed recovery of invertebrate communities



## Fish communities on Atlantic OCS shoals

- Shoal habitats have been designated as EFH or HAPC for several species
  - direct linkages to these habitats are not well established
- Multiple life stages (larvae, juveniles, adults)
- Within shoal complexes, some species may be obligate users of ridges or shoal faces

  (e.g., sand lances, stargazers, lizardfishes)
  - Associated with burrowing behavior in coarse sands

## Fish communities on Atlantic OCS shoals

- Studies reveal that shoal fish community composition similar to surrounding areas
- More demersal than pelagic species at all life stages
- Hakes, flounders, skates occurred commonly
- Small pelagics (e.g., anchovies, butterfish), drums, and sea robins were also common

## Fishes as protected/fishery resources

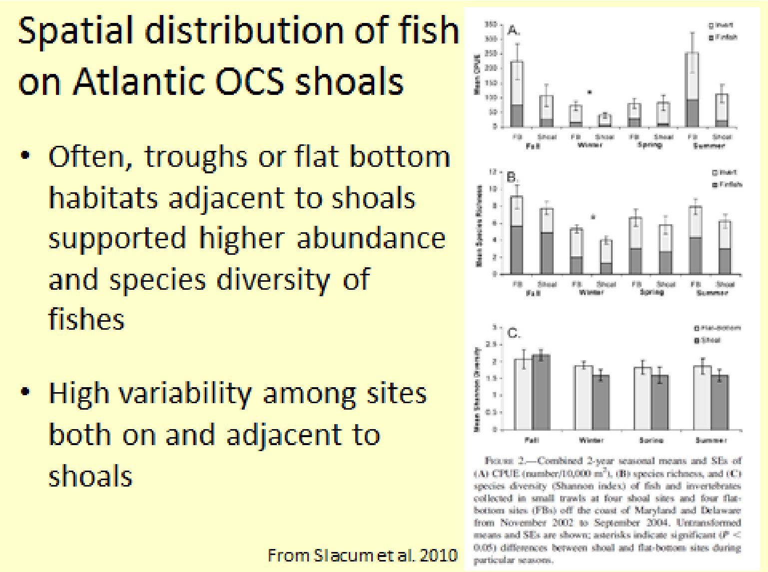
- Atlantic sturgeon, Dusky sharks, and smalltooth sawfish documented on Atlantic OCS shoals
- Economically valuable fishery resources
  - Striped bass
  - Atlantic croaker
  - Weakfish
  - Spanish mackerel
  - Spiny dogfish
  - Summer flounder
  - Snapper/grouper spp.
- Shoals may serve as important sites for spawning aggregations (e.g., clupeids, red drum, grouper)

## Spatial distribution of fish on Atlantic OCS shoals

- Fine scale habitat use within shoal complexes influenced by:

| | |
|---|---|
| sediment grain size | bedform features |
| biogenic structure | invertebrate distribution |
| proximity to shoal/ridge | hydrographic features |

- Shoals may serve as:
  - Physical refuge for juvenile demersals and schooling pelagics
  - Habitat for invertebrate communities, creating trophic resource for fishes
  - Potential spawning aggregation sites

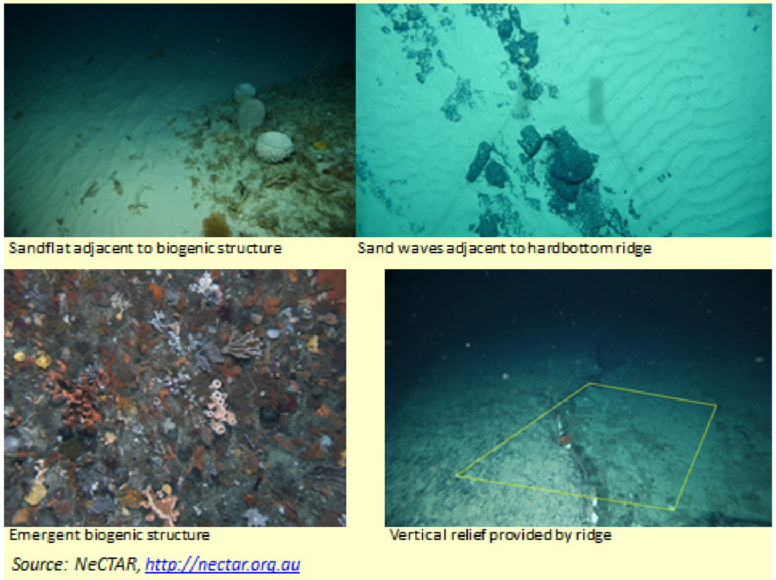


## Spatial distribution of fish on Atlantic OCS shoals

- Often, troughs or flat bottom habitats adjacent to shoals supported higher abundance and species diversity of fishes
- High variability among sites both on and adjacent to shoals

FIGURE 2.—Combined 2-year seasonal means and SEs of (A) CPUE (number/10,000 $m^2$), (B) species richness, and (C) species diversity (Shannon index) of fish and invertebrates collected in small trawls at four shoal sites and four flat-bottom sites (FBs) off the coast of Maryland and Delaware from November 2002 to September 2004. Untransformed means and SEs are shown; asterisks indicate significant ($P < 0.05$) differences between shoal and flat-bottom sites during particular seasons.

From Slacum et al. 2010



Sandflat adjacent to biogenic structure

Sand waves adjacent to hardbottom ridge

Emergent biogenic structure

Vertical relief provided by ridge

*Source: NeCTAR, http://nectar.org.au*

Sea robin near biogenic features

Diurnal resting in silver hake

Polychaete tube mat

Tube sponges mixed with shell hash

Sources: Uconn NURTEC, WHOI HabCam, NOAA

## Temporal variation in fish shoal use

Diel patterns

- Use of shoals may be higher at night, dependent on the amount of vertical relief provided
- Fish distributed non-randomly during the day, with random distributions and greater movement at night

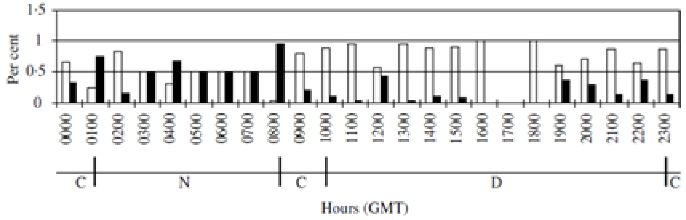


FIG. 4. Per cent of the total number of silver hake resting on the seafloor (☐) and swimming near bottom (■), on Georges Bank, for 1 h time periods. N, night; D, day; C, crepuscular.

From Auster et al. 2003

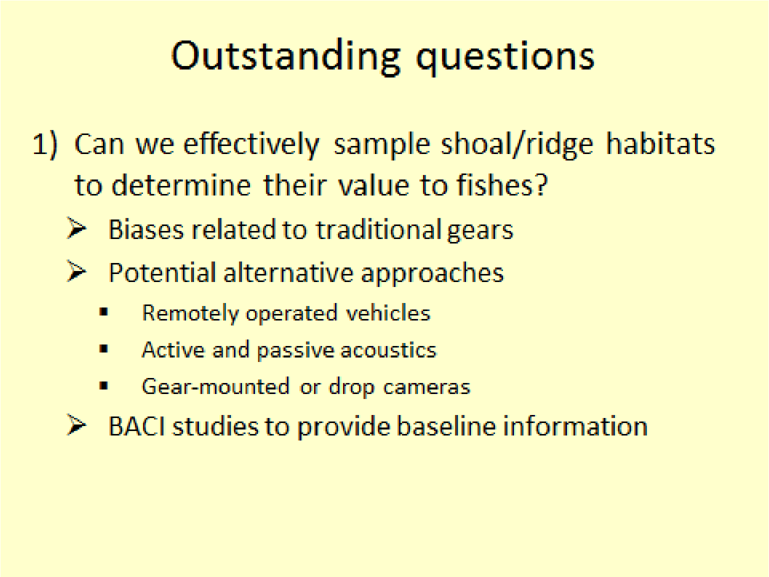
## Temporal variation in use of Atlantic OCS shoals by fishes

Interannual/seasonal patterns

- Considerable seasonal variation in the use of shoals by fishes
  - Shoal use aligned with seasonal migratory and recruitment patterns
  - Abundance generally lowest in winter
  - Species composition specific to seasons
- Level of interannual and seasonal variation observed in multiyear studies hinders detection of disturbance signal

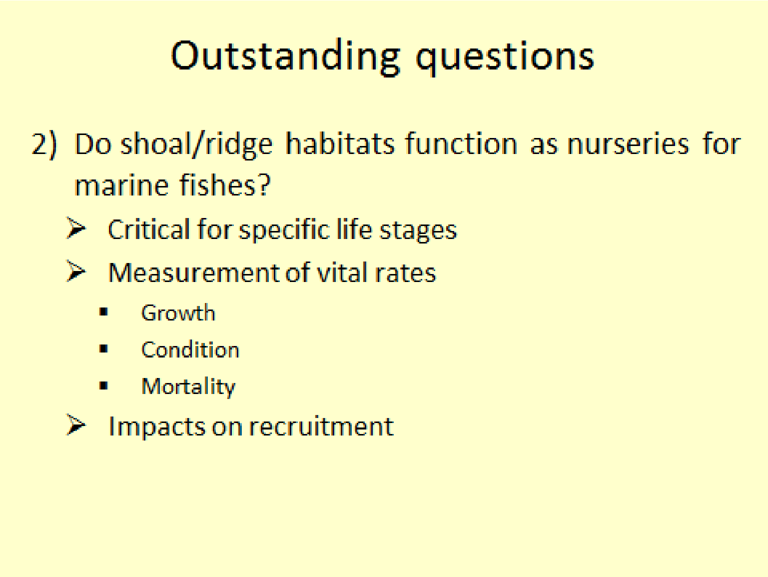
## Summary

- Limited information available on the value of Atlantic OCS shoals to fishes
- Many species common to shelf assemblages have been encountered on shoals
- Shoal function likely to be life stage-specific
  - Foraging, predation refuge, spawning
- Spatial and temporal variation is high
  - Seasonal and diel patterns observed
- Microscale features likely important in creating overall habitat value



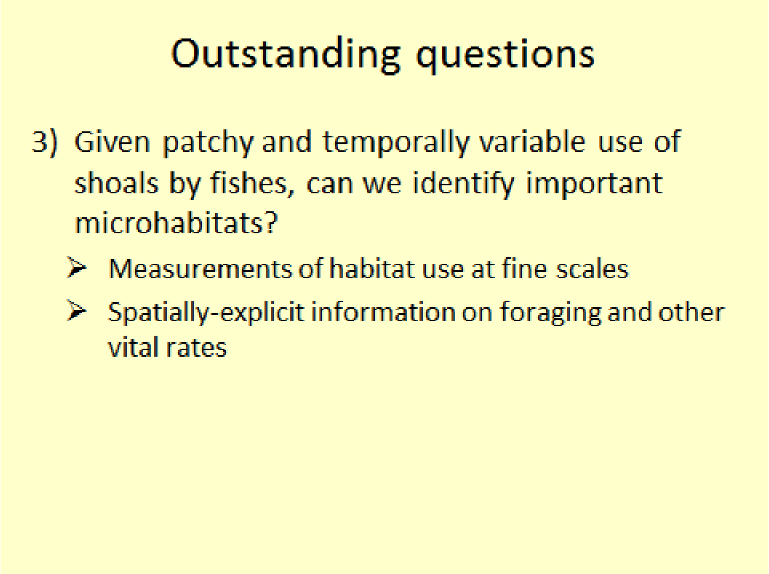
## Outstanding questions

1) Can we effectively sample shoal/ridge habitats to determine their value to fishes?
   - ➢ Biases related to traditional gears
   - ➢ Potential alternative approaches
     - Remotely operated vehicles
     - Active and passive acoustics
     - Gear-mounted or drop cameras
   - ➢ BACI studies to provide baseline information



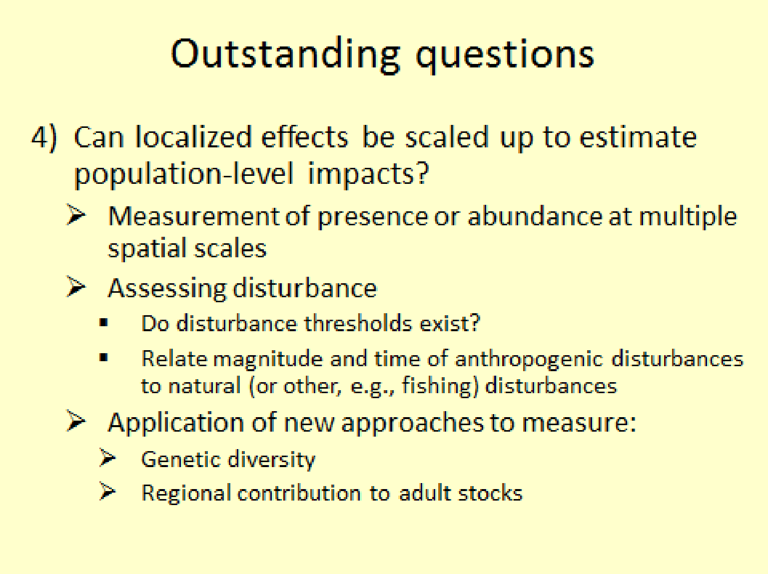
## Outstanding questions

2) Do shoal/ridge habitats function as nurseries for marine fishes?
   - ➢ Critical for specific life stages
   - ➢ Measurement of vital rates
     - Growth
     - Condition
     - Mortality
   - ➢ Impacts on recruitment



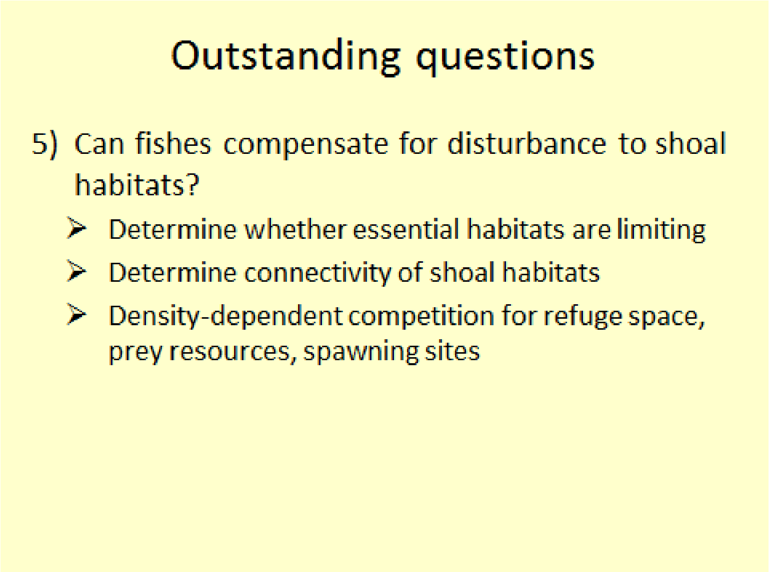
## Outstanding questions

3) Given patchy and temporally variable use of shoals by fishes, can we identify important microhabitats?
   - ➢ Measurements of habitat use at fine scales
   - ➢ Spatially-explicit information on foraging and other vital rates



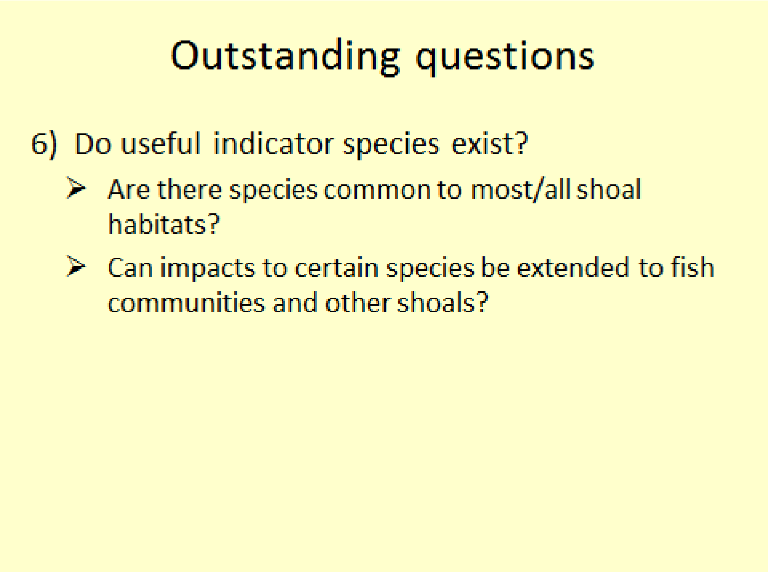
## Outstanding questions

4) Can localized effects be scaled up to estimate population-level impacts?
   - ➢ Measurement of presence or abundance at multiple spatial scales
   - ➢ Assessing disturbance
     - Do disturbance thresholds exist?
     - Relate magnitude and time of anthropogenic disturbances to natural (or other, e.g., fishing) disturbances
   - ➢ Application of new approaches to measure:
     - ➢ Genetic diversity
     - ➢ Regional contribution to adult stocks



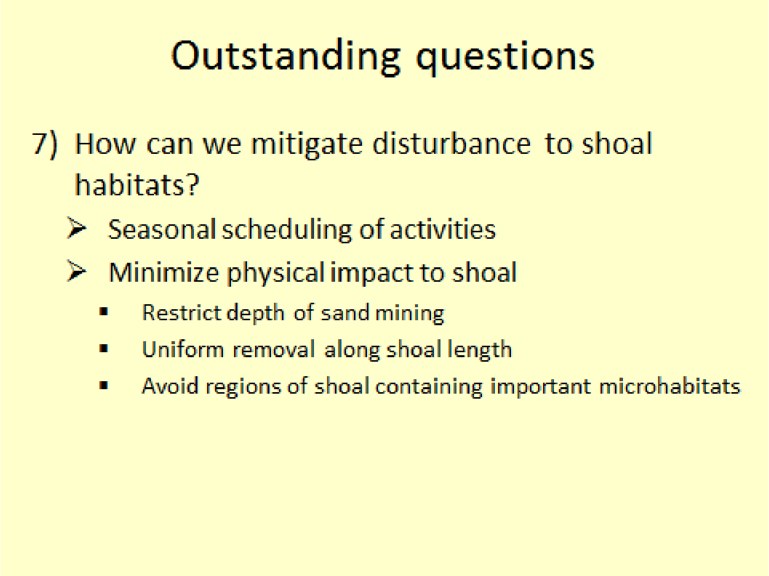
## Outstanding questions

5) Can fishes compensate for disturbance to shoal habitats?
   - ➢ Determine whether essential habitats are limiting
   - ➢ Determine connectivity of shoal habitats
   - ➢ Density-dependent competition for refuge space, prey resources, spawning sites



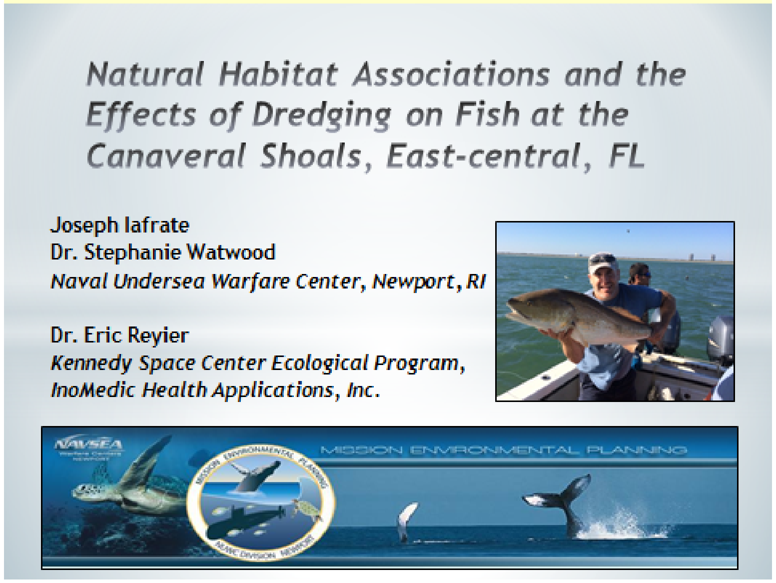
## Outstanding questions

6) Do useful indicator species exist?
   - ➢ Are there species common to most/all shoal habitats?
   - ➢ Can impacts to certain species be extended to fish communities and other shoals?



## Outstanding questions

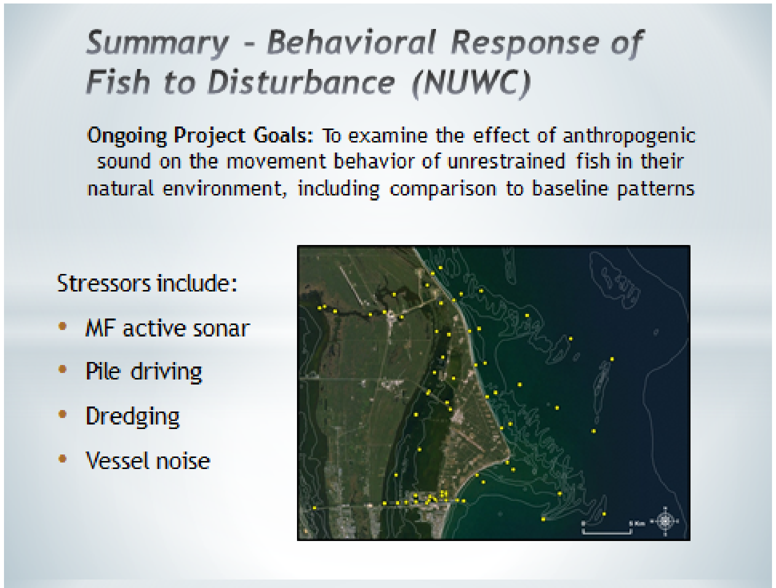
7) How can we mitigate disturbance to shoal habitats?
   - ➢ Seasonal scheduling of activities
   - ➢ Minimize physical impact to shoal
     - ▪ Restrict depth of sand mining
     - ▪ Uniform removal along shoal length
     - ▪ Avoid regions of shoal containing important microhabitats



## *Natural Habitat Associations and the Effects of Dredging on Fish at the Canaveral Shoals, East-central, FL*

Joseph Iafrate
Dr. Stephanie Watwood
*Naval Undersea Warfare Center, Newport, RI*

Dr. Eric Reyier
*Kennedy Space Center Ecological Program, InoMedic Health Applications, Inc.*

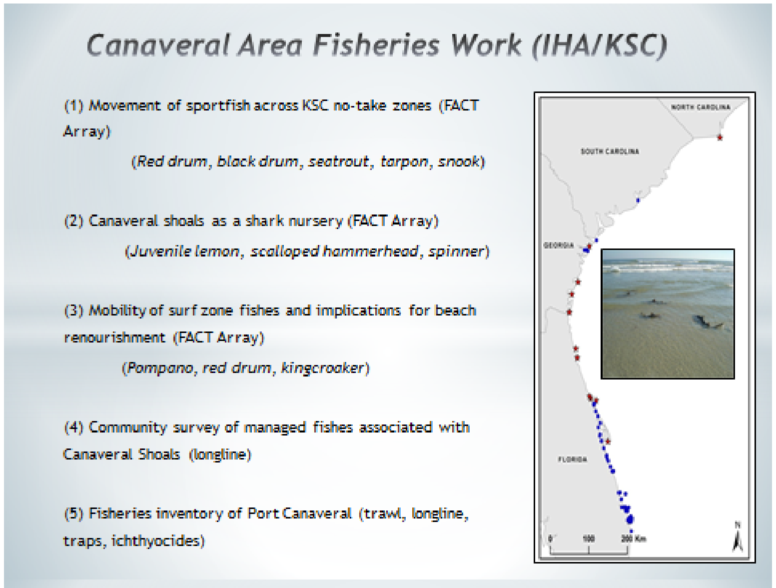


## Summary - Behavioral Response of Fish to Disturbance (NUWC)

**Ongoing Project Goals:** To examine the effect of anthropogenic sound on the movement behavior of unrestrained fish in their natural environment, including comparison to baseline patterns

Stressors include:

- MF active sonar
- Pile driving
- Dredging
- Vessel noise



## Canaveral Area Fisheries Work (IHA/KSC)

(1) Movement of sportfish across KSC no-take zones (FACT Array)

*(Red drum, black drum, seatrout, tarpon, snook)*

(2) Canaveral shoals as a shark nursery (FACT Array)

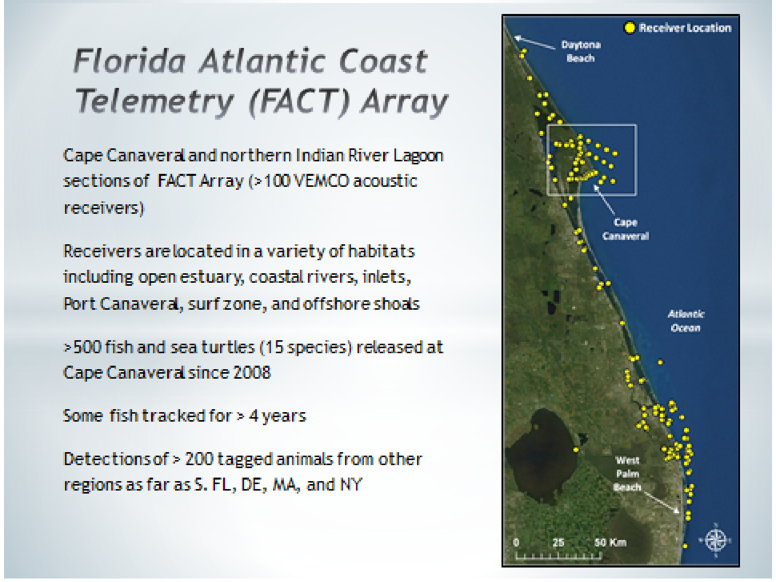
*(Juvenile lemon, scalloped hammerhead, spinner)*

(3) Mobility of surf zone fishes and implications for beach renourishment (FACT Array)

*(Pompano, red drum, kingcroaker)*

(4) Community survey of managed fishes associated with Canaveral Shoals (longline)

(5) Fisheries inventory of Port Canaveral (trawl, longline, traps, ichthyocides)



## Florida Atlantic Coast Telemetry (FACT) Array

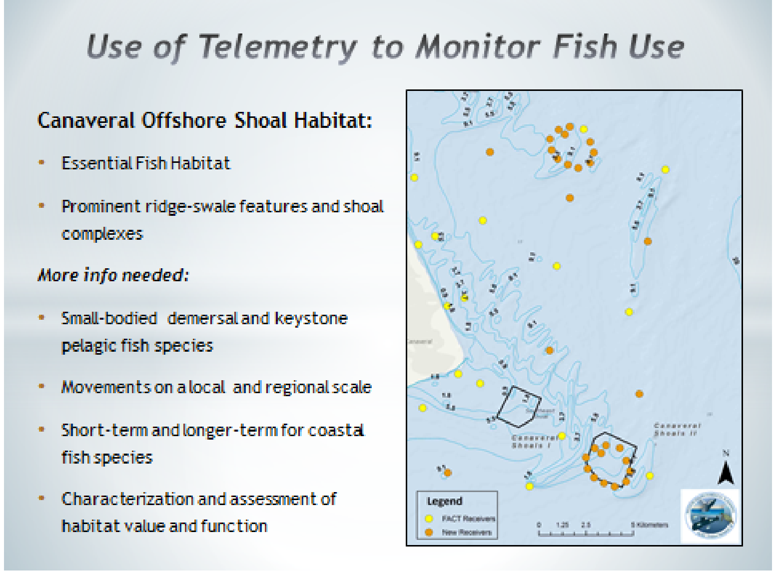
Cape Canaveral and northern Indian River Lagoon sections of FACT Array (>100 VEMCO acoustic receivers)

Receivers are located in a variety of habitats including open estuary, coastal rivers, inlets, Port Canaveral, surf zone, and offshore shoals

>500 fish and sea turtles (15 species) released at Cape Canaveral since 2008

Some fish tracked for > 4 years

Detections of > 200 tagged animals from other regions as far as S. FL, DE, MA, and NY



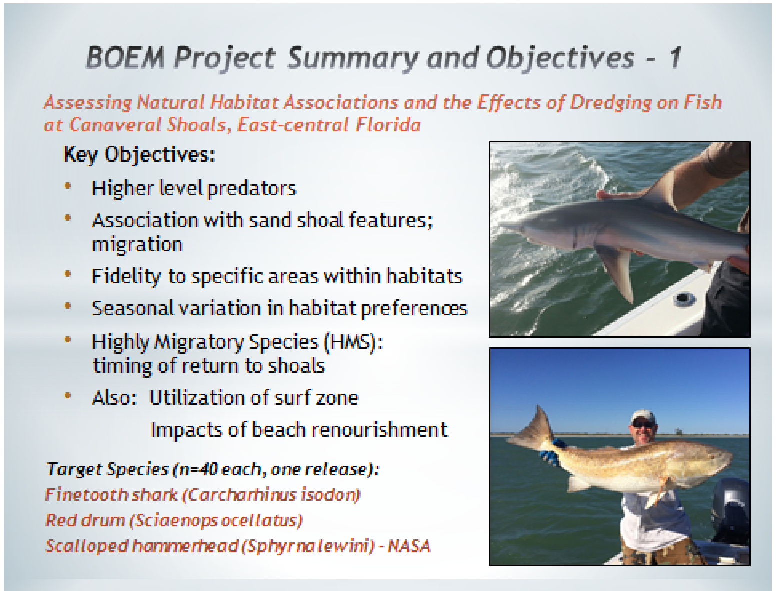
## Use of Telemetry to Monitor Fish Use

**Canaveral Offshore Shoal Habitat:**

- Essential Fish Habitat
- Prominent ridge-swale features and shoal complexes

***More info needed:***

- Small-bodied demersal and keystone pelagic fish species
- Movements on a local and regional scale
- Short-term and longer-term for coastal fish species
- Characterization and assessment of habitat value and function



## BOEM Project Summary and Objectives - 1

*Assessing Natural Habitat Associations and the Effects of Dredging on Fish at Canaveral Shoals, East-central Florida*

**Key Objectives:**

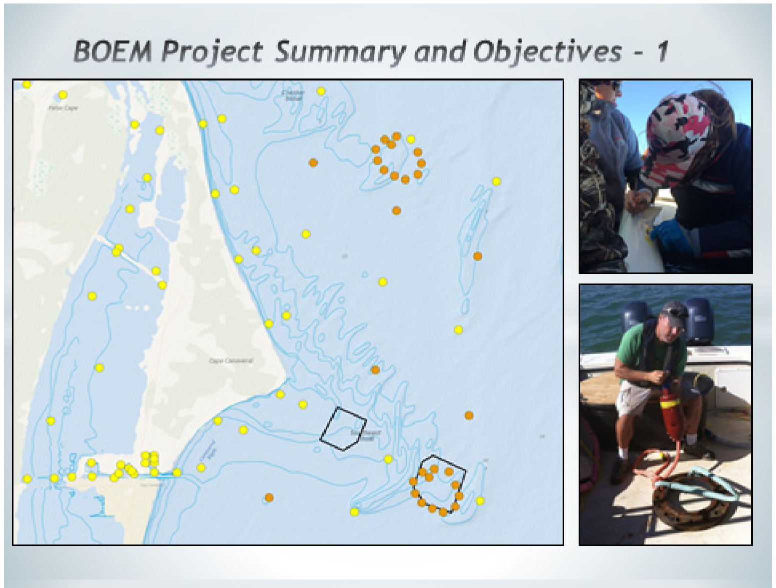
- Higher level predators
- Association with sand shoal features; migration
- Fidelity to specific areas within habitats
- Seasonal variation in habitat preferences
- Highly Migratory Species (HMS): timing of return to shoals
- Also: Utilization of surf zone
  Impacts of beach renourishment

***Target Species (n=40 each, one release):***

*Finetooth shark (Carcharhinus isodon)*

*Red drum (Sciaenops ocellatus)*

*Scalloped hammerhead (Sphyrna lewini) - NASA*



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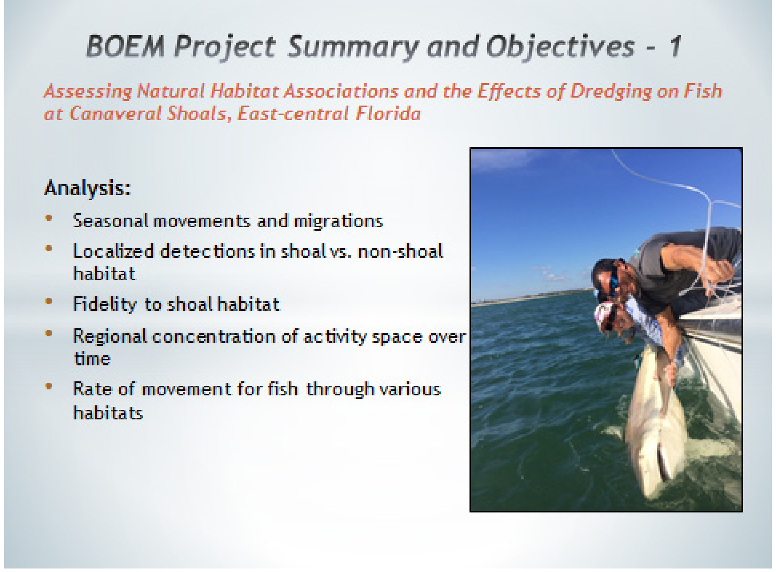
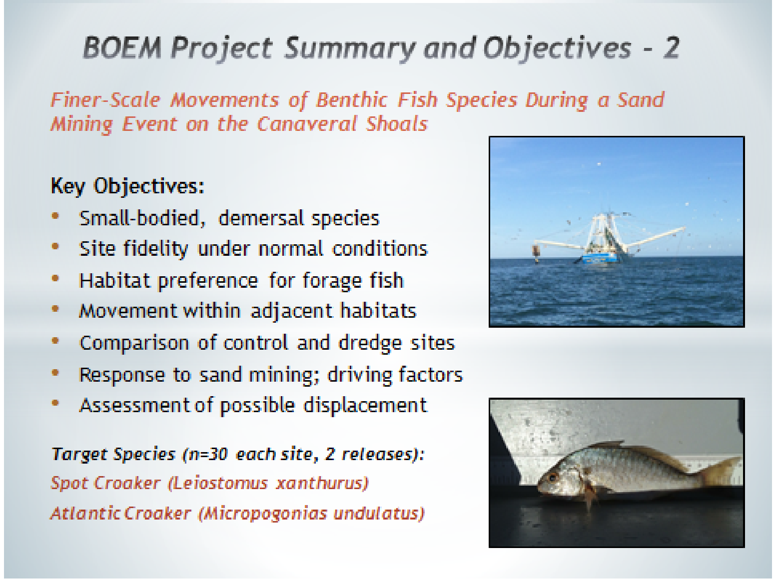


## BOEM Project Summary and Objectives - 1

*Assessing Natural Habitat Associations and the Effects of Dredging on Fish at Canaveral Shoals, East-central Florida*

**Analysis:**

- Seasonal movements and migrations
- Localized detections in shoal vs. non-shoal habitat
- Fidelity to shoal habitat
- Regional concentration of activity space over time
- Rate of movement for fish through various habitats



## BOEM Project Summary and Objectives - 2

*Finer-Scale Movements of Benthic Fish Species During a Sand Mining Event on the Canaveral Shoals*

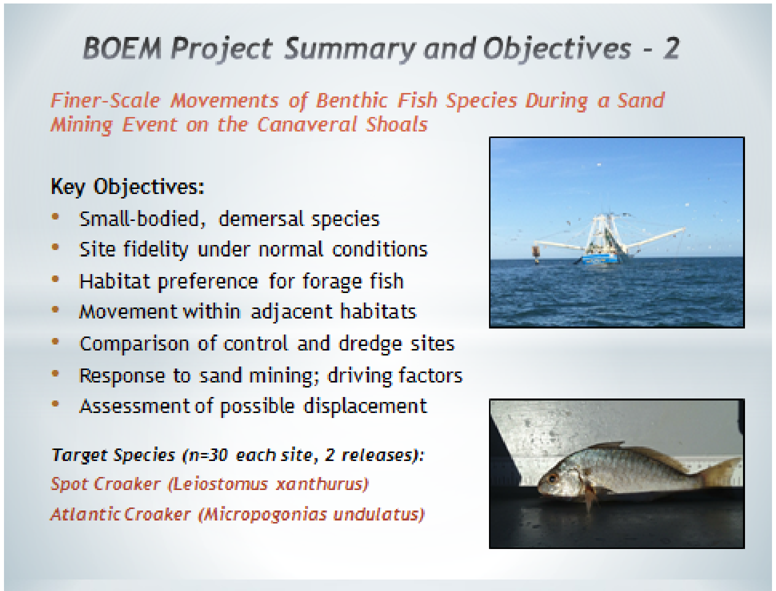
**Key Objectives:**

- Small-bodied, demersal species
- Site fidelity under normal conditions
- Habitat preference for forage fish
- Movement within adjacent habitats
- Comparison of control and dredge sites
- Response to sand mining; driving factors
- Assessment of possible displacement

***Target Species (n=30 each site, 2 releases):***

*Spot Croaker (Leiostomus xanthurus)*

*Atlantic Croaker (Micropogonias undulatus)*



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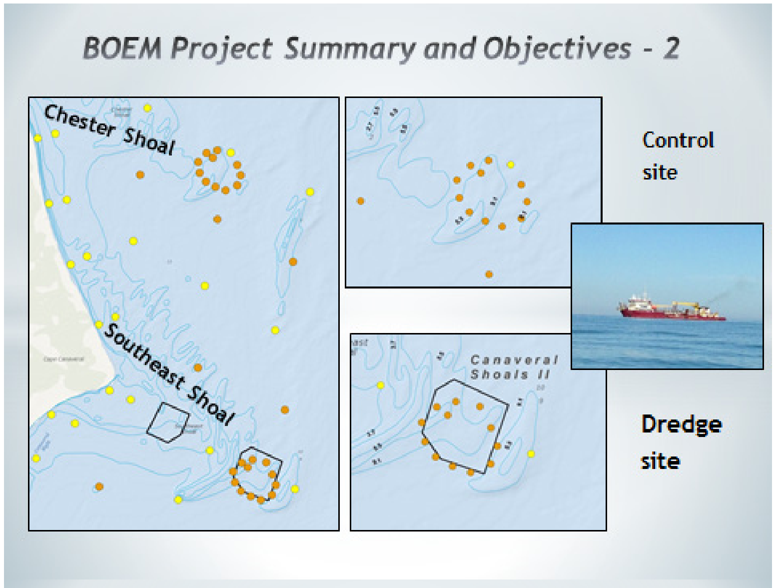
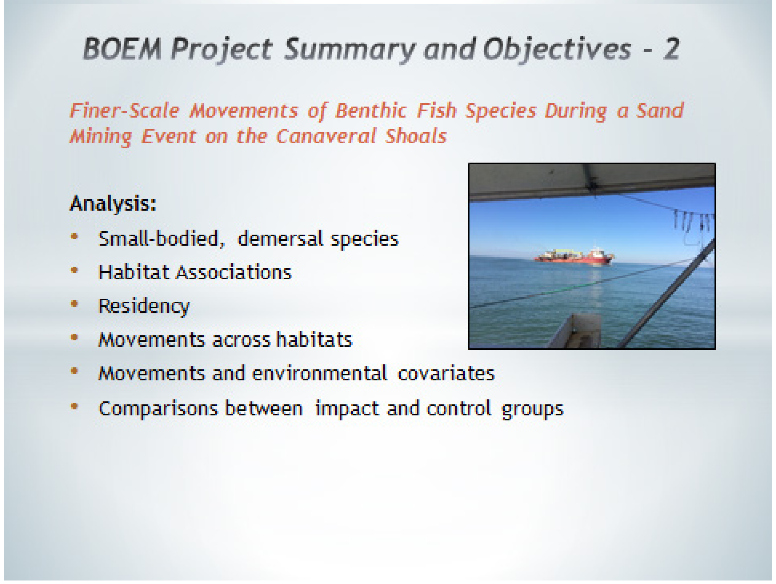


## BOEM Project Summary and Objectives - 2

Control site

**Dredge site**



## BOEM Project Summary and Objectives - 2

*Finer-Scale Movements of Benthic Fish Species During a Sand Mining Event on the Canaveral Shoals*

**Analysis:**

- Small-bodied, demersal species
- Habitat Associations
- Residency
- Movements across habitats
- Movements and environmental covariates
- Comparisons between impact and control groups

## Summary of Collection and Tagging

**Dec 2013 - January 2014:**

***Natural Habitat Associations and the Effects of Dredging***

- ***31 adult red drum***
- ***9 finetooth sharks***

***Finer Scale Movements of Benthic Fish Species***

- ***30 croaker and 30 spot (CSII)***
- ***36 croaker and 24 spot (Chester)***

*Acknowledgements

Jane Provancha, Doug Scheidt, Carla Garreau, Russell Lowers, Karen Holloway-Adkins, Brenton Back, Shannon Gann Kennedy Space Center Ecological Program

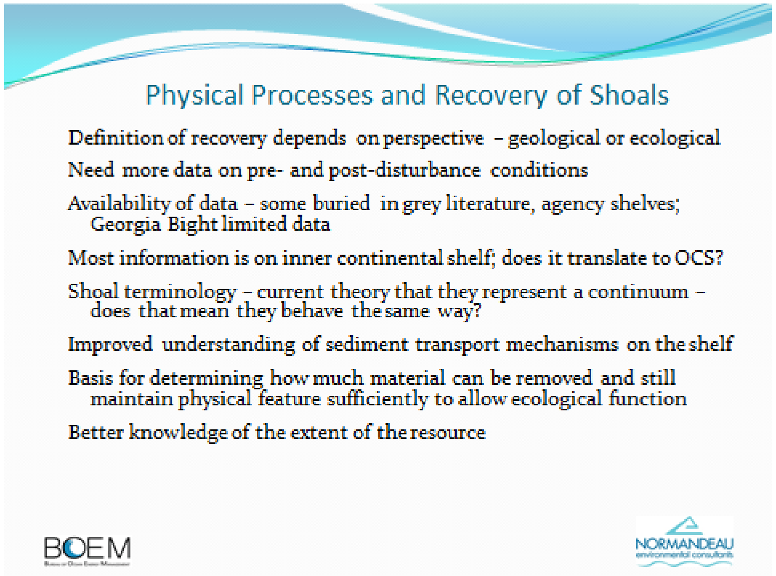
Don George Air Force 45th Space Wing Natural Assets Office

Jessica Kutcher, Jennifer James MRC, Inc

Deb Murie University of Florida

Jennifer Culbertson, Geoff Wikel, Sally Valdes BOEM

*Thank you



## Physical Processes and Recovery of Shoals

Definition of recovery depends on perspective – geological or ecological

Need more data on pre- and post-disturbance conditions

Availability of data – some buried in grey literature, agency shelves; Georgia Bight limited data

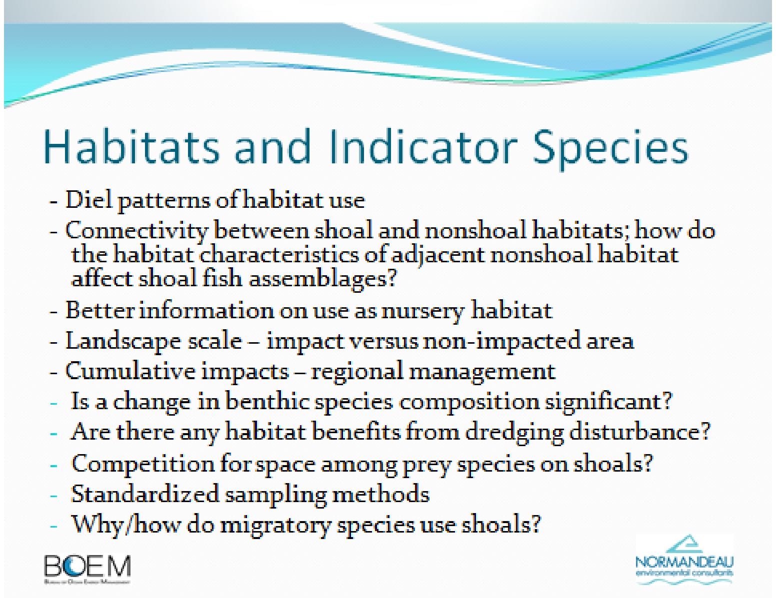
Most information is on inner continental shelf; does it translate to OCS?

Shoal terminology – current theory that they represent a continuum – does that mean they behave the same way?

Improved understanding of sediment transport mechanisms on the shelf

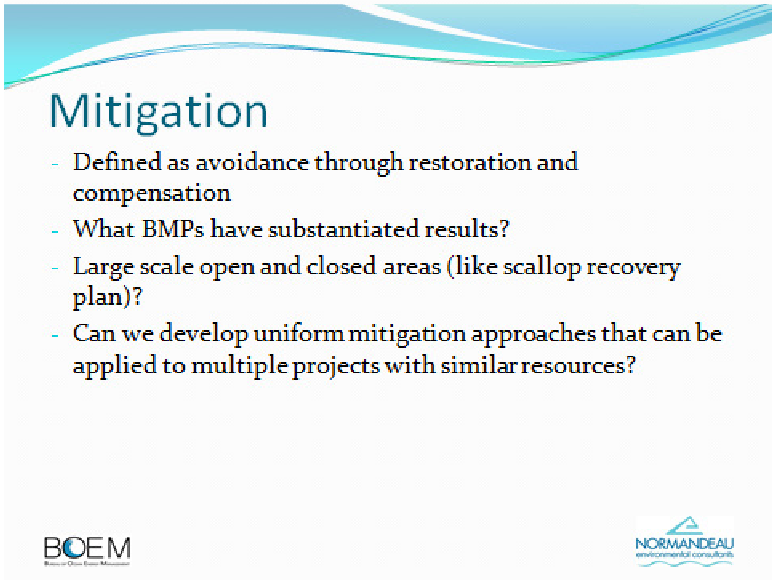
Basis for determining how much material can be removed and still maintain physical feature sufficiently to allow ecological function

Better knowledge of the extent of the resource



## Habitats and Indicator Species

- Diel patterns of habitat use
- Connectivity between shoal and nonshoal habitats; how do the habitat characteristics of adjacent nonshoal habitat affect shoal fish assemblages?
- Better information on use as nursery habitat
- Landscape scale – impact versus non-impacted area
- Cumulative impacts – regional management
- Is a change in benthic species composition significant?
- Are there any habitat benefits from dredging disturbance?
- Competition for space among prey species on shoals?
- Standardized sampling methods
- Why/how do migratory species use shoals?



## Mitigation

- Defined as avoidance through restoration and compensation
- What BMPs have substantiated results?
- Large scale open and closed areas (like scallop recovery plan)?
- Can we develop uniform mitigation approaches that can be applied to multiple projects with similar resources?

# Appendix B: Summary of Ecological Conditions in Bureau of Ocean Energy Management 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 NEFMC, the MAFMC, and the 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 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 GOM 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 GOM OCS and their scientific names. Appendix Table B-2 gives all fish species in the GOM OCS identified by the NMFS Office of Protected Resources as endangered, threatened, or species of concern. The GMFMC has designated EFH for 46 species of fish and invertebrates in the GOM 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 GOM, 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 GOM regions are provided in GMFMC (1998) and the EFH Mapper.

## Supplemental Tables

Appendix Table B–4 lists the common and scientific names of fish and invertebrate species that are cited in this Synthesis.

**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* | Grouper, yellowfin | *Epinephelus cyanopodus* |
| AmberJack | *Seriola* spp. | Groupers | *Serranidae* spp. |
| AmberJack, greater | *Seriola dumerili* | Haddock | *Melanogrammus aeglefinus* |
| AmberJack, lesser | *Seriola fasciata* | Hagfish | *Myxine glutinosa* |
| Bass, striped | *Morone saxatilis* | Hake, Atlantic, red/white | *Urophycis* spp. |
| Bluefish | *Pomatomus saltatrix* | Hake, offshore silver | *Merluccius albidus* |
| Butterfish | *Peprilus triacanthus* | Hake, red | *Urophycis chuss* |
| Clam, arc, blood | *Anadara olivaris* | Hake, silver | *Merluccius bilinearis* |
| Clam, Atlantic Jackknife | *Ensis directus* | Hake, white | *Urophycis tenuis* |
| Clam, Atlantic surf | *Spisula solidissima* | Halibut, Atlantic | *Hippoglossus hippoglossus* |
| Clam, northern quahog | *Mercenaria mercenaria* | Herring, Atlantic | *Clupea harengus* |
| Clam, ocean quahog | *Arctica islandica* | Herring, Atlantic thread | *Opisthonema oglinum* |
| Clam, quahog | *Mercenaria campechiensis* | Herring, blueback | *Alosa aestivalis* |
| Clam, softshell | *Mya arenaria* | Herrings | *Clupea* spp. |
| Clams or bivalves | *Bivalvia* spp. | Hind, red | *Epinephelus guttatus* |
| Cobia | *Rachycentron canadum* | Hind, rock | *Epinephelus adscensionis* |
| Cod, Atlantic | *Gadus morhua* | Hogfish | *Lachnolaimus maximus* |
| Crab, Atlantic horseshoe | *Limulus polyphemus* | Tilefish, blueline | *Caulolatilus microps* |
| Crab, Atlantic rock | *Cancer irroratus* | Lobster, American | *Homarus americanus* |
| Crab, blue | *Callinectes sapidus* | Lobster, Caribbean spiny | *Panulirus argus* |
| Crab, florida stone | *Menippe mercenaria* | Lobster, slipper | *Scyllarides aequinoctialis* |
| Crab, golden deepsea | *Chaceon fenneri* | Mackerel, Atlantic | *Scomber scombrus* |
| Crab, green | *Carcinus maenas* | Mackerel, chub | *Scomber colias* |
| Crab, jonah | *Cancer borealis* | Mackerel, king | *Scomberomorus cavalla* |
| Crab, spider | *Libinia emarginata* | Mackerel, king and cero | *Scomberomorus* spp. |
| Crabs | *Cancer* spp. | Mackerel, Spanish | *Scomberomorus maculatus* |
| Croaker, Atlantic | *Micropogonias undulatus* | Mako, shortfin | *Isurus oxyrinchus* |
| Dogfish, smooth | *Mustelis canis* | Menhaden | *Brevoortia tyrannus* |
| Dogfish, spiny | *Squalus acanthias* | Mullet, striped (liza) | *Mugil cephalus* |
| Dolphinfish | *Coryphaena hippurus* | Mullet, white | *Mugil curema* |
| Drum, black | *Pogonias cromis* | Mullets | *Mugil* spp. |
| Drum, freshwater | *Aplodinotus grunniens* | Oyster, eastern | *Crassostrea virginica* |
| Drum, red | *Sciaenops ocellatus* | Oyster, European flat | *Ostrea edulis* |
| Eel, American | *Anguilla rostrata* | Pollock | *Pollachius virens* |
| Flounder, fourspot | *Paralichthys oblongus* | Pompano, African | *Alectis ciliaris* |
| Flounder, southern | *Paralichthys lethostigma* | Pompano, Florida | *Trachinotus carolinus* |
| Flounder, summer | *Paralichthys dentatus* | Porgy, jolthead | *Calamus bajonado* |
| Flounder, windowpane | *Scophthalmus aquosus* | Porgy, knobbed | *Calamus nodosus* |
| Flounder, winter | *Pseudopleuronectes americanus* | Porgy, red | *Pagrus pagrus* |
| Flounder, witch | *Glyptocephalus cynoglossus* | Pout, ocean | *Zoarces americanus* |
| Flounder, yellowtail | *Limanda ferruginea* | Redfish, Acadian | *Sebastes fasciatus* |
| Flounder,American plaice | *Hippoglossoides platessoides* | Salmon, Atlantic | *Salmo salar* |
| Gag | *Mycteroperca microlepis* | Scallop, bay | *Argopecten irradians* |
| Goosefish (monkfish) | *Lophius americanus* | Scallop, sea | *Placopecten magellanicus* |

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Scamp | *Mycteroperca phenax* | Shrimp, royal red | *Pleoticus robustus* |
| Scup | *Stenotomus chrysops* | Shrimp, white | *Litopenaeus setiferus* |
| Scups or porgies | Sparidae spp. | Skate, barndoor | *Dipturus laevis* |
| Sea bass, black | *Centropristis striata* | Skate, little | *Leucoraja erinacea* |
| Sea bass, rock | *Centropristis philadelphica* | Snapper, blackfin | *Lutjanus buccanella* |
| Seatrout, sand | *Cynoscion arenarius* | Snapper, cubera | *Lutjanus cyanopterus* |
| Seatrout, spotted | *Cynoscion nebulosus* | Snapper, gray | *Lutjanus griseus* |
| Shad, American | *Alosa sapidissima* | Snapper, lane | *Lutjanus synagris* |
| Shad, gizzard | *Dorosoma cepedianum* | Snapper, mutton | *Lutjanus analis* |
| Shad, hickory | *Alosa mediocris* | Snapper, red | *Lutjanus campechanus* |
| Shark, Atlantic sharpnose | *Rhizoprionodon terraenovae* | Snapper, silk | *Lutjanus vivanus* |
| Shark, blacknose | *Carcharhinus acronotus* | Snapper, vermilion | *Rhomboplites aurorubens* |
| Shark, blacktip | *Carcharhinus limbatus* | Snapper, yellowtail | *Ocyurus chrysurus* |
| Shark, blue | *Prionace glauca* | Snappers | *Lutjaninae* spp. |
| Shark, bonnethead | *Sphyrna tiburo* | Spot | *Leiostomus xanthurus* |
| Shark, bull | *Carcharhinus leucas* | Squid, longfin | *Loligo pealei* |
| Shark, common thresher | *Alopias vulpinus* | Squid, northern shortfin | *Ilex Illex illecebrosus* |
| Shark, dusky | *Carcharhinus obscurus* | Squids | Squid spp. |
| Shark, finetooth | *Carcharhinus isodon* | Swordfish | *Xiphias gladius* |
| Shark, great hammerhead | *Sphyrna mokarran* | Tautog | *Tautoga onitis* |
| Shark, lemon | *Negaprion brevirostris* | Tilefish, golden | *Lopholatilus chamaeleonticeps* |
| Shark, makos | *Isurus* spp. | Tilefish, sand | *Malacanthus plumieri* |
| Shark, porbeagle | *Lamna nasus* | Tilefishes | *Malacanthidae spp.* |
| Shark, sand tiger | *Odontaspis taurus* | Triggerfish, gray | *Balistes capriscus* |
| Shark, sandbar | *Carcharhinus plumbeus* | Tuna, albacore | *Thunnus alalunga* |
| Shark, scalloped hammerhead | *Sphyrna lewini* | Tuna, bigeye | *Thunnus obesus* |
| Shark, silky | *Carcharhinus falciformis* | Tuna, blackfin | *Thunnus atlanticus* |
| Shark, smooth hammerhead | *Sphyrna zygaena* | Tuna, bluefin | *Thunnus thynnus* |
| Shark, spinner | *Carcharhinus brevipinna* | Tuna, skipJack | *Katsuwonus pelamis* |
| Shark, tiger | *Galeocerdo cuvier* | Tuna, yellowfin | *Thunnus albacares* |
| Sharks | *Chrondrichthys* | Tunas | *Thunnus* spp. |
| Shrimp, brown | *Farfantepenaeus aztecus* | Tunny, little | *Euthynnus alletteratus* |
| Shrimp, dendrobranchiata | *Dendrobranchiata* spp. | Wahoo | *Acanthocybium solandri* |
| Shrimp, marine, other | Caridea | Weakfish | *Cynoscion regalis* |
| Shrimp, pink | *Farfantepenaeus duorarum* | Wolffish, Atlantic | *Anarhichas lupus* |
| Shrimp, rock | *Sicyorzia brevirostris* | | |

**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 |
| 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*<br>*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 |

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

| Common Name | Scientific Name | Range | Status; Date listed |
|---|---|---|---|
| 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 sanctaeluciae* | 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. | Jack, Crevalle | *Caranx hippos* |
| AmberJack, greater | *Seriola dumerili* | Jack, Horse-eye | *Caranx latus* |
| AmberJack, lesser | *Seriola fasciata* | King Whiting | *Menticirrhus americanus* |
| Ballyhoo | *Hemiramphus brasiliensis* | Ladyfish | *Elops saurus* |
| Barracudas | *Sphyraena spp.* | Leather Jacket | *Oligoplites saurus* |
| Barrelfish | *Hyperoglyphe perciformis* | Lionfish | *Pterois volitans* |
| Bass, Longtail | *Hemanthias leptus* | Lobster, Caribbean spiny | *Panulirus argus* |
| Black Driftfish | *Hyperoglyphe bythites* | Lobster, slipper | *Scyllarides aequinoctialis* |
| Bluefish | *Pomatomus saltatrix* | Lookdown | *Selene vomer* |
| Bonito, Atlantic | *Sarda sarda* | Mackerel, chub | *Scomber colias* |
| Brotula, Bearded | *Brotula barbata* | Mackerel, king | *Scomberomorus cavalla* |
| Butterfish | *Peprilus burti* | Mackerel, king and cero | *Scomberomorus* spp. |
| Clam, southern quahog | *Mercenaria campechiensis* | Mackerel, Spanish | *Scomberomorus maculatus* |
| Cobia | *Rachycentron canadum* | Mantis shrimps | Stomatopoda |
| Crab, blue | *Callinectes sapidus* | Margate | *Diabasis aurolineatus* |
| Crab, florida stone | *Menippe mercenaria* | Menhaden | *Brevoortia spp.* |
| Crabs | *Cancer* spp. | Mojarras | *Eucinostomus spp.* |
| Croaker, Atlantic | *Micropogonias undulatus* | Mullet, striped (liza) | *Mugil cephalus* |
| Cusk | *Brosme brosme* | Mullet, white | *Mugil curema* |
| Atlantic Cutlassfish | *Trichiurus lepturus* | Mullets | *Mugil* spp. |
| Dolphinfish | *Coryphaena hippurus* | Octopus | Octopoda |
| Drum, black | *Pogonias cromis* | Oilfish | *Ruvettus pretiosus* |
| Drum, freshwater | *Aplodinotus grunniens* | Opah | *Lampris guttatus* |
| Drum, red | *Sciaenops ocellatus* | Oyster, Eastern | *Crassostrea virginica* |
| Escolar | *Lepidocybium flavobrunneum* | Parrotfishes | Scaridae |
| Flounder, southern | *Paralichthys lethostigma* | Permit | *Trachinotus falcatus* |
| Flounder, summer | *Paralichthys dentatus* | Pigfish | *Orthopristis chrysoptera* |
| Flyingfishes | Exocoetidae | Pinfish | *Lagodon rhomboides* |
| Gag | *Mycteroperca microlepis* | Pomfrets | *Brama spp.* |
| Graysby | *Cephalopholis cruentata* | Pompano, African | *Alectis ciliaris* |
| Grouper, black | *Mycteroperca bonaci* | Pompano, Florida | *Trachinotus carolinus* |
| Grouper, Marbled | *Dermatolepis inermis* | Porgy, jolthead | *Calamus bajonado* |
| Grouper, Misty | *Epinephelus mystacinus* | Porgy, knobbed | *Calamus nodosus* |
| Grouper, red | *Epinephelus morio* | Porgy, Longspine | *Stenotomus caprinus* |
| Grouper, snowy | *Hypothodus niveatus* | Porgy, red | *Pagrus pagrus* |
| Grouper, yellowedge | *Hyporthodus flavolimbatus* | Puffers | *Sphoeroides spp.* |
| Grouper, yellowfin | *Epinephelus cyanopodus* | Ray,Stingrays | *Dasyatis spp.* |
| Grouper, red | *Epinephelus morio* | Rays | Myliobatiformes |
| Grunts | *Haemulon spp.* | Rosefish, Blackbelly | *Helicolenus dactylopterus* |
| Hake, Atlantic, red/white | *Urophycis* spp. | Rudderfish, Banded | *Seriola zonata* |
| Herring, Atlantic thread | *Opisthonema oglinum* | Runner, Blue | *Caranx crysos* |
| Herrings | *Clupea* spp. | Sand Perch | *Diplectrum formosum* |
| Hind, red | *Epinephelus guttatus* | Sardine, Spanish | *Sardinella aurita* |
| Hind, rock | *Epinephelus adscensionis* | Scad, Bigeye | *Selar crumenophthalmus* |
| Hind, Speckled | *Epinephelu drummondhayi* | Scads | *Decapterus spp.* |
| Hogfish | *Lachnolaimus maximus* | Scamp | *Mycteroperca phenax* |
| Jack, Almaco | *Seriola rivoliana* | Scorpionfish, Spinycheek | *Neomerinthe hemingwayi* |
| Jack, Bar | *Caranx ruber* | Scups or porgies | *Sparidae spp.* |

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| Sea bass, black | *Centropristis striata* | Snapper, gray | *Lutjanus griseus* |
| Sea bass, rock | *Centropristis philadelphica* | Snapper, lane | *Lutjanus synagris* |
| Sea Catfishes | Ariidae | Snapper, mutton | *Lutjanus analis* |
| Seatrout, sand | *Cynoscion arenarius* | Snapper, vermilion | *Rhomboplites aurorubens* |
| Seatrout, spotted | *Cynoscion nebulosus* | Snapper, yellowtail | *Ocyurus chrysurus* |
| Shad, gizzard | *Dorosoma cepedianum* | Snappers | *Lutjaninae* spp. |
| Shark, Atlantic sharpnose | *Rhizoprionodon terraenovae* | Spadefishes | *Chaetodipterus faber* |
| Shark, blacknose | *Carcharhinus acronotus* | Sponges | Porifera |
| Shark, blacktip | *Carcharhinus limbatus* | Spot | *Leiostomus xanthurus* |
| Shark, bull | *Carcharhinus leucas* | Squids | Squid spp. |
| Shark, Hammerhead | *Sphyrna spp.* | Squirrelfishes | Holocentridae |
| Shark, lemon | *Negaprion brevirostris* | Swordfish | *Xiphias gladius* |
| Shark, sandbar | *Carcharhinus plumbeus* | Tilefishes | *Malacanthidae spp.* |
| Shark, Shortfin Mako | *Isurus oxyrinchus* | Tilefish, Blueline | *Caulolatilus microps* |
| Shark, silky | *Carcharhinus falciformis* | Tilefish, golden | *Lopholatilus chamaeleonticeps* |
| Shark, spinner | *Carcharhinus brevipinna* | Tilefish, Goldface | *Caulolatilus chrysops* |
| Shark, tiger | *Galeocerdo cuvier* | Tilefish, sand | *Malacanthus plumieri* |
| Sharks | *Chrondrichthys* | Triggerfish, gray | *Balistes capriscus* |
| Sheepshead | *Archosargus probatocephalus* | Tripletail | *Lobotes surinamensis* |
| Shrimp, brown | *Farfantepenaeus aztecus* | Tuna, albacore | *Thunnus alalunga* |
| Shrimp, dendrobranchiata | *Dendrobranchiata spp.* | Tuna, bigeye | *Thunnus obesus* |
| Shrimp, pink | *Farfantepenaeus duorarum* | Tuna, blackfin | *Thunnus atlanticus* |
| Shrimp, rock | *Sicyorzia brevirostris* | Tuna, bluefin | *Thunnus thynnus* |
| Shrimp, royal red | *Hymenopenaeus robustus* | Tuna, Little Tunny | *Euthynnus alletteratus* |
| Shrimp, seabob | *Xiphopenaeus kroyeri* | Tuna, skipJack | *Katsuwonus pelamis* |
| Shrimp, white | *Litopenaeus setiferus* | Tuna, yellowfin | *Thunnus albacares* |
| Snapper, Black | *Apsilus dentatus* | Wahoo | *Acanthocybium solandri* |
| Snapper, blackfin | *Lutjanus buccanella* | Weakfish | *Cynoscion regalis* |
| Snapper, cubera | *Lutjanus cyanopterus* | Wenchman | *Pristipomoides aquilonaris* |
| Snapper, dog | *Lutjanus jocu* | Wreckfish | *Polyprion americanus* |

**Appendix Table B-4. Common and scientific names of fish and invertebrate species that are discussed in Section 4.0 of this Synthesis.**

**Fish Species**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| agujon | *Tylosurus acus* | band cusk-eel | *Ophidion holbrookii* |
| alewife | *Alosa pseudoharengus* | banded drum | *Larimus fasciatus* |
| American harvestfish, harvestfish | *Peprilus paru* | banded rudderfish | *Seriola zonata* |
| american sailfin eel | *Letharchus velifer* | bandtail puffer | *Sphoeroides spengleri* |
| American shad | *Alosa sapidissima* | bandtail searobin | *Prionotus ophryas* |
| Atlantic albacore tuna | *Thunnus alalunga* | bank sea bass | *Centropristis ocyurus* |
| Atlantic angel shark | *Squatina dumeril* | bar jack | *Caranx ruber* |
| Atlantic bigeye tuna | *Thunnus obesus* | barbfish | *Scorpaena brasiliensis* |
| Atlantic bluefin tuna | *Thunnus thynnus* | barndoor skate | *Dipturus laevis* |
| Atlantic bonito | *Sarda sarda* | basking shark | *Cetorhinus maximus* |
| Atlantic bumper | *Chloroscombrus chrysurus* | bay anchovy | *Anchoa mitchilli* |
| Atlantic cod | *Gadus morhua* | bay whiff | *Citharichthys spilopterus* |
| Atlantic croaker | *Micropogonias undulatus* | bearded brotula | *Brotula barbata* |
| Atlantic cutlassfish | *Trichiurus lepturus* | belted sandfish | *Serranus subligarius* |
| Atlantic guitarfish | *Rhinobatos lentiginosus* | bigeye anchovy | *Anchoa lamprotaenia* |
| Atlantic herring | *Clupea harengus* | bigeye scad | *Selar crumenopthalmus* |
| Atlantic mackerel | *Scomber scombrus* | bigeye searobin | *Prionotus longispinosus* |
| Atlantic menhaden | *Brevoortia tyrannus* | bighead searobin | *Prionotus tribulus* |
| Atlantic midshipman | *Porichthys plectrodon* | bignose shark | *Carcharhinus altimus* |
| Atlantic moonfish | *Selene setapinnis* | black drum | *Pogonias cromis* |
| Atlantic sharpnose shark | *Rhizoprinodon terraenovae* | black sea bass | *Centropristis striatus* |
| Atlantic silverside | *Menidia menidia* | blackbear sea bass | *Serranus atrobranchus* |
| Atlantic skipjack tuna | *Katsuwonus pelamis* | blackcheek tonguefish | *Symphurus plagiusa* |
| Atlantic spadefish | *Chaetodipterus faber* | blackedge cusk-eel | *Lepophidium pheromystax* |
| Atlantic sturgeon | *Acipenser oxyrhynchus* | blacknose shark | *Carcharhinus acronotus* |
| Atlantic thread herring | *Opisthonema oglinum* | blacktip shark | *Carcharhinus limbatus* |
| Atlantic yellowfin tuna | *Thunnus albacres* | blackwing searobin | *Prionotus rubio* |
| balao | *Hemiramphus balao* | blotched cusk-eel | *Ophidion grayi* |
| balloonfish | *Diodon holacanthus* | blue goby | *Ioglossus calliurus* |
| ballyhoo | *Hemiramphus basiliensis* | blue marlin | *Makaira nigricans* |

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| blue runner | *Caranx crysos* | duckbill flathead | *Bembrops anatirostris* |
| blue shark | *Prionace glauca* | dusky anchovy | *Anchoa lyolepis* |
| blueback herring | *Alosa aestivalis* | dusky carinalfish | *Phaeoptyx pigmentaria* |
| bluefish | *Pomatomus saltatrix* | dusky flounder | *Syacium papillosum* |
| bluespotted cornetfish | *Fistularia tabacaria* | dusky shark | *Carcharhinus obscurus* |
| bluespotted searobin | *Prionotus roseus* | dwarf goatfish | *Upeneus parvus* |
| blunthead puffer | *Sphoeroides pachygaster* | dwarf herring | *Jenkinsia lamprotaenia* |
| bluntnose jack | *Hemicaranx amblyrhynchus* | dwarf sand perch | *Diplectrum bivittatum* |
| bluntnose stingray | *Dasyatis say* | emerald parrotfish | *Nicholsina usta* |
| bonnethead shark | *Sphyrna tiburo* | eyed flounder | *Bothus ocellatus* |
| bridled burrfish | *Chilomycterus antennatus* | false pilchard | *Harengula clupeola* |
| broad flounder | *Paralichthys squamilentus* | feather blenny | *Hypsoblennius hentz* |
| bull pipefish | *Syngnathus springeri* | finetooth shark | *Carcharhinus isodon* |
| bull shark | *Carcharhinus leucas* | flat anchovy | *Anchoviella perfasciata* |
| bullnose ray | *Myliobatis freminvillei* | flat needlefish | *Ablennes hians* |
| butterfish | *Peprilus triacanthus* | Florida pompano | *Trachinotus carolinus* |
| Caribbean reef shark | *Carcharhinus perezi* | Florida smoothhound | *Mustelus norrisi* |
| cero | *Scomberomorus regalis* | flying halfbeak | *Euleptorhamphus velox* |
| chain pipefish | *Syngnathus louisianae* | fourbeard rockling | *Enchelyopus cimbrius* |
| channel flounder | *Syacium micrurum* | fourspine stickleback | *Apeltes quadracus* |
| checkered puffer | *Sphoeroides testudineus* | fourspot flounder | *Paralichthys oblongus* |
| clearnose skate | *Raja eglanteria* | freckled pike-conger | *Hoplunnis macrurus* |
| cobia | *Rachycentron canadum* | freckled stargazer | *Gnatholepis egregius* |
| conger eel | *Conger oceanicus* | freckled tonguefish | *Symphurus nebulosus* |
| cottonmouth jack | *Uraspis secunda* | fringed filefish | *Monacanthus ciliatus* |
| cownose ray | *Rhinoptera bonasus* | fringed flounder | *Etropus crossotus* |
| crested cusk-eel | *Ophidion welshi* | fringed sole | *Gymnachirus texae* |
| crevalle jack | *Caranx hippos* | gafftopsail catfish | *Bagre marinus* |
| cuban anchovy | *Anchoa cubana* | gag | *Mycteroperca microlepis* |
| cubbyu | *Pareques umbrosus* | goby flathead | *Bembrops gobioides* |
| cunner | *Tautolabrus adspersus* | goosefish | *Lophius americanus* |
| deepwater flounder | *Monolene sessilicauda* | gray flounder | *Etropus rimosus* |
| devil ray | *Mobula hypostoma* | gray flounder | *Etropus rimosus* |
| dolphin | *Coryphaena hippurus* | gray snapper | *Lutjanus griseus* |
| dotterel filefish | *Aluterus heudeloti* | gray triggerfish | *Balistes capriscus* |

| **Common Name** | **Scientific Name** | **Common Name** | **Scientific Name** |
|---|---|---|---|
| great hammerhead shark | *Sphyrna mokarran* | ladyfish | *Elops saurus* |
| grubby | *Myoxocephalus aenaeus* | lancer stargazer | *Kathetostoma albigutta* |
| grunt (juvenile) | *Haemulon spp.* | lane snapper | *Lutjanus synagris* |
| Gulf butterfish | *Peprilus burti* | largescale lizardfish | *Saurida brasiliensis* |
| Gulf flounder | *Paralichthys albigutta* | largescale tonguefish | *Symphurus minor* |
| Gulf kingfish | *Menticirrhus littoralis* | least puffer | *Sphoeroides parvus* |
| Gulf of Mexico barred searobin, barred searobin | *Prionotus martis* | leather jacket | *Oligoplites saurus* |
| Gulf of Mexico ocellated flounder, ocellated flounder | *Ancylopsetta ommata* | lemon shark | *Negaprion brevirostris* |
| Gulf Stream flounder | *Citharichthys arctifrons* | leopard searobin | *Prionotus scitulus* |
| haddock | *Melanogrammus aeglefinus* | lined seahorse | *Hippocampus erectus* |
| halfbeak | *Hyporhamphus meeki* | lined sole | *Achirus lineatus* |
| hardhead catfish | *Arius felis* | little skate | *Raja erinacea* |
| hickory shad | *Alosa mediocris* | little tunny | *Euthynnus alletteratus* |
| highfin scorpionfish | *Pontinus rathbuni* | little-eye round herring | *Jenkinsia majua* |
| high-hat | *Pareques acuminatus* | littlehead porgy | *Calamus proridens* |
| hogchoker | *Trinectes maculatus* | longbill spearfish | *Tetrapturus pfluegeri* |
| honeycomb cowfish | *Acanthostracion polygonius* | longhorn sculpin | *Myoxocephalus octodecemspinosus* |
| honeycomb cowfish | *Lactophrys polygonia* | longnose batfish | *Ogcocephalus corniger* |
| honeycomb moray | *Gymnothorax saxicola* | longnose cusk-eel | *Ophidion antipholus* |
| horned searobin | *Bellator militaris* | longspine porgy | *Stenotomus caprinus* |
| horned whiff | *Citharichthys cornutus* | longspine scorpionfish | *Pontinus longispinis* |
| horse-eye jack | *Caranx latus* | mackeral scad | *Decapterus macarellus* |
| houndfish | *Tylosurus crocodilus* | marbled puffer | *Sphoeroides dorsalis* |
| inland silverside | *Menidia beryllina* | margintail conger | *Paraconger caudilimbatus* |
| inquiline snailfish | *Liparis inquilinus* | Mexican flounder | *Cyclopsetta chittendeni* |
| inshore lizardfish | *Synodus foetens* | mojarra | *Gerreidae* |
| jack-knifefish | *Equetus lanceolatus* | mooneye cusk-eel | *Ophidion selenops* |
| keeltail needlefish | *Platybelone argalus* | naked goby | *Gobiosoma bosc* |
| key worm eel | *Ahlia egmontis* | naked sole | *Gymnachirus melas* |
| king mackerel | *Scomberomorus cavalla* | night shark | *Carcharhinus signatus* |

| **Common Name** | **Scientific Name** | **Common Name** | **Scientific Name** |
|---|---|---|---|
| northern kingfish | *Menticirrhus saxatilis* | pygmy sea bass | *Serraniculus pumilio* |
| northern pipefish | *Syngnathus fuscus* | pygmy tonguefish | *Symphurus parvus* |
| northern puffer | *Sphoeroides maculatus* | queen triggerfish | *Balistes vetula* |
| northern searobin | *Prionotus carolinus* | rainbow runner | *Elagatis bipinnulatus* |
| northern sennet | *Sphyraena borealis* | red drum | *Sciaenops ocellata* |
| northern stargazer | *Astroscopus guttatus* | red grouper | *Epinephelus morio* |
| nurse shark | *Ginglymostoma cirratum* | red hake | *Urophycis chuss* |
| ocean pout | *Zoarces americanus* | red snapper | *Lutjanus campechanus* |
| ocean triggerfish | *Canthidermis sufflamen* | redear sardine | *Harengula humeralis* |
| ocean sunfish | *Mola mola* | redtail scad | *Decapterus kurroides* |
| offshore lizardfish | *Synodus poeyi* | ribbon halfbeak | *Euleptorhamphus viridis* |
| offshore tonguefish | *Symphurus civitatus* | rock gunnel | *Pholis gunnellus* |
| orange filefish | *Aluterus schoepfi* | rock sea bass | *Centropristis philadelphica* |
| orangebelly goby | *Varicus marilynae* | rosette skate | *Raja garmani* |
| orangespotted filefish | *Cantherhines pullus* | rough scad | *Trachurus lathami* |
| orangespotted goby | *Nes longus* | rough triggerfish | *Canthidermis maculatus* |
| oyster toadfish | *Opsanus tau* | roughback batfish | *Ogcocephalus parvus* |
| palometa | *Trachinotus goodei* | roughtail stingray | *Dasyatis centroura* |
| pancake batfish | *Halieutichthys aculeatus* | round herring | *Etrumeus teres* |
| permit | *Trachinotus falcatus* | round scad | *Decapterus punctatus* |
| pigfish | *Orthopristis chrysoptera* | roundel skate | *Raja texana* |
| pinfish | *Lagodon rhomboides* | sailfish | *Istiophorus platypterus* |
| planehead filefish | *Monacanthus hispidus* | sand lance species | *Ammodytes spp.* |
| planehead filefish | *Stephanolepis hispidus* | sand perch | *Diplectrum formosum* |
| plumed scorpionfish | *Scorpaena grandicornis* | sand seatrout | *Cynoscion arenarius* |
| pollock | *Pollachius virens* | sand stargazer | *Dactyloscopus tridigitatus* |
| porcupinefish | *Diodon histrix* | sand tiger shark | *Odontaspis taurus* |
| porcupinefish | *Diodon spp.* | sand whiff | *Citharichthys arenaceus* |
| porgy (juvenile) | *Calamus spp.* | sandbar shark | *Carcharhinus plumbeus* |
| pygmy filefish | *Monacanthus setifer* | sargassum triggerfish | *Xanthichthys ringens* |

| **Common Name** | **Scientific Name** | **Common Name** | **Scientific Name** |
|---|---|---|---|
| sash flounder | *Trichopsetta ventralis* | silver hake | *Merluccius bilinearis* |
| scad | *Decapterus spp.* | silver jenny | *Eucinostomus gula* |
| scaled sardine | *Harengula jaguana* | silver perch | *Bairdiella chrysoura* |
| scalloped hammerhead shark | *Sphyrna lewini* | silver seatrout | *Cynoscion nothus* |
| scawled cowfish | *Acanthostracion quadricornis* | silverstripe halfbeak | *Hyporhamphus unifasciatus* |
| scrawled cowfish | *Lactophrys quadricornis* | singlespot frogfish | *Antennarius radiosus* |
| scrawled filefish | *Aluterus scriptus* | slantbrow batfish | *Ogcocephalus declivirostris* |
| scup | *Stenotomus chrysops* | slender filefish | *Monacanthus tuckeri* |
| sea raven | *Hemitripterus americanus* | slim flounder | *Monolene antillarum* |
| seaboard goby | *Gobiosoma ginsburgi* | smallmouth flounder | *Etropus microstomus* |
| seaweed blenny | *Parablennius marmoreus* | smallmouth flounder | *Etropus microstomus* |
| Seminole goby | *Microgobius carri* | smalltooth sawfish | *Pristis pectinata* |
| sergeant major | *Abudefduf saxatilis* | smooth butterfly ray | *Gymnura micrura* |
| sharpnose puffer | *Canthigaster rostrata* | smooth dogfish | *Mustelus canis* |
| sharptail goby | *Gobionellus hastatus* | smooth puffer | *Lagocephalus laevigatus* |
| sharptail sunfish | *Mola lanceolata* | smooth trunkfish | *Lactophrys triqueter* |
| sheepshead | *Archosargus probatocephalus* | smoothead scorpionfish | *Scorpaena calcarata* |
| shelf flounder | *Etropus cyclosquamus* | snakeblenny | *Lumpenus lampretaeformis* |
| shelf flounder | *Etropus cyclosquamus* | snakefish | *Trachinocephalus myops* |
| shoal flounder | *Syacium gunteri* | southern flounder | *Paralichthys lethostigma* |
| short bigeye | *Pristigenys alta* | southern hake | *Urophycis floridana* |
| shortbeard cusk-eel | *Lepophidium brevibarbe* | southern kingfish | *Menticirrhus americanus* |
| shortfin mako shark | *Isurus oxyrinchus* | southern puffer | *Sphoeroides nephelus* |
| shortfin searobin | *Bellator brachychir* | southern sennet | *Sphreaena picudilla* |
| shortnose batfish | *Ogcocephalus nasutus* | southern stargazer | *Astroscopus y-graecum* |
| shortwing searobin | *Prionotus stearnsi* | southern stingray | *Dasyatis americana* |
| shrimp eel | *Ophichthus gomesii* | Spanish mackerel | *Scomberomorus maculatus* |
| shrimp flounder | *Gastropsetta frontalis* | Spanish sardine | *Sardinella aurita* |
| silky shark | *Carcharhinus falciformis* | spinner shark | *Carcharhinus brevipinna* |
| silver anchovy | *Engraulis eurystole* | spiny butterfly ray | *Gymnura altavela* |

| **Common Name** | **Scientific Name** | **Common Name** | **Scientific Name** |
|---|---|---|---|
| spiny dogfish | *Squalus acanthias* | thresher shark | *Alopias vulpinus* |
| spiny flounder | *Engyophrys senta* | tidewater mojarra | *Eucinostomus harengulus* |
| spiny searobin | *Prionotus alatus* | tiger shark | *Galeocerdo cuvieri* |
| spot | *Leiostomus xanthurus* | tilefish | *Lopholatilus chamaeleonticeps* |
| spotfin flounder | *Cyclopsetta fimbriata* | timucu | *Strongylura timucu* |
| spotfin goby | *Oxyurichthys stigmalophius* | tomtate | *Haemulon aurolineatum* |
| spottail tonguefish | *Symphurus urospilus* | trunkfish | *Lactophrys trigonus* |
| spotted batfish | *Ogcocephalus pantostictus* | twospot flounder, Robins flounder | *Bothus robinsi* |
| spotted burrfish | *Chilomycterus atinga* | unicorn filefish | *Aluterus monoceros* |
| spotted burrfish | *Chilomycterus atinga* | unicorn whiff | *Citharichthys gymnorhinus* |
| spotted goatfish | *Pseudupeneus maculatus* | wahoo | *Acanthocybium solanderi* |
| spotted hake | *Urophycis regia* | weakfish | *Cynoscion regalis* |
| spotted whiff | *Citharichthys macrops* | whale shark | *Rhincodon typus* |
| spottedfin tonguefish | *Symphurus diomedianus* | white bass | *Morone americana* |
| star drum | *Stellifer lanceolatus* | white grunt | *Haemulon plumierii* |
| stellate codlet | *Bregmaceros houdei* | white hake | *Urophycis tenuis* |
| streamer searobin | *Bellator egreta* | white marlin | *Tetrapturus albidus* |
| striped anchovy | *Anchoa hepsetus* | white mullet | *Mugil curema* |
| striped bass | *Morone saxatilis* | white shark | *Carcharodon carcharias* |
| striped burrfish | *Chilomycterus schoepfi* | whitespotted filefish | *Cantherhines macrocerus* |
| striped burrfish | *Chilomycterus schoepfi* | whitespotted soapfish | *Rypticus maculatus* |
| striped cusk-eel | *Ophidion marginatum* | windowpane | *Scophthalmus aquosos* |
| striped searobin | *Prionotus evolans* | winter flounder | *Pseudopleuronectes americanus* |
| stripedfin flounder | *Poecilopsetta beani* | winter skate | *Leucoraja ocellata* |
| summer flounder | *Paralichthys dentatus* | witch flounder | *Glyptocephalus cynoglossus* |
| swordfish | *Xiphias gladius* | wormfish | *Microdesmidae* |
| tarpon | *Tarpon atlanticus* | yellow conger | *Hildebrandia flava* |
| tattler | *Serranus phoebe* | yellow jack | *Caranx bartholomaei* |
| tautog | *Tautoga onitis* | yellowfin menhaden | *Brevoortia smithi* |
| three-eye flounder | *Ancylopsetta dilecta* | yellowtail flounder | *Limanda ferruginea* |
| threespine stickleback | *Gasterosteus aculeatus* | | |

**Invertebrate Species**

| Common Name | Scientific Name | Common Name | Scientific Name |
|---|---|---|---|
| American lobster | *Homarus americanus* | ocean quahog | *Arctica islandica* |
| Atlantic rock crab | *Cancer irroratus* | pink shrimp | *Farfantepenaeus duorarum* |
| Atlantic surfclam | *Spisula solidissima* | royal red shrimp | *Pleoticus robustus* |
| blue crab | *Callinectes sapidus* | sea scallop | *Placopecten magellanicus* |
| brown shrimp | *Farfantepenaeus aztecus* | short-finned squid | *Illix illecebrosus* |
| Florida stone crab | *Menippe mercenaria* | slipper lobster | *Scyllarides nodif* |
| Gulf stone crab | *Menippe adina* | spiny lobster | *Panulirus argus* |
| hard clam | *Mercenaria mercenaria* | surf clam | *Spisula solidissima* |
| horseshoe crab | *Limulus polyphemus* | white shrimp | *Litopenaeus setiferus* |
| long-finned squid | *Loligo pealei* | | |

**The Department of the Interior Mission**

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under US administration.

**The Bureau of Ocean Energy Management**

As a bureau of the Department of the Interior, the Bureau of Ocean Energy (BOEM) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS) in an environmentally sound and safe manner.

**The BOEM Environmental Studies Program**

The mission of the Environmental Studies Program (ESP) is to provide the information needed to predict, assess, and manage impacts from offshore energy and marine mineral exploration, development, and production activities on human, marine, and coastal environments.