OCS Study
BOEM 2016-003

NOAA Technical Memorandum NOS NCCOS 196

Benthic Habitat Mapping and Assessment in the Wilmington-East Wind Energy Call Area

Final Report

US Department of the Interior
Bureau of Ocean Energy Management
Office of Renewable Energy Programs

US Department of Commerce
National Oceanic and Atmospheric Administration
National Centers for Coastal Ocean Science

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Executive Summary

The Bureau of Ocean Energy Management (BOEM) is responsible for oversight and management of the development of energy resources on the Outer Continental Shelf (OCS). In 2012, BOEM identified three Wind Energy Call Areas and later defined Wind Energy Areas on the OCS of North Carolina. Presently, sufficient uncertainty exists regarding cumulative impacts to ecosystem services such as essential fish habitat and maritime cultural resources as a result of the construction or operation of offshore energy facilities to merit preliminary studies. From rocky outcrops to shipwrecks, hardbottom habitats serve as essential fish habitat for reef fisheries off of North Carolina and along the southeast OCS. This project accomplished the primary objective of describing and delineating rocky outcrops, within the Wilmington-East Call Area. The delineation of rocky outcrops and artificial hardbottom habitats guided an intensive diver visual assessment characterizing the benthic and fish communities, the seasonal changes in communities, and influences of sand and sediment movement around hardbottom habitats. This report is the result of a collaborative effort between the University of North Carolina Institute of Marine Sciences and NOAA's National Centers for Coastal Ocean Science, and the Bureau of Ocean Energy Management.

Key findings are:

Delineation of hardbottom habitats and shipwrecks

- We provide the first complete coverage by hydrographic sidescan and multibeam sonar of the Wilmington-East Call Area. These GIS products show a varied seafloor interpreted as sand shoals, pavement, rocky outcrops, ledges, and shipwrecks. The pattern of seafloor sediments is consistent with the geological framework of Long Bay and nearby Frying Pan Shoals.
- The distribution of rocky outcrops is clustered in patches in discrete regions of the study area. The distribution and clusters of notable outcrops appears to conform to areas of fishing uses previously identified by stakeholders.
- While clusters and isolated hardbottom features are present in the Wind Energy Area, large clusters of delineated rocky outcrops occur in the southern and eastern regions of the study area, outside of the Wilmington-East Wind Energy Area, which defines the OCS blocks that may be available for wind energy lease and development.
- Five shipwrecks have been confirmed with their position accuracy improved. Two potential new shipwrecks were found within the study area.

Benthic habitats and fish communities on hardbottom in the study area

- The community composition and physical structure formed by invertebrates and macroalgae in the study area are diverse and in some ways distinct from those seen in neighboring Onslow Bay.
- The fish community composition is similar to that seen in neighboring Onslow Bay.
- Complex, high relief hardbottom and the associated benthic communities support higher numbers of species and biomass of large apex predators, including species in the snapper-grouper management complex.

- Remotely sensed fish distributions using echosounders show patterns of high fish densities that conform spatially to the distribution of hardbottom habitats. During the day, the majority of fish were within 150 m of the hardbottom. At night, fish distribution extended as far as 1000 m from the hardbottom features.

Seasonal dynamics in sediment cover, benthic and fish communities

- Repeated surveys over natural and artificial hardbottom habitats characterized seasonal changes in the biological communities, particularly related to structural complexity and sediment dynamics.
- The benthic community in the study area, in Long Bay's highly dynamic sedimentary environment, experiences more frequent burial and abrasion by sediment than sites further north in Onslow Bay.
- Fish community metrics related to seafloor complexity revealed that reef fish use a wide range of hardbottom habitat types.

Shipwrecks are used much like hardbottom habitat supporting reef fish

- Shipwrecks provide substrate for a diverse assemblage of attached biological communities that support high diversity of reef fishes.
- The fish community composition differs between shipwrecks and natural reefs due to the presence of large aggregations of planktivorous fishes near shipwrecks.

This report follows decades of research on the importance of hardbottom habitats on the southern Atlantic OCS that support the ocean ecology and economies of North Carolina and other southeastern US coastal states. This study represents an important baseline condition of US south Atlantic benthic habitats offshore Wilmington, NC and of their value to fishes, in preparation for offshore development of wind energy facilities.

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Abbreviations and Acronyms

AIS	Automated Information System
ANOSIM	Analysis of Similarities
ANOVA	Analysis of Variance
AOI	Area of Interest
AWOIS	Automated Wreck and Obstruction Information System
BAG	Bathymetry Attributed Grid
BOEM	Bureau of Ocean Energy Management
CCA	Canonical Correspondence Analysis
CMECS	Coastal and Marine Ecological Classification Standard
CTD	Conductivity-Temperature-Density Rosette
D	Distance of the natural surface contour
DGPS	Differential Global Positioning System
DRR	Digital Reef Rugosity
EFH	Essential Fish Habitat
FMP	Fisheries Management Plan
GAM	Generalized Additive Models
GIS	Geographic Information Systems
GPS	Global Positioning System
H'	Shannon-Wiener Diversity
HB	Hardbottom
hrs	hours
HSM	High Speed Mode
IOCM	Integrated Ocean and Coastal Mapping
J	Pielou's measure of species evenness
LPI	Line Point Intercept
m	meter
MBES	Multibeam Echosounder
MDS	Multi-Dimensional Scaling
MOTSP	Military Ocean Terminal Sunny Point
NC	North Carolina
nMDS	Nonmetric multidimensional scaling
NMEA	National Marine Electronics Association
NMFS	National Marine Fisheries Service
nmi	nautical mile
NOAA	National Oceanic and Atmospheric Administration
^{o}C	degrees Celsius

OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OREP	Office of Renewable Energy Programs
OTF	On-the-fly
PC	Principal Component
PCA	Principal Component Analysis
PERMANOVA	Permutational Analysis of Variance
psi	pounds per square inch
RNA	Regulated Navigation Areas
S	Sand
s	Species richness
SAFMC	South Atlantic Fishery Management Council
SBES	Splitbean Echosounder System
SEAMAP-SA	Southeast Area Monitoring and Assessment Program – South Atlantic
SIMPER	Similarity Percentage Analysis
SSS	Sidescan Sonar
TL	Total Length
TPU	Total Predicted Uncertainty
TS	Target Strength
UNC-IMS	University of North Carolina Institute of Marine Sciences
USCG	United States Coast Guard
UTM	Universal Transverse Mercator
VRM	Vector Ruggedness Measure
WEA	Wind Energy Area
WECA	Wilmington-East Call Area
XBT	Expendable Bathythermograph Probe
ZDF	Zone Definition File

1. Introduction

The Bureau of Ocean Energy Management (BOEM) is responsible for oversight and management for the development of offshore energy resources on the Outer Continental Shelf (OCS). A large proportion of the Atlantic OCS blocks deemed likely suitable for wind energy development is located offshore of North Carolina. Prior to making OCS blocks available for lease, BOEM must satisfy criteria of the Outer Continental Shelf Lands Act, of which Section 20 mandates the conduct of environmental and socioeconomic studies needed for the assessment and management of environmental impacts on the human, marine, and coastal environments that may be affected by development.

As part of the marine spatial planning process for offshore wind energy, BOEM works with each State's Wind Energy Task Force to identify and publicize which OCS lease blocks are most appropriate for offshore wind energy development. Areas deemed most suitable for development are called Areas of Interest while they are reviewed by federal and state agencies, as well as non-governmental organizations. Areas of Interest evolve to Call Areas whose boundaries and coordinates are published in the Federal Register seeking input from all US agencies and citizens. All received information is synthesized and typically further constrains the spatial extent of the OCS blocks that will be available for lease as a Wind Energy Areas (WEA).

In 2012, BOEM identified three Wind Energy Call Areas off of North Carolina (US Government, Federal Register Vol 77, No. 240, December 2012): the Kitty Hawk Call Area is located near the North Carolina-Virginia border whereas both the Wilmington-West and Wilmington-East Call Areas are located near the North Carolina-South Carolina border, near Cape Fear and Frying Pan Shoals (Figure 1-1). In August 2014, BOEM announced three, fully vetted, WEAs offshore of North Carolina, in which each of the three Call Areas were reduced in size. This research project examined the seafloor and benthic communities in the Wilmington-East Call Area with some assessments focused on the smaller Wilmington-East WEA.

The pursuit of developing offshore wind energy resources along the US coast was initiated in northern Atlantic waters and has progressed southward to the central and southern Atlantic regions. The geology of the Outer Continental Shelf (OCS) seafloor varies along the US Atlantic coast with higher densities of rocky reef hardbottom habitat occurring south of Cape Lookout, NC. Although hardbottom habitats are common in the Onslow and Long Bays of the NC OCS, their exact locations and quantitative uses by fishes are not well determined. Hardbottom habitats, shipwrecks and artificial reefs are designated as Essential Fish Habitats (EFH) by National Marine Fisheries Service (NMFS) due to their importance to some important fishery species in the snapper-grouper complex, and consequently, are protected under the authority of the Magnuson-Stevens Fisheries Conservation and Management Act. The University of North Carolina developed a comprehensive planning study for the NC Wind Energy Task Force which synthesized existing information on consistency of wind resources, geological and socioeconomic factors that might reduce conflict and maximize resource extractions from offshore wind energy development (UNC-CH 2009).

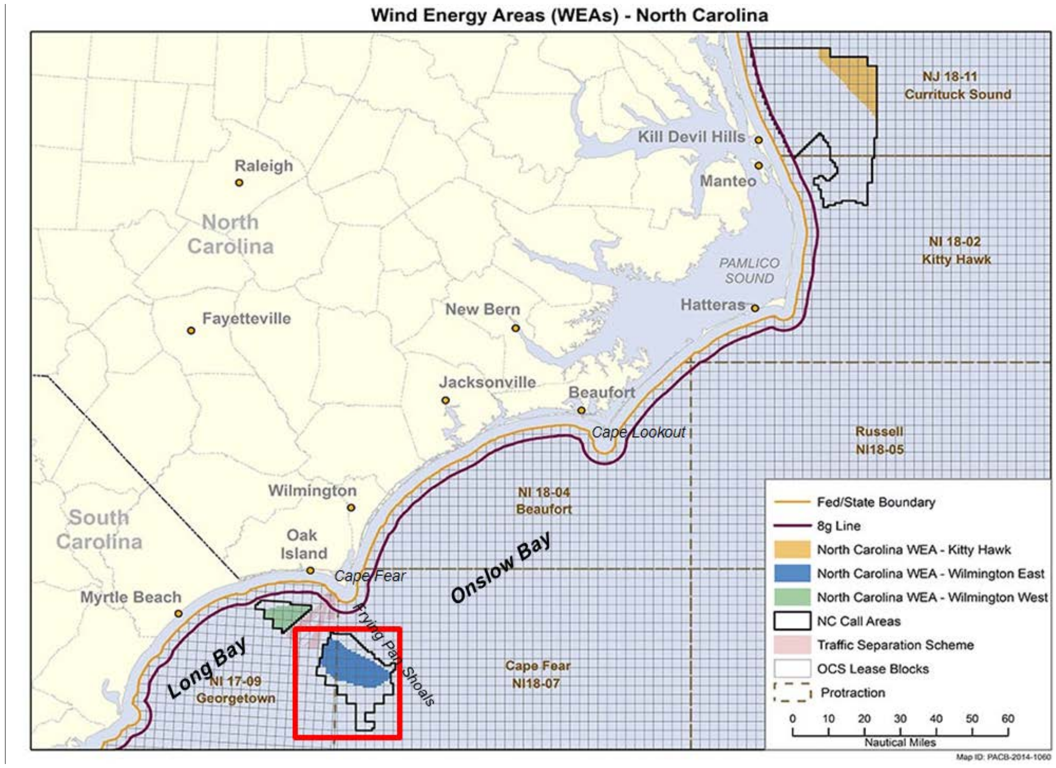

Figure 1-1. Three Wind Energy Areas within the outlined Wind Energy Call Areas on the North Carolina Outer Continental Shelf, with the study area in red box. Modified from: BOEM Renewable Energy Program http://www.boem.gov/state-activities-north-carolina/ (accessed 24 April 2015).

The study area, located in Long Bay, just south of Cape Fear, begins about 29 km south of Bald Head Island, and extends 50 – 55 km to the south-southeast. The widest portion of the area is about 40 km, with Frying Pan Shoals Tower just to the east. The study area is 1,120 km^2 (112,019 hectares) and is comprised of 66 complete or partial lease blocks in waters ranging in depth from around 20 m in the north to 35m in the south (Figure 1-1).

Long Bay, a cuspate embayment typical of the southeast US Atlantic coastline, occurs on the southern flank of the mid-Carolina Platform High, otherwise known as the Cape Fear Arch, a regional tectonic high. This flank reveals a broad, shallow shelf that is underlain by sequences of indurated Cretaceous to Pliocene strata and blanketed by thin, discontinuous layers of sand and mud of Quaternary age (Riggs and Ames 2009), with the exception of accretions of sand on the shoal fields of Frying Pan Shoals. While there is broad understanding of the sediment dynamics and the origin of sediment material and emergent rock, field surveys have not delineated rocky outcrops and emergent hardbottom at a suitable spatial scale for evaluating important habitat for fish species.

Hardbottom habitat in Long Bay, as well as Onslow Bay to the north, forms temperate reefs that vary in structural complexity and degree of sediment cover. These reefs include flat pavements, rubble fields, and substantial ledge systems with up to several meters of vertical relief. Man-made artificial reefs and shipwrecks also provide an alternative source of hardbottom habitat in the area varying in structural complexity; composition of these man-made structures range from concrete pipes to large ships. Despite the recognized importance of hardbottom habitats in supporting ecologically and economically important fish taxa, less than 10% of the southeast US OCS has been mapped using modern hydrographic techniques to provide the sufficient resolution in depth and topography necessary to characterize and delineate hardbottom habitats in the region.

The hardbottom habitats, including artificial reefs, in NC provide substratum for benthic communities that in turn support ecologically and commercially important fish and invertebrates (Parker and Dixon 1998, Quattrini et al. 2004, Kendall et al. 2009, Whitfield et al. 2014). The fishes that reside on these hardbottom habitats are highly valued by sectors of the commercial and recreational fishing and diving communities (Voss et al. 2013). The unique geographic location near Cape Hatteras contains the convergence of cooler mid-Atlantic currents and warmer southern currents. This confluence supports diverse diverse groups of tropical and temperate reef fishes and bottom organisms such as sponges, corals and macroalgae. The main goal of our work was to identify and characterize the biological communities on hardbottom in the study area and adjacent areas offshore Cape Fear, NC.

Hardbottom habitats of NC experience dramatic changes in the degree of sediment cover, alternately burying and exposing reefs due to dynamic sedimentary, biological, and physical processes(Riggs et al. 1996, 1998, Renaud et al. 1996, 1997, 1999). Flat pavements of exposed hardbottom are covered with a thin veneer of sand, rubble fields with 2-6 cm of sediment cover, and ledges with sparse dustings of sediment (Renaud et al. 1996, Riggs et al.1998). Expanses of sediment often surround these habitats, radiating from the reef edge (Riggs et al. 1996). Episodic storm events may suspend and clear sand from flat hardbottom but have little impact on locations, such as ledges, that had low sediment cover prior to storms (Renaud et al. 1996, 1997). Changes in sediment cover over various temporal scales have the potential to bury or expose hardbottom habitats, such that habitats of some structural types in NC offshore waters may be ephemeral

Structural complexity of the reef refers to the three-dimensional physical habitat topography. Structural complexity has been shown to increase fundamental fish community metrics, including abundance (Roberts and Ormond 1987, McCormick 1994, Friedlander et al. 2003), richness (Luckhurst and Luckhurst 1978), species diversity (Risk 1972, Friedlander et al. 2003), and biomass (Jennings et al. 1996, Friedlander et al. 2003) of coral reef fishes. Reef architecture also plays a fundamental role in organizing marine communities, as it can affect recruitment success (Almany 2004), early post-recruitment mortality (Connell and Jones 1991), resource acquisition (Crowder and Cooper 1982, Gotceitas and Colgan 1989, Diehl 1992), and predation risk (Gotceitas and Colgan 1989, Beukers and Jones 1997) in fishes. Most studies that investigate how structural complexity influences fish community metrics and habitat use focus on tropical coral reef systems. Fewer studies have determined whether this relationship is evident in temperate hardbottom reefs (Kendall et al. 2007, Kendall et al. 2008, Johnson et al. 2013), such as those off the coast of North Carolina.

The purpose of this report is to determine and describe the surface geology of the sea floor, as well as to provide a baseline assessment of benthic biological communities and habitat use by fish assemblages of hardbottom habitats in the Wilmington-East Wind Energy Call Area. We present maps and interpretation of acoustic imagery from an intensive seafloor mapping to characterize and delineate the distribution of hardbottom habitats, including rocky reef ledges, mixed hardbottom rubble, low-relief pavement and artificial hardbottom structures in the form of shipwrecks and variously structured material serving as artificial reefs. This study represents the first complete coverage of the Wilmington-East Call Area using modern hydrographic survey methods. Fishery echosounders were used to remotely sense and map the distribution and density of fish in the area. The new seafloor imagery and acoustically-derived fish density maps were used to identify and delineate natural hardbottom habitats and shipwrecks.

The methods and results of this report are organized in four parts: (1) detailed description of hydrographic surveys of the seafloor and interpretation of seafloor imagery to delineate hardbottom habitats; (2) description and interpretation of fishery echosounder (splitbeam echosounder system; SBES) surveys to map the distribution of fish densities across the mosaic of seafloor habitats including hardbottom and unconsolidated sediments; (3) a detailed ecological assessment of benthic biological communities and fish utilization patterns of hardbottom habitats, including shipwrecks; and (4) an assessment of the seasonal dynamics of hardbottom fishes and benthic communities, with specific attention paid to a comparison of the benthic and fish communities that occupy and use natural versus artificial hardbottom habitats (shipwrecks and artificial reefs) and the potential role of sediment dynamics and its effect on benthic habitats. This report follows decades of research on the importance of hardbottom habitats on the southern Atlantic OCS that support the ocean ecology and economies of NC and other southeastern US coastal states. This study represents an important baseline condition of benthic habitats, invertebrates and fish communities of the US south Atlantic benthic habitats and of their potential implications to offshore development of wind energy facilities.

2. Methods

2.1. Sidescan and Multibeam Mapping of Seafloor

2.1.1. Seafloor Mapping Survey Design

As part of this collaborative study to develop a better understanding of hardbottom habitats and potential archaeological resources of the seafloor within the Wilmington-East Call Area in Long Bay, North Carolina, Geodynamics was tasked with collecting sidescan sonar (SSS) data, overseeing multibeam echosounder (MBES) data acquisition, and generating subsequent data and map products.

HYPACK hydrographic survey and processing software was used for the planning of seafloor mapping surveys. The main-scheme survey lines were designed with 260 m spacing, oriented at 177°, clockwise from North. This line spacing was chosen to provide approximately 115% coverage for sidescan sonar surveys. MBES data were collected simultaneously, with water depth constraining areal coverage to 30-45% coverage. This survey approach was chosen to provide the most efficient technique to obtain full-coverage SSS while still obtaining multibeam swath bathymetry.

The remote sensing surveys of the study area took place over four cruises occurring during the summer and fall of 2013 and spring 2014 (Table 2-1). The fourth survey was primarily focused on dive operations. MBES surveys of specific sites and/or areas were conducted at night, with a focus on areas of concentrated hard bottom habitats identified in previous surveys. An overview of survey dates and activities can be found in Table 2-1 and the area of the study area covered in each survey is shown in Figure 2-1.

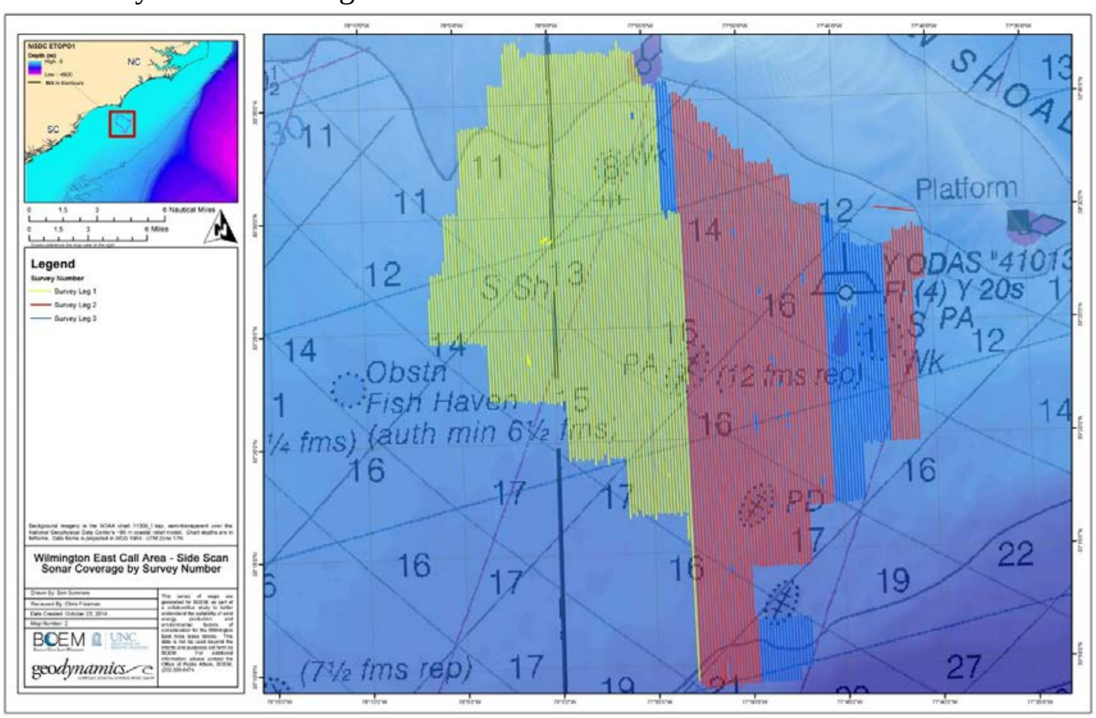

Figure 2-1. Overview of sidescan and multibeam sonar coverage by survey leg number.

Table 2-1. Survey dates, schedule, and activity.

	Survey Dates	Julian Day	No. of Days	Activity
Leg I	18-Jun-13	169	1	Mobilize
	19-Jun-13	170	1	Mobilize
	20-Jun-13	171	1	Transit
	June 21-29, 2013	172 – 180	9	MBES & SSS Survey (mostly eastern portion)
	30-Jun-13	181	0.5	Transit
	30-Jun-13	181	0.5	Demobilize
Leg II	31-Aug-13	243	1	Mobilize
	Sept 1-6, 2013	244 – 249	6	MBES & SSS Survey (mostly central portion)
	7-Sep-13	250	1	Demobilize
Leg III	5-Nov-13	309	1	Mobilize
	Nov 6-8, 2013	310 – 312	3	MBES & SSS Survey (mostly western portion)
	9-Nov-13	313	1	MBES Survey (areas of interest)
	10-Nov-13	314	1	Transit/Demobilize
Leg IV	5-May-14	125	1	Mobilize
	May 6-14, 2014	126-134	9	Nighttime MBES Survey of areas and sites
	15-May-14	135	1	Demobilize
	Total Mobilization/Transit:		10	
	Total Survey Days:		28	
	Total Days:		38	

2.1.2. Survey Vessel and Instrumentation

As part of the interagency agreement between BOEM and NOAA, the NOAA ship, *Nancy Foster* was used for all survey efforts. The ship measures 57 m in length, with a beam of 12 m and a vessel draft of approximately 3 m. Equipped with state of the art navigation, propulsion, missions systems, and over-deck deployment systems, the vessel is well outfitted for both habitat and bathymetric surveys. A critical component to the ship's ability to serve as a seafloor mapping platform is attributable to the "reference frame surveys" that had been performed on the ship, in 2005, and again during a dry-dock period in 2011. Referred to as an "Orthogonal Survey" in 2011, this procedure precisely located all relevant sensors and critical ship components, as well as strategically placed reference marks into a 3-dimensional reference frame. This document serves as a vital key to ensure properly aligned and geo-referenced hydrographic surveys. For a complete listing of the *Nancy Foster's* specifications and the Orthogonal Survey see Appendix.

Figure 2-2. Photograph of the NOAA ship Nancy Foster (R352), courtesy of the Marine Operation Centers website.

Accurate and precise navigation and attitude integration is a critical component to a successful hydrographic survey. The *Nancy Foster* is equipped with the POS/MV 320 v4, a state-of-the-art inertial navigation system to calculate attitude, position, and heading. True Heave software was used for post-processing multibeam data (NOAA 2013, 2014). Positioning was aided by a Trimble DSM132 Differential Global Positioning System (DGPS) beacon, resulting in position accuracy between 0.5 – 2 m.

Aboard the *Nancy Foster*, NOAA crew maintains and operates two hull-mounted MBES systems aligned to the ship's navigation and attitude system. A Reson 7125 V1 and V2 array (Figure 2-3), capable of single or dual-frequency, at 200 and/or 400 kHz, was used for the majority of the study area. The Reson 7125 has 256 beams at 0.5^{o} or 512, 1^{o} beams in equidistant mode. With 128^{o} coverage, the system is capable of obtaining a swath about 3.5 - 4 times the water depth. The second MBES is a Kongsberg EM1002 system which operates 111 individual, 2^{o} beams at 95 kHz, making this system optimal for deeper waters. Both systems are roll-stabilized and capable of recording backscatter intensity data. Sound speed measurements were conducted using either an Expendable Bathythermograph probes (XBT) or a Conductivity-Temperature-Density Rosette (CTD) as per NOAA Field Procedures Manual (NOAA 2013).

Table 2-2. Equipment used for multibeam and side scan sonar surveys.

Hardware Equipment	Manufacturer	Model	Description
Side Scan Sonar	Edgetech	4200	230/540 kHz
Primary Echosounder	Reson	7125 V1 & V2	200/400 kHz
Secondary Echosounder System	Kongsberg	EM1002	95 kHz
Sound Speed at Surface	Seabird	SBE 45	Thermosalinograph at EM1002 Head
Sound Speed Profiler	Seabird	SBE 19 Plus	CTD Rosette for Sound velocity profiles
Sound Speed Profiler	Sippican	XBT Mk-21 and Deep-blue	Sound velocity profiles

Sidescan operations were conducted with an Edgetech, Inc. topside unit and 4200 model towfish, with operating frequencies at 300/600 kHz (Figure 2-4). For the majority of the survey, the SSS towfish was outfitted with a depressor wing attached to allow greater tow-speeds and a stable flight pattern. A steel cable drum/ hydraulic winch outfitted with controls that stretched to the acquisition station within the dry lab, allowed constant monitoring of payout and control of towfish altitude. A complete list of all SSS equipment used throughout the surveys and detailed methods are described in Appendix.

Figure 2-3. Picture of the hull-mounted Reson 7125 transmit/receive array.

Processing of all SSS data and products was conducted by Geodynamics. The multibeam bathymetry data were primarily processed by the ship's survey staff and finalized by Geodynamics. The MBES data from survey Leg IV was acquired by the ship's survey staff.

Figure 2-4. Picture of the Edgetech towfish used to collect sidescan sonar data.

2.1.3. Sidescan Data Acquisition

The acquisition of all SSS data employed Hypack software, suite version 2013a (Hypack 2015) with Discover series 4200 software (Edgetech 2014) used to facilitate the acquisition of SSS data. During the real-time collection of raw SSS data, the high-speed mode and low frequency, or 300 kHz channel, settings were used to maximize data coverage and efficiency.

Data were collected continuously, 24 hrs on each survey day in 2013, with the vessel travelling at a speed of 4-8 kts, depending on conditions (see Appendix). Sidescan sonar data files were collected in 20-min segments to constrain file size for improved usability during post-processing. During each survey, all data acquisition processes were monitored constantly (Figure 2-5). The altitude (depth) of the towfish was carefully maintained to keep the sonar within an optimal range from the sea floor (10-20% of range), while also operating in homogeneous water, avoiding haloclines or pycnoclines in the water column that have potential to refract the sound and degrade data quality at greatest range from the towfish.

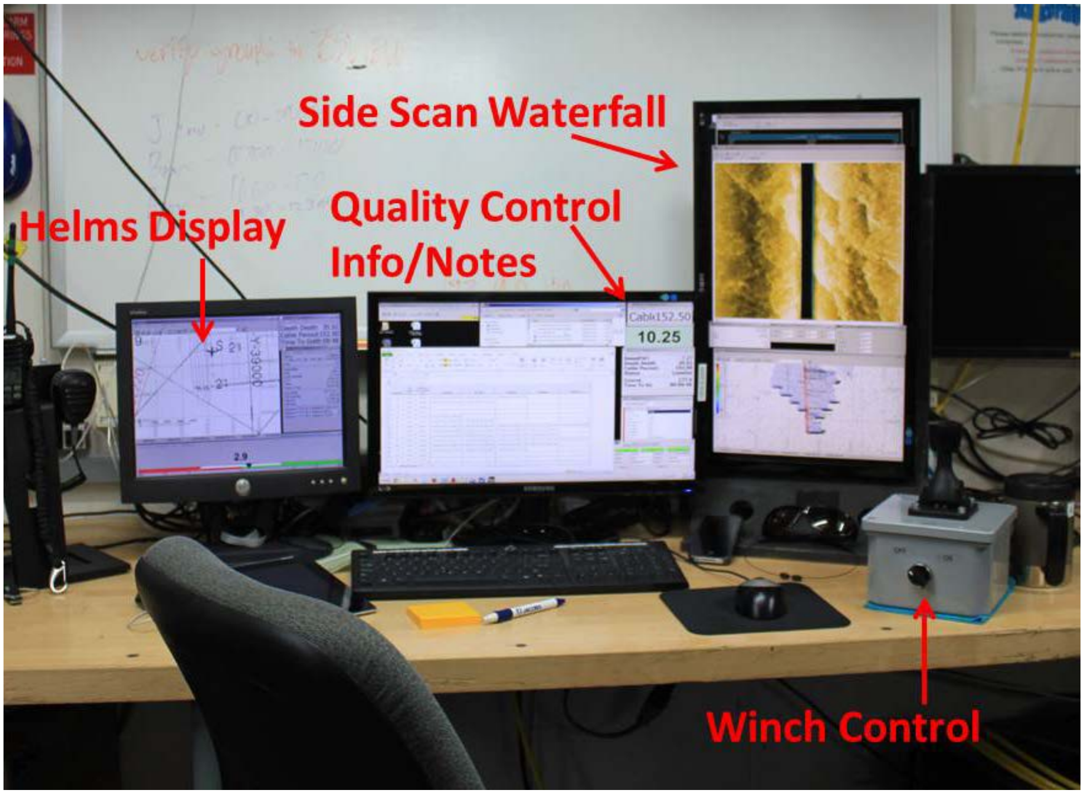

Figure 2-5. Data acquisition station for sidescan sonar operations.

2.1.4. Sidescan Data Processing

Management and processing of the sidescan sonar data employed the HYPACK 2013a software suite. Data were initially processed using the HYPACK (version 2013a) Sidescan Targeting and Mosaicking software from which individual tiles at a 25-cm scale were created for the high-resolution detection of objects and mapping of seafloor features (see Appendix).

2.1.5. Multibeam Data Acquisition

Multibeam sonar data was acquired simultaneous with sidescan sonar during all 2013 surveys. Data acquisition was performed by NOAA ship survey technicians following the appropriate protocols found in the NOAA Field Procedures Manual (NOAA 2013, 2014). All MBES data were acquired using the HYPACK 2013 software suite. The primary echosounder for this project was the Reson 7125 SV2; however, the Kongsberg EM1002 unit was used for a small subset of MBES data collection. Sound velocity of the water column was measured by deployment of Expendable Bathythermograph (XBT) probes every 4-6 hours. Conductivity, water temperature, and depth were measured using a CTD sonde deployed 1-2 times daily. Soundings were compensated for position and attitude in real-time from the POS/MV. Sound velocity was constantly measured near the Reson 7125 transducers, aiding beam forming in real time. Additional details may be found in the Appendix.

2.1.6. Multibeam Data Processing

Multibeam data were processed using CARIS HIPS software version 7.1 with Service Pack 2, Hotfilx 6, following guidelines in the NOAA Field Procedures Manual (NOAA 2013, 2014). True Heave data were recorded concurrently with the POS/MV data and applied in post-processing for an improved heave record from real-time heave corrections. Data were post-processed for sound velocity using the "Nearest in Time" method for including either CTD or XBT sound velocity profiles. Tide was incorporated by using the NOAA CO-OPS tide zone definition file (ZDF) in 6-min intervals, referenced to Chart Datum. Sounding and sensor data were then merged for bathymetric surface production. Total Propagated Uncertainty was computed using vessel settings within the Caris HVF file. Given the size of the survey area, seven fieldsheets were generated to manage bathymetric surface production. Additional fieldsheets were generated for specific sites or areas surveyed with greater coverage. Combined Uncertainty and Bathymetric Estimator (CUBE) surfaces were generated at 1-m bins. Survey tracklines were reviewed in a line-by-line process in subset view using CARIS software to remove erroneous information or "sonar noise". Due to problems with MBES instrument integration aboard the *Nancy Foster*, survey data were reviewed for excessive motion artifacts (see Section 4.2.1 in Appendix). For this project, some survey lines (soundings) were removed from portions of survey tracks where surface artifacts exceeded ~0.5 m. Final datasets were exported as Bathymetry Attributed Grid (BAG) files, and exported for Geographic Information Systems (GIS) development and analysis.

2.1.7. Creation of Seafloor Habitat Layers in GIS

To manage the large datasets and create a usable product for a wide range of users, both MBES and SSS data imagery were developed into ESRI GIS products. ArcGIS 10.2 software was used to catalog all of the individual surfaces and imagery as two separate "*Mosaic Datasets*". A mosaic dataset allows the user to store, manage, view, and query small to vast collections of raster and image data. The mosaic dataset was developed within a "*File Geodatabase*" which allows access by multiple users at once, but only one user at a time can edit the same data. This tiered approach to managing the files allows the user to access the collection of raster datasets stored as a referenced catalog and viewed as a mosaic image. The data model provides a template for image enhancement, overviews, and mosaicking options without actually changing the original data files as it creates mosaics that are optimal at specific visibility scales.

2.1.8. Sidescan Sonar Data Products

Sidescan sonar data products were developed using both HYPACK and ArcGIS 10.2 software suites with resulting datasets developed for use in ArcGIS software or comparable GIS software. Georeferenced TIFF images include individual survey lines as well as 1 m resolution mosaics. An additional mosaic dataset in ArcGIS includes 1,174 georeferenced TIFFs resolved to 25 cm. Digitized potential outcrops were produced from on-the-fly object identification and are represented as point and polyline shapefiles.

2.1.9. Multibeam Sonar Data Products

Multibeam bathymetry was exported from CARIS as a Bathymetry Attributed Grid (BAG) file. A BAG file is an open source data exchange format created to facilitate the processing and storage of large volume multibeam sonar data. When viewed in ArcGIS, a BAG contains both elevation and uncertainty calculated from known uncertainties/specification limits of the MBES system calculated in CARIS. BAG files may also be opened in most commercial bathymetric data processing software. All MBES data products were derived from the BAG files. The following items were generated as MBES products:

2.1.10. Synthesis of Sidescan Sonar and Multibeam Echosounder Datasets

Targets logged in the HYPACK Side Scan Targeting and Mosaicking software were exported and converted to an ArcGIS point shapefile (Table 2-3).

Table 2-3. Sidescan sonar data attribute table.

FID	Unique Identifier
Target_Nam	Target name assigned during identification
X	Northing - UTM Zone 17N coordinates
Y	Easting - UTM Zone 17N coordinates
Latitude	WGS84 Latitude in decimal degrees
Longitude	WGS84 Longitude in decimal degrees
Event	Event number generated in HYPACK
Comments	Description of site, units in meters
Cruise_Leg	Portion of cruise the feature was surveyed
INFO	BOEM State Call Area
PROT_NUMBE	BOEM OPD Name
BLOCK_NUMB	BOEM Block Number
BLOCK_LAB	BOEM Block Label
SUB_BLK	BOEM Sub-block
SubArea	BOEM Sub-area
File_name_	Side scan sonar survey file name
Distance	Distance from Nadir
Image_Link	Relative pathway for hyperlinked image
image2	Direct pathway for hyperlinked image
Dive_Site	Site name according to dive record
Dist_to_Di	Distance from dive site location (meters)
CODE	Attribute assigned based on interpretation, with one of the following assignments; morphological, biological, morphological/biological, possible wreck, known wreck, unknown

Side scan sonar survey navigation lines were then exported from HYPACK and converted to polyline shapefiles in ArcGIS. Attribute information for each polyline refers to the respective sidescan sonar survey line file name (Table 2-4).

Table 2-4. Output table of side scan navigation lines.

Side Scan Navigation Lines Attributes	
FID	Unique Identifier
Shape	Shapefile type
File_Name	Sidescan sonar survey line name
Shape_Length	Feature length

On-the-fly (OTF) digitization was reviewed to highlight apparent outcrops or objects of interest. The mosaic dataset was overlaid by 1 km^2 square polygons to systematically pan through the side scan imagery at a scale of ~1:4,000. Visible outcrops were then digitized into a polyline shapefile. This shapefile highlights apparent features interpreted as hardbottom habitats in the SSS imagery (Table 2-5).

Table 2-5. Attribute table of digitized outcrops.

FID	Unique Identifier
INFO	BOEM State Call Area
PROT_NUMBE	BOEM OPD Number
BLOCK_NUMB	BOEM Block Number
BLOCK_LAB	BOEM Block Label
SUB_BLK	BOEM Sub-block
SubArea	BOEM Sub-area
Length	Length of feature (meters)
X_midpoint	Easting midpoint of feature (UTM Zone 17N)
Y_midpoint	Northing midpoint of feature (UTM Zone 17N)

2.2. Mapping Fish Densities Using Splitbeam Echosounders

A splitbeam echosounder (SBES) detects fish and other objects in the water column by propagating rapid pulses of high-frequency sound and recording the reflection or echo from objects (or the seafloor) having differing density than the surrounding water. The fish swimbladder, an organ that many fish use to regulate buoyancy, reflects the majority of the sound that is transmitted by the SBES transducer. The intensity of the reflected sound (target strength) is proportional to the size of the swimbladder resulting in an echo that is positively correlated to fish size. When fish are in close proximity such as in schools or aggregations, it is not possible to discern individual fish and characterize individual target strength. In this case, the total intensity of the reflected sound from the school provides an index of the density of the school.

The SBES system used was a Simrad EK60 splitbeam echosounder operated at three frequencies, 38, 120 and 200 kHz. Three transducers were mounted into the hull of the ship and surveyed to a common reference point to provide precise offsets relative to ship's navigation, multibeam sonars and other data acquisition systems. Each transducer has a nominal beam geometry of 7° and results in a swath or footprint that is about 12% of range from the transducer face (or water depth). The pulse transmission (ping) characteristics, data acquisition and data viewing were controlled from a workstation operating Simrad ER60 software (Simrad Fisheries, version 2.4.3) and connected by local area network to three General Purpose Transceivers (GPTs). The ping timing was triggered by and synchronized to the Reson 7125 MBES. Each ping is co-registered with the ship's time server, navigation and motion system including time in GMT, latitude and longitude, pitch, roll, and heave. Output power, pulse length, and other ping transmission properties are provided in Table 2-6. Data files are logged in 100 MB file segments and stored on the ship server for archiving and analysis.

During each survey, the system is calibrated using methods described in Foote et al. (1987). Briefly, a standard 38.1 mm diameter tungsten carbide (WC) sphere is hung below the transducer. This target has a known theoretical acoustic target strength based on the composition sphere diameter and environmental conditions. The LOBE program in ER60 software (Simrad Fisheries, v. 2.4.3) is used to acquire position and target strength for the sphere. The calibration sphere was systematically moved through the beam from forward to aft and port to starboard. The LOBE program calculates the system receiver gain to bring the observed target strength in concordance with the theoretical target strength for the sphere. The process is repeated for each operating frequency.

Table 2-6. Data acquisition and control parameter for the Simrad EK60 SBES on the NOAA Ship Nancy Foster. Nominal values are provided for sound velocity and absorption. These values are recorded in the raw data and updated for temperature and salinity.

Parameter	Echosounder Frequency		
	38 kHz	120 kHz	200 kHz
Transducer depth (m)	3.43	3.43	3.43
Transmit power (dB-W)	1000	220	100
Pulse length (µs)	256	128	128
Absorption (dB-km)	6.4	47.0	88.0
Sound velocity (nominal, m s^{-1})	1540	1540	1540
Calibration gain (dB)	22.6	20.14	20.3

2.2.1. Splitbeam Echosounder Survey Design

The SBES surveys were designed in three ways. First, SBES data were collected simultaneously with SSS and MBES surveys in 2013. The 2013 survey covered the entire original Wilmington-East Call Area over three cruise legs, surveying continuously over 24 hours (see Section 2.1.1 for additional details on survey design, line spacing, effort and timing).

For the second survey design, we used the delineated hardbottom detections from the SSS survey as well as the preliminary fish density distribution maps from the SBES surveys conducted in 2013 to select two focus areas for high-resolution MBES and SBES surveys that were conducted during the 2014 diver assessment cruise. Line spacing was dictated by the MBES survey to ensure >100% bottom coverage by the MBES, from 80 to 100 m spacing between survey lines.

With the diver assessments conducted during the day, all MBES and SBES surveys were restricted to dusk-night-dawn operations in 2014.

Lastly, we selected 28 hardbottom features and conducted SBES surveys to: (1) detect fish and their location and distance from seafloor; and (2) collect SBES data as soon as feasible after the dive observations to make comparisons of the diver data to SBES fish density estimates over hardbottom habitats. The specific sites were selected opportunistically and determined by the daily dive operations. Sites were surveyed in the morning closest in time to the first dive station for the day, or in the afternoon over the last dive stations for the day. Five parallel lines were spaced about 30 m apart and 1 km in length (with variation in length determined by ship's turns). The orientation of the lines was usually perpendicular to the orientation of the hardbottom feature (if a discrete and linear ledge). In some cases, when hardbottom features were in close proximity, a single survey was used to cover multiple stations. In these cases, the survey lines were simply extended to include two or more survey stations.

2.2.2. Splitbeam Echosounder Data Processing

The SBES data were processed using Echoview software (version 6.0, Echoview Pty Ltd, Hobart, Tasmania). The data were heave corrected to remove vertical motion caused by swell and waves. The seafloor was delineated and data were cleaned to remove interference and air bubbles prior to processing the water column data for fishes. Faint echoes that were likely plankton and other non-fish targets were excluded using a threshold of -55 dB. The remaining echoes were used in a single target detection algorithm to derive fish greater than about 6 cm in length. The speed of the vessel and rate of ping transmissions resulted in multiple and sequential targets from individual fish. The split-beam transducer detects the range and horizontal position of the target within the beam at each ping using a phase-differential array. A fish tracking algorithm was used to accumulate sequential echoes from single fish targets. The fish that were identified by the single target and tracking algorithm were stored in a database with a geographic position determined by the ship's GPS and corrected for relative position of fish within the acoustic beam, depth below the sea surface, and a mean target strength (TS, in dB). The target strength in dB is a log-scale measure of the acoustic backscattering strength. A fish size (total length) in centimeters was derived from the acoustic target strength using a generalized acoustic size to fish length relationship

$$TL = 10^{(TS+64.0035)/19.2}$$

where TS is target strength measured in dB, TL is calculated length in cm (Love 1977). The equation above fits closely with observation of reef fish of the same taxonomy that were observed during diver surveys for this project and published elsewhere (Johnston et al. 2006).

Individual fish targets were counted and binned into 100-m intervals along survey transects. The density calculation took into account the increasing detection of individual fish as the acoustic beam footprint increases by depth, standardizing the beam width to a 1-m swath using the following equation:

$$C_w = 2 \text{ x range x } \tan(0.5BA)^{-1}$$

where C_w is the weighted count of an individual fish accounting for detection in an increasing beam swath with increasing range, and the tangent of the half beam angle (BA = 7°). Weighted counts are summed for each 100 m interval producing a density with the unit fish 100 m^{-2}.

When fish are aggregated in schools or in close proximity (e.g., less than about 20 cm vertical spacing), individual targets cannot be discerned or enumerated. In this case, the acoustic backscatter is the sum of the backscatter from the individual. Fish schools were delineated using a schools detection algorithm that isolates the acoustic backscatter in the school from the background noise. Polygons are drawn around the shape of the school and the total acoustic backscatter intensity (Sv, in units of inverse area, m^2), a process known as echo-integration. To calculate fish density in schools, the total acoustic backscatter must be scaled to the size of the average fish in the school. Some schools included discernable tracks from individual fish on the outer margin of the schools. The total acoustic backscatter is divided by the average backscatter of an individual fish, creating a density that has units of fish m^{-2}, which is then multiplied by 100 to achieve similar magnitude of values as in the density estimates of area swept for individual fish (fish 100 m^{-2}). Acoustic fish density layers are created for each survey as point shapefiles with the centroid of the interval used as the geographic position for densities of individual fish and the centroid of the fish school as the geographic location of the school.

2.2.3. Mapping Fish Densities

The SBES fish density shapefiles were divided into size categories that represent small prey species, conspicuous fishes, and large fishery-important species. Small fish, less than 11 cm, likely represent smaller reef species and smaller planktivorous fish species. Medium fish, between 11 cm and 29 cm, include juvenile or small adults of targeted fishery species. Large fish, greater than 29cm, include larger economically valuable fish within the grouper/snapper complex and other pelagic predators. Densities were plotted using symbols proportional to the magnitude of fish density (fish 100 m^{-2}) with zero densities excluded. Similarly, the fish schools were plotted with symbols proportional to the magnitude of fish density. The resulting maps from the 2013 surveys were used to identify “hot spots” within the survey area and were one of the spatial tools used to refine a survey domain to produce higher resolution seafloor and fish distribution maps in 2014.

Spatial indicators were derived for the fish density maps to characterize the level of aggregation and clustering in the distribution patterns (Petigas 1998). This initial spatial analysis was done in the absence of underlying drivers such as habitat, geomorphological or environmental variables. This approach allows for a comparison of the independently derived spatial distributions between the two survey designs, to determine similarities in distributions that could suggest consistent “hotspots” associated with hardbottom, artificial, or even unconsolidated/sand seafloor types. The fish density maps from 2013 and 2014 were interpolated using geostatistical kriging. Kriging is an unbiased spatial prediction that applies spatial weights from measured observations using a model-based variogram of the relatedness of density observations as a function of spatial distance. The density values were highly skewed with numerous zero and a few extreme values. To reduce bias and skewness, the density values were transformed using a Box-Cox log transformation, ln (D+c), where D is the density value and c is a small addend to ensure positive values. Here, c is the smallest positive density value greater than 0 for each survey. Density values for the 2013 and 2014 surveys were interpolated over a 200 m x 200 m resolution grid. Because the 2013 surveys were conducted throughout the day and night, we also interpolated the night-only observations from 2013 so that the interpolations were comparable to the night-only surveys conducted in 2014. Interpolations were created for densities of all fish size classes (including fish schools) and for only large fish size class densities. Geostatistical kriging was performed using the open-source statistical programming language R (R Development Core Team) and ArcGIS (Version 10.2, ESRI).

The interpolated grids were used to calculate two forms of aggregation indices: presence area (PA) and concentration curves. Presence area is the proportion of the survey area that had positive density values. Concentration curves represent the proportion of non-zero density as a function of the proportion of samples. The density values were ranked and cumulatively summed in descending order. The cumulative sum of the densities was plotted against cumulative area. The curve is compared to a diagonal line with slope=1, which would be the expected pattern for a spatially homogeneous distribution. The spatial selectivity index is twice the difference in area between the concentration curve and a line of slope equal to 1, characterizing bias versus evenness of density distributions.

Lastly, a regional hotspot analysis was carried out using the Getis-Ord analysis of spatial associations (Getis and Ord 1992) in ArcGIS. For this analysis we selected only densities of large fish classes, most likely attributed to fishery-targeted species, to conduct the hotspot analysis. The approach compares the proximity of high values compared to a distribution that would be considered random. A statistical z-score is used to determine the level of significance for each cluster using a p-value. Three levels of p-values were used to grade the hotspots according to significance levels of 90%, 95% and 99%.

2.2.4. Mapping Fish Locations Relative to Hardbottom Features

The proximity of fish to hardbottom features was assessed using targeted surveys over the diver stations and subsets of the MBES night surveys conducted in 2014. The two surveys afforded the opportunity to compare the relative proximity of fish targets during day (2014 diver surveys) and night (2014 MBES surveys). Individual fish targets and habitat features were visualized in a map and the proximity toolset in ArcGIS was used to compute the closest distance to a vertex along a the delineated ledge feature or area delineation of seafloor class consistent with mixed hardbottom/sand. Each fish target detected during the diver surveys was assigned a proximity measure (in meters) and the coordinate of the closest ledge feature. The fish was also assigned the closest diver survey station. Cumulative frequency histograms of proximity to hardbottom features were plotted for ledge and mixed hardbottom separately. Proximity analysis was computed likewise for the fish targets detected during the 2014 night MBES surveys.

Fish densities detected over the dive surveys were compared with the densities observed by divers at 28 selected hardbottom stations. The scale of fish density estimates for the SBES surveys was reduced from 100m intervals to 25 m intervals to increase spatial resolution and pinpoint the location of fishes relative to hardbottom features surveyed by divers. The closest SBES density was spatially joined to the diver observation. Density values for all size classes and fish schools were then aggregated by averaging over 50 m, 100 m, and 250 m range scales relative to the diver observation. The two densities from diver surveys and SBES surveys were compared using total fish density (including all size classes and fish schools) and only large fish densities using bivariate correlations.

2.2.5. Relating Acoustic Fish Densities to Acoustic Seafloor Complexity

Seafloor complexity was derived from multibeam bathymetry with Benthic Terrain Modeler for ArcGIS 10.1 (Wright et al. 2012). The output, vector ruggedness measure (VRM), measures terrain ruggedness, or rugosity, as the variation in three-dimensional orientation of grid cells within a neighborhood (Sappington et al. 2007). Vector analysis is used to calculate the dispersion of vectors normal (orthogonal) to grid cells within the specified neighborhood. This method effectively captures variability in slope and aspect into a single measure. Ruggedness values in the output raster can range from 0 (no terrain variation) to 1 (complete terrain variation). The output from this analysis is referred to as multibeam-derived rugosity in the following sections.

We modeled the distribution of fish in relation to habitat within the North and South focus areas of the study area using SBES data and habitat predictors derived from MBES and the SBES backscatter. SBES densities for large, medium, and small size classes were calculated within 100-m lengths of the ship tracklines, with the geographic position indicated by the centroid. We detected 3848 points within the North area and 4252 points within the South area. Response variables included abundance for large, medium and small fish size classes.

Relationships between categorical fish acoustic density response variables (i.e., large, medium, small fish) and environmental predictors were tested using generalized additive models (GAM) with a Tweedie distribution to accommodate zero-inflated data (R package *mgcv*). Initial predictor variable categories included: (1) fish acoustic data from size classes other than the response variable, and (2) environmental data. Models were run with both predictor categories and separately with only environmental data predictors. Environmental predictors included: (1) UTM latitude and longitude coordinates; (2) the following metrics derived from multibeam bathymetry: depth, slope, slope of the slope (change in slope), rugosity at 3 and 5 grid cell resolutions from Benthic Terrain Modeler, and backscatter (a proxy for habitat classification); and (3) the following metrics derived from Kongsberg EK60 return: roughness, hardness, and return strength (a proxy for habitat classification). Because instrument settings were different for data collection for North and South areas, separate models that included multibeam backscatter were built for North and South areas. Models were constructed stepwise. Results with lowest Akaike Information Criterion scores and most deviance explained were retained.

2.3. Diver Assessments of Hardbottom and Artificial Habitats and Fish Communities

2.3.1. Sampling Domain, Design, and Site Selection

Using data collected during SSS and MBES surveys of the WEA, investigators identified probable hardbottom features such as potential outcrops and ledges, mixed hardbottom and sand, shipwrecks, and areas of fish aggregations that may be associated with hardbottom habitat. Diver site selection was based on these remotely-sensed classifications as well as a minimum site separation distance of 200 m to maintain independence of sampling efforts and maximum depth of 33m (110 ft) within the WEA (Figure 2-6).

All dives were conducted from May 7-14, 2014 within the WEA. Uncertainty in the interpretation of seafloor imagery coupled with depth and time restraints resulted in an unbalanced design by expected seafloor habitat type. Only two wrecks were identified; both were subsequently included in diver-based characterization and are hereafter referred to as artificial sites. Habitat types, including ledge, pavement, mixed hardbottom/sand, artificial (mixed HB/sand), and unconsolidated sediment, were assigned by divers in situ. If divers found that a site did not contain hardbottom habitat, or depths exceeded maximum survey depth, a general habitat description was recorded, the dive was aborted and an alternate site was picked from the site list.

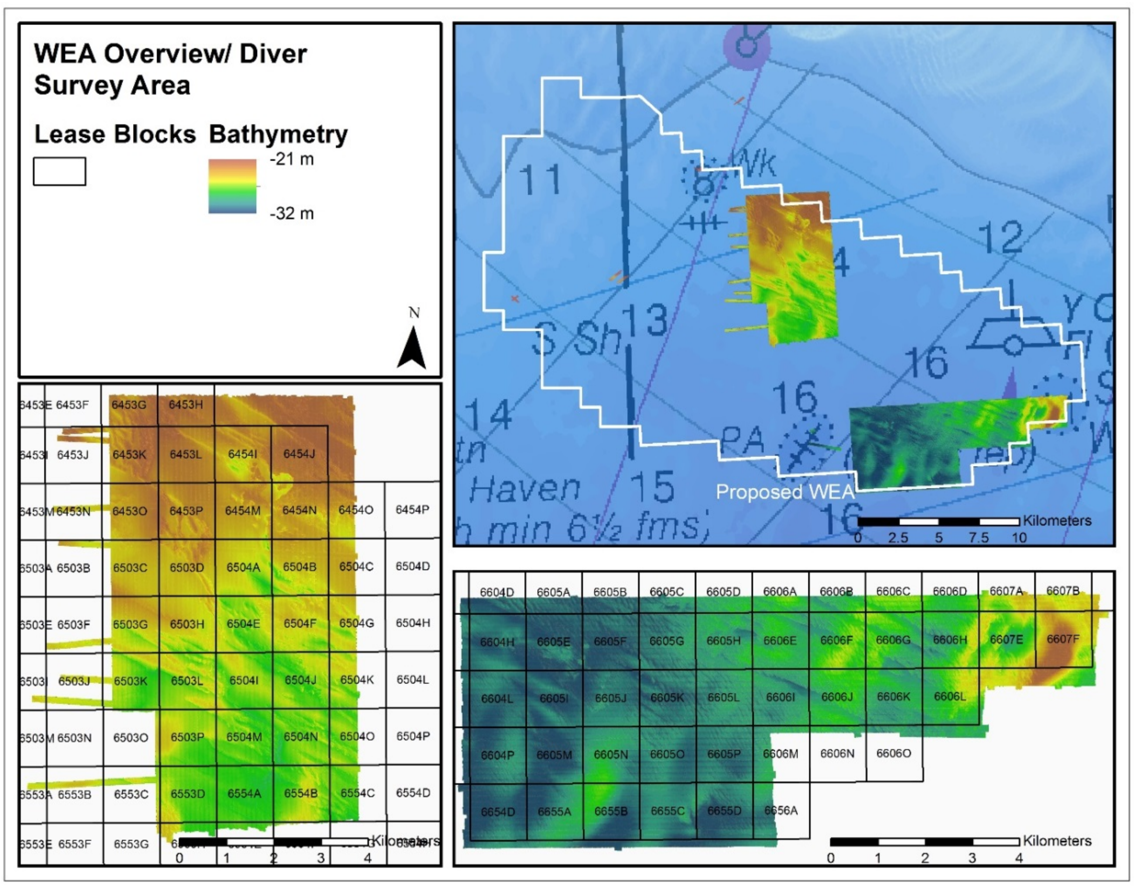

Figure 2-6. Map of the Wilmington-East wind energy area, including north and south focus areas.

Following each day's diving activities, data were entered into a customized Microsoft Access database. Upon completion of the monitoring cruise, all data were migrated to a Microsoft Access database stored on a server. Data quality control was implemented at three main stages:

1) Training of observers (initial training (September 2013), refresher training (April 2014))

2) Data check following data collection. This occurred immediately following a dive while divers were still on small boats. Divers traded datasheets to ensure all data were collected accurately and required information was complete.

3) Error checking the database. (A third person compared the original datasheet to information that was entered into the database ensuring there were no transcription or sizing errors. Queries were run on the data and outliers were examined for data irregularities).

2.3.2. Assessment of Benthic Habitat Characteristics

Four diver-based methods were used to survey the benthic community composition along a 50 m band transect fish survey described below (Figure 2-7). 1) Structural complexity was measured to provide an estimate of habitat height, both biotic and abiotic, at the site level. 2) A rapid visual assessment of biotic benthic cover was surveyed using line point intercept (LPI) method. Habitat categories included major functional categories and some targeted species or genus-level identification. The LPI assessment provides a rapid estimate of benthic community composition. 3) Seasonally persistent benthic macro-invertebrates including soft corals, hard corals, and sponges, were surveyed to provide a detailed estimate of abundance, density, and height. Finally, 4) benthic quadrats were photographed as a second estimate of percent cover of benthic communities and to provide a baseline record of the site.

Figure 2-7. Diver conducting a benthic survey in the wind energy area off Wilmington, NC.

2.3.2.1. Topographic complexity surveys

In this study, both abiotic and epibiotic heights were measured to define habitat structure at local scales (Figure 2-8). Topographic complexity surveys, hereafter referred to as topographic surveys, were conducted to provide information on fine-scale structural complexity of survey sites. Surveys were conducted concurrently and along the same transect as LPI and fish surveys. Divers recorded the maximum heights (in cm) of abiotic structure and biotic organisms within contiguous 2 m x 1 m areas (25 total bins) along the transect line. Biotic structure was identified to categorical group (macroalgae, hard coral, soft coral, sponge, hydroid, or bare substrate). At each sample point, the presence of an undercut (10 cm) was noted. Additional site information recorded at the completion of the dive included: minimum and maximum depth (m), presence of crevice/holes (10 cm or greater). As a protected species, presence of seaturtles was also noted. A detailed description of the topography survey protocols is provided in Appendix I. As a consequence of logistical constraints inherent in field sampling (e.g., limited bottom time for divers, adverse weather) some topographic surveys were less than the 25 total bins. Only sites with greater than 5 survey bins (10 m of transect length) were analyzed.

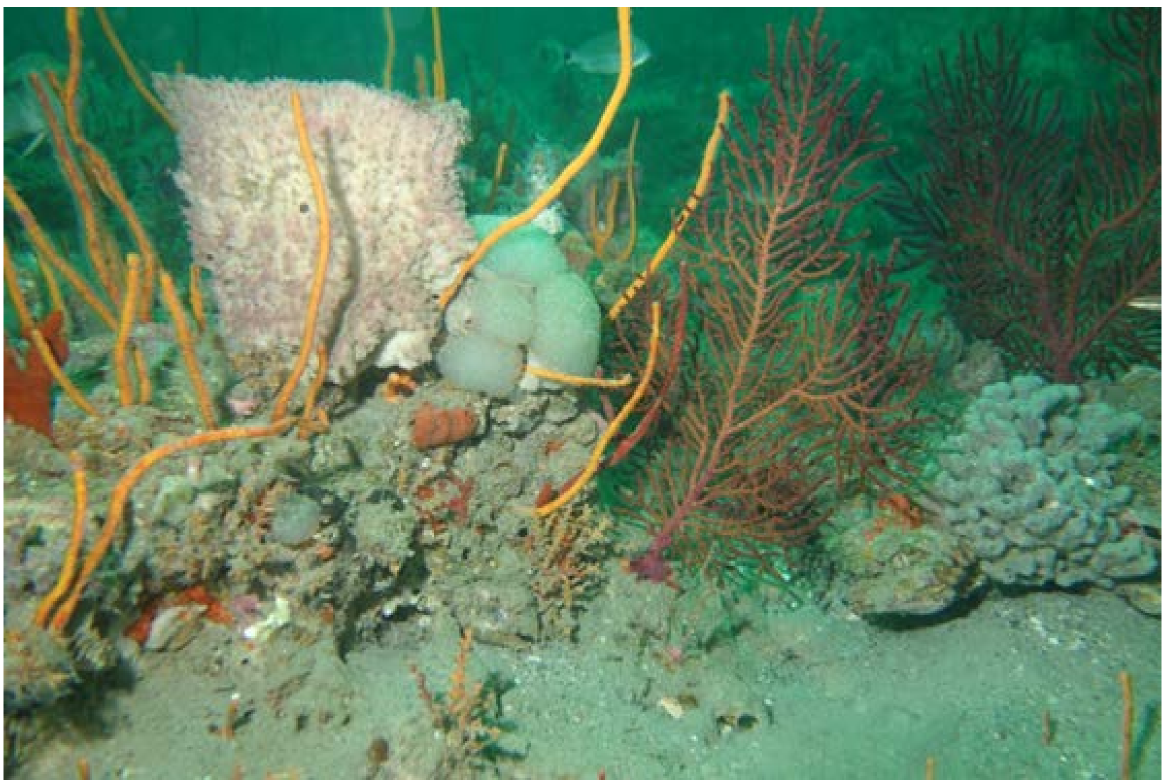

Figure 2-8. An example of hardbottom habitats within the study area. Heights of abiotic and biotic components contribute to the reef structure, which is influential in structuring fish communities.

2.3.2.2. Line Point Intercept (LPI) surveys

Biotic and abiotic bottom cover were quantified using LPI for 100 points at 50 cm intervals along the fish transect (starting at 0 m and ending at 49.5 m). Each sample point was identified based on functional categories (Table 2-7) and the underlying abiotic type (hardbottom, soft/sand, or rubble) was noted. Hereafter we define hardbottom as rock with or without a dusting of sand (maximum sand depth 2.5 cm or 1”). Rubble is defined as moveable rock, up to about 10 cm maximum dimension. Sand was selected where sand depth exceeded 2.5 cm (or 1”).

A detailed description of the LPI protocol is provided in Appendix II and a quick reference species identification guide for each LPI species/species group can be found in Appendix III. Some benthic cover surveys comprised fewer than 100 points due to logistical constraints, only sites with greater than 40 points were included in analyses. Total sample points per transect ranged from 42 – 110.

For each site, percent cover of each functional and general category was calculated as the sum of the individual category points divided by the total number of points per transect. This approach scaled all species/functional groups to 100% cover for the entire site.

Table 2-7. Line point intercept classification categories and descriptions. Points were classified every 50 cm along the transect for 100 total points using the functional category and scoring type of abiotic structure underlying organism (hardbottom, soft/sand, or rubble).

General Category	Functional Category	Description
Bare substrate	Bare	Uncolonized substratum (hardbottom (rock), rubble, or sand)
Macroalgae/ Brown Algae	*Sargassum*	Any macroalgae within this genus. Primarily *S. filipendula* present.
	Zonaria	Any macroalgae within this genus. Primarily *Z. tournefortii* present.
	Dictyopteris	Any macroalgae within this genus. *D. hoytii* primarily with *D. polypoidioides* also present.
	Dictyota	Any macroalgae within this genus. Molecular data suggest 3 main species.
	Other brown	Any other brown algae, including brown dominated turf algae.
Macroalgae/ Green Algae	*Codium* erect	Mostly *C. isthmocladum* but may also include *C. decorticatum, C. taylorii,* and a new species revealed by molecular data
	Codium decumbent	Mainly *C. carolineanum*
	Other green	Any other green algae, including green dominated turf algae.
Macroalgae/ Red Algae	*Amphiroa*	Any macroalgae within this genus. Primarily *A. beauvosii.*
	Peysonnellia- like	Any macroalgae within this group. Molecular data suggest 3 genera.
	CCA	Any crustose coralline algae.
	Rhodymenia/ Graciliaria	Any macroalgae within these genera.
	Other red	Any other red algae, including red dominated turf algae.
Macroalgae	Unknown turf	Turf algae that cannot be identified to class (red, green, or brown).
Cnidarians/ hard coral	*Oculina* species	Any hard coral in this genus.
	Other hard coral	All other hard corals; primarily cup corals (*Paracyathus* species).
Cnidarians/ soft coral	*Titanideum fraufeldii*	
	Thesea nivea	

General Category	Functional Category	Description
	Other soft coral	Any other soft corals
Cnidarians	Anemone/Zoanthids	All other cnidarians; primarily anemones and zoanthids
Other Invertebrates	Hydroid	All hydroid species.
	Sponge- encrusting	All encrusting sponge forms (<1 cm height)
	Sponge – upright	All upright sponge forms (>1 cm height)
	Tunicate – encrusting	All encrusting tunicates (<1 cm height)
	Tunicate – upright	All upright tunicates (>1 cm height)
	Filograna implexa	Structure building colonial worm
	Worms	All other worms/annelids
	Molluscs	All molluscs
	Bryozoan – encrusting	All encrusting bryozoans (<1 cm height)
	Bryozoan – upright	All upright bryozoans (>1 cm height)
	Unknown Invert	All other invertebrates unable to identify to finer category.

At the completion of the dive LPI divers characterized the general habitat type of the surveyed area (see Table 2-8 and Figure 2-9) using dominant habitat type within the entire transect area (50 m x 5 m) for classification. Habitat types were related to the coastal and marine ecological classification standard (CMECS, in Table 2-8). CMECS provides a framework for organizing information about coasts and oceans and their living systems (FGDC 2012). In addition to the CMECS classifications for individual habitat types, the entire survey area of this study was within the South Atlantic Bight biogeographic setting and continental shelf physiographic setting (FGDC 2012).

Table 2-8. Habitat type categories assigned *in situ* by LPI divers.

WEA habitat type	Geoform Component	Substrate Component	Biotic Setting	Biotic Component	Page Reference in CMECS for each site description
Sand	Sediment Wave Field	Unconsolidated mineral Substrate	None	None	
Ledge	Rock Outcrop	Rock Substrate	Benthic/ Attached Biota	Attached fauna and diverse colonizers and benthic macroalgae including sponges, soft corals, gorgonians and algae	Pg 148, 152-173
Mixed HB	Rubble Field	Coarse Unconsolidated Substrate: Boulder and Cobble	Benthic/ Attached Biota	Attached fauna and diverse colonizers and benthic macroalgae including sponges, soft corals, gorgonians and algae	Pg 148, 152-173
Pavement	Pavement Area	Unconsolidated mineral substrate	Benthic/ Attached Biota	Sparse attached fauna and diverse colonizers and benthic macroalgae including sponges, soft corals, gorgonians and algae	
Artificial	Wreck	Anthropogenic Wood or Metal	Benthic/ Attached Biota	Sparse attached fauna and diverse colonizers and benthic macroalgae including sponges, soft corals, gorgonians and algae	Pg 148, 152-173

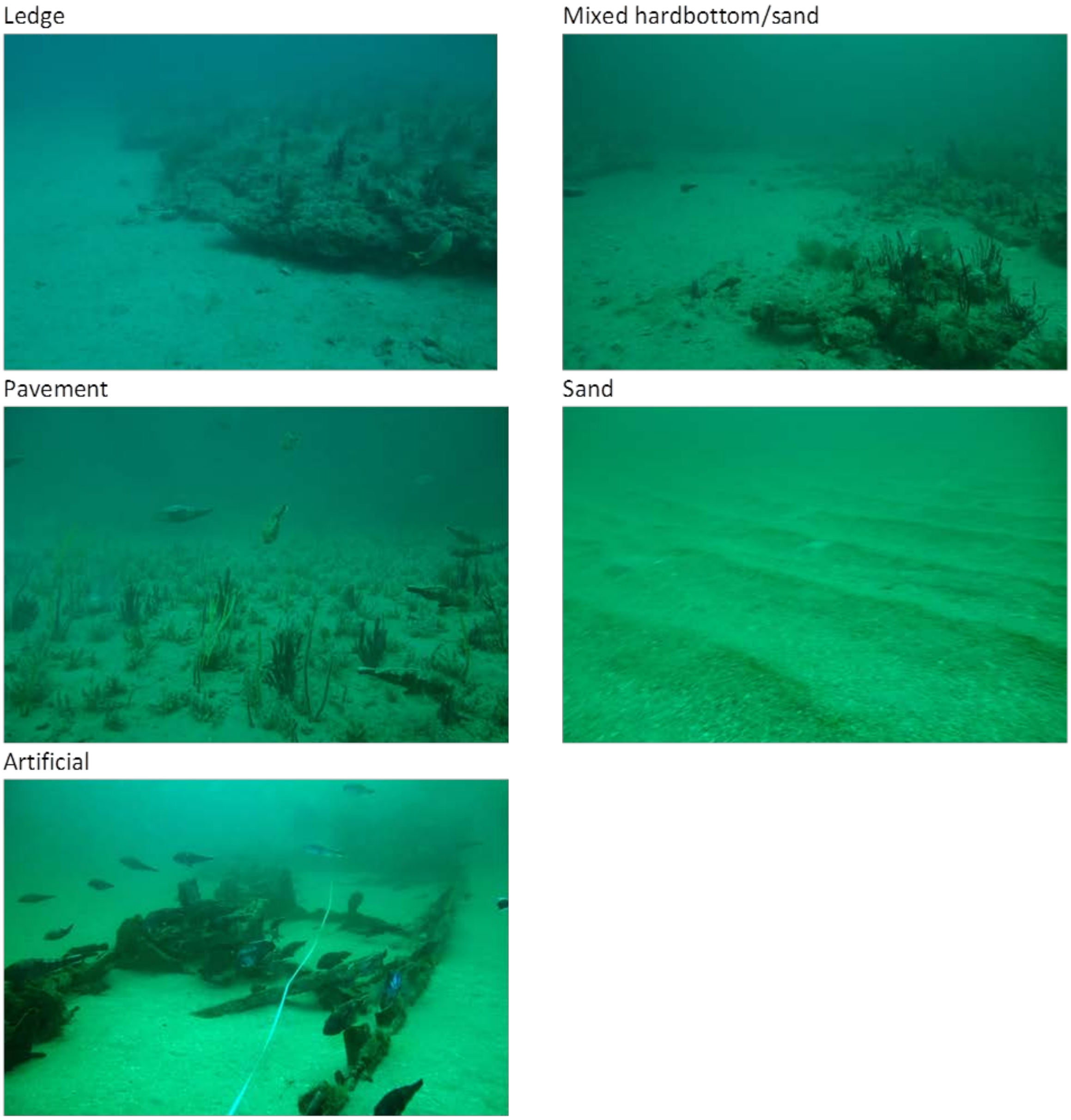

Figure 2-9. Examples of habitat types surveyed. See Table 2 for a description of each habitat type.

2.3.2.3. Targeted benthic macro-invertebrate surveys

The objective of targeted benthic macro-invertebrate surveys was to quantify density, abundance and height of less ephemeral species (soft coral species, hard coral species, and barrel/vase sponges). These surveys were conducted at a haphazardly-selected subset of survey sites due to requirements for extended sampling time and specialized expertise in field identification.). A complete list of the species and species groups recorded is listed in Table 2-9 and a detailed description of the macro-invertebrate survey protocol is provided in Appendix IV along with a species identification guide in Appendix III. Along the transect used by the LPI surveyor and within a 1 m-wide belt transect, the macro-invertebrate survey diver counted and recorded height

(10 cm intervals) for each soft coral species, hard coral species/species group, and vase/barrel sponge encountered. Targeted benthic surveys ranged in area covered, 10 – 27m^2; survey length varied based upon time limitations at depth. Where species were abundant (e.g., Pavement image in Figure 2-9) and counting individuals was time prohibitive, the species was identified as abundant a maximum number of 100 individuals per size class was recorded. This occurred at 9 sites (number of sites by habitat type: ledge = 5, mixed HB/sand = 3, pavement = 1).

Table 2-9. Macro-invertebrate/Octocroal survey species and species groups. All organisms recorded within the survey area were identified to species/species group level and maximum height was recorded in 10 cm bins. See Appendix III for species identification guide.

General Category	Species or Functional Category
Soft Coral	*Carioja riisei*
	Leptogorgia hebes
	Leptogorgia setacea
	Leptogorgia virgulata
	Muricea pendula
	Telesto sanguinea
	Thesea nivea
	Titanideum frauenfeldii
	Other soft coral
Hard Coral	*Oculina* spp.
	Solenastrea hyades
	Cup corals
Sponge	Barrel/Vase sponge

2.3.2.4. Photo-quadrat Surveys

Photo-quadrats were collected to provide another estimate of percent cover of benthic species and a baseline record of benthos at the time of sampling (Figure 2-10). Photo-quadrats and LPI both describe percent cover of benthic habitats, the data collected by photo-quadrats is at a finer resolution (both taxonomically and spatially) than that collected during LPI surveys. These surveys were conducted at a subset of fish/LPI survey sites. Photo quadrats (30 x 30 cm) were collected every two meters along the fish transect beginning at 0 and ending at 50 m. A complete list of species and species groups recorded during photo quadrat analysis is provided in Appendix V and a detailed description of the photo quadrat survey protocol is provided in Appendix VI. Following data collection, photographs were downloaded for later analysis back at the laboratory.

Photo-quadrats were analyzed using CoralNet (Beijbom et al. 2012). Images were cropped to fit the 30 x 30 cm quadrat frame and was further subdivided into 32 grid cells (6 x 6 cells). Seventy-two points were randomly placed within the frame, two per grid cell. Substrate type, when exposed, and epibenthic organisms (macroalgae, sessile invertebrates) under each point were identified to the lowest taxonomic level possible or to functional groups and entered into the program using a code file developed for this project. Benthic cover values (in %) within photo-quadrats for each species/group were exported from CoralNet and compiled within major categories using JMP (SAS Institute 2013).

Figure 2-10. An example of a photo quadrat image.

2.3.2.5. Benthic Characterization Statistics

Parametric and non-parametric tests were conducted in JMP (SAS Institute 2013). A t-test was used to compare differences in biotic and abiotic heights between habitat types and to test for differences in biotic and abiotic height within the sampling domain. A Kruskal-Wallis test was conducted to evaluate differences in abiotic cover where all sites were combined. Data approximated the normal distribution so ANOVA was run for LPI means by habitat type. For all statistical tests, an alpha level of 0.05 was used, the machine learning algorithm random forests was used to examine potential relationships with macroalgal cover and invertebrate cover, respectively, and environmental predictors. Random forests is a non-parametric statistical method of ensemble modeling of classification and regression trees that uses a set of bootstrap samples on each population sub-sample without assumptions of distributions between covariates and response variables (package randomForestSRC; Breiman 2001, Ishwaran and Kogalur 2014, R Development Core Team, 2013). Model fit and validation are included in the algorithm; each bootstrap sample in each of the 5,000 trees in the forest included approximately 63.2% of the population, and the remaining observations were used as a hold-out test set. Comparisons included: (1) diver-measured habitat characteristics (i.e., hardbottom cover, maximum depth, hardbottom height); (2) products derived from multibeam bathymetry (i.e., slope, change in slope, rugosity over 3x3 or 5x5 surrounding grid cells; and (3) spatial coordinates (UTM). Only sites that were within the multibeam survey area were included in analyses.

2.3.3. Assessing Fish Community Composition and Sizes

Fish communities were surveyed in a narrow depth range, 81-105 feet in salt water (23 – 30 m), using two types of underwater visual census band transects referred to in this document as conspicuous and cryptic fish surveys as documented in Whitfield et al. (2014). Focusing on highly mobile and conspicuous fish, divers identified fish of all sizes to lowest possible taxonomic level within a 50 m x 10 m (500 m^2) transect (Figure 2-11). When limited by visibility, divers documented the width of the transect adjusting for reduced visibility. Fish were sized using total length (TL) in 10 cm categories up to 90 cm. Actual length was used for fish greater than 90 cm. Divers also noted height of the conspicuous fish over the bottom to link the diver data in with acoustic sampling conducted from the vessel. Cruise duration dictated the number of sites surveyed resulting in 52 conspicuous surveys conducted over a mixture of natural and artificial hardbottom sites.

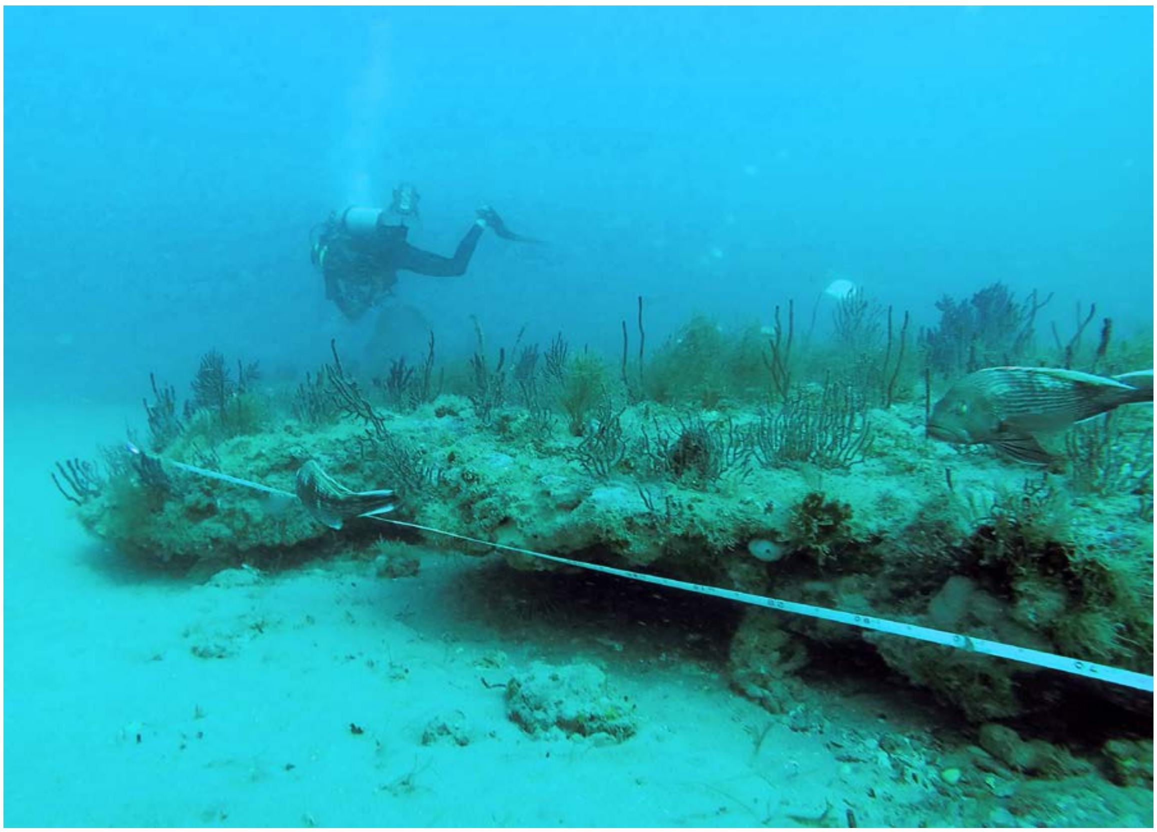

Figure 2-11. Science diver conducting a conspicuous visual census band transect at a ledge habitat.

A cryptic fish survey was implemented to target smaller benthic-oriented (cryptic) fish species. Divers documented small-bodied (2-20 cm TL) cryptic and juvenile fish to species over a 25 m x 2 m (50 m^2) band transect on the return swim from the conspicuous survey. Fish were sized in smaller bins for this survey type up to 20 cm TL. Fish greater than 20 cm seen during the cryptic survey were not documented as the methods focus on smaller fish. Divers were also tasked with documenting certain macroinvertebrates (sea urchins, spiny and slipper lobsters) on a gross scale (single, few, or many) as well as noting the presence of threatened and endangered species (sea turtles, marine mammals). Due to time constraints at depth cryptic surveys were conducted at 47 of the 52 sites.

2.3.3.1. Fish Community Statistical Analysis

Fish community metrics were calculated separately for conspicuous and cryptic surveys by site and habitat type (ledge, mixed HB/sand, pavement, artificial). Summary statistics were estimated for fish communities, trophic groups, commercially important species, family level, and apex predators (density and mean density (± SE) per 100 m^2, biomass and mean biomass (± SE) in kg/100m^2, and species richness). Trophic guilds surveyed included: benthic carnivores, herbivore, invertivores, omnivores, piscivores, and planktivores based on published information or from information from FishBase (Froese and Pauly 2008). Biomass was calculated using the length-weight power function ($W = aL^b$) and converted to kilograms. The midpoint of each size class was used for L up to 90 cm after which reported actual lengths were used. A TL of 3 cm was used for the smallest size class. Species-specific values for *a* and *b* parameters were provided by FishBase. Biomass was then adjusted by area (100 m^2): for the remainder of this report when biomass is referred to it is in the context of kg/100 m^2.

Initial exploratory results indicated that data from both conspicuous and cryptic communities to be non-normally distributed, requiring the use of non-parametric statistical analyses. Fish community metrics (abundance, biomass, and species of richness) were compared by bottom type using the non-parametric Kruskal-Wallis test (Z).

Relationships between fish community metrics and benthic parameters (biotic: percent cover of macroalgae, invertebrates, and bare (lack of live cover); abiotic: percent hardbottom, softbottom, and rubble) were explored using non-parametric Spearman's ρ (rho) rank correlations. Due to uneven sampling across habitat strata and outlier exclusions, comparisons of conspicuous and cryptic community data were reduced depending on the variables of investigation: benthic cover (Consp N = 50, Cryptic N = 44); biota height (Consp N = 44, Cryptic N = 43); hardbottom height (Consp N = 43, Cryptic N = 39); octocoral height (Consp N = 41, Cryptic N = 40); and multibeam-derived rugosity (Consp = 43, Cryptic = 38).

Differences and similarities in species composition by habitat type and benthic community metrics were further examined using multivariate statistical techniques (Primer v6, Clarke et al. 2006). Density and biomass data were 4^{th} root transformed to down-weight the importance of highly abundant species prior to analysis. Analysis of Similarities (ANOSIM), a multivariate, non-parametric version of ANOVA was used to test for significant differences in similarity of community structure by habitat type. Non-metric multi-dimensional scaling (nMDS) plots of fish community structure (based on biomass or density) were used to visualize the multivariate results.

To determine the role of continuous habitat variables (depth, rugosity, habitat height, and percent cover of hardbottom, rubble, sand, macroalgae, and invertebrates) in structuring fish communities the global BEST procedure was conducted with 999 permutations. This procedure determines which community variable(s) 'best' explained the pattern of fish community structure (based on density or biomass): variables with the highest spearman rank correlation with the corresponding fish community resemblance matrix reflect those factors most important in structuring the fish communities.

2.4. Seasonal Diver Assessments of Hardbottom Habitats

2.4.1. Seasonal Survey Site Selection

To determine the effects of hardbottom habitat complexity and sediment dynamics on fish and benthic communities, we conducted comprehensive *in situ* SCUBA-diver surveys of sixteen reefs off the coast of NC (Figure 2-12; Table 2-10). Half of these temperate reefs are located in southwestern Onslow Bay in an area of known hardbottom with varying complexity, while the other half are within northeastern Long Bay in the study area. The sites in Onslow Bay were selected *a priori* based on a design that stratified by water depth, which is correlated with distance from shore. The sites in the study area were selected from side-scan sonar and multibeam bathymetry datasets acquired during the seafloor mapping cruise in June 2013. Half of these sixteen sites are natural reefs, ranging from flat pavements to extensive ledges, while half are artificial reefs and include ships that were purposely sunk as part of the NC Artificial Reef Program, as well as historic and previously undiscovered shipwrecks. Sites were sampled seasonally during 2013 – 2014 in the fall, winter, spring, and summer (Appendix VII). Most sites were sampled during each season, but due to sea conditions, several were sampled during only one season.

At each site, two 30-m long transects were established along prominent hardbottom features. The distance of transects for seasonal assessments were shorter than the ground validation surveys above due to the same limits of bottom time and need to record additional metrics related to sediment dynamics (described below). When no prominent feature existed, the transect direction was opportunistically directed towards any hardbottom that was present or, if hardbottom was present is multiple directions, the transect direction was selected from a list of randomly generated compass headings. The transect location at each site varied among seasons. Surveys to quantify fishes, benthic cover, structural complexity, sediment cover, and water temperature were conducted along each transect. A total of 131 transects were conducted across all sites.

2.4.2. Assessment of Benthic Communities and Environment

2.4.2.1. Fish Community Assessments

To quantify variability in fish community metrics, such as composition and abundance, over a spectrum of reef complexities, we conducted *in situ* fish transects and corresponding habitat surveys. Divers sampled along a 30 m x 4 m (120 m^2) belt transect (e.g., Brock 1954, Brock 1982, Samoilys and Carlos 2000) while recording the species and abundance of all fish present throughout the water column, including both conspicuous and cryptic categories of reef fish, to the lowest taxonomic level possible (Figure 2-13A). Fish fork length was estimated to the nearest cm.

Table 2-10. Sixteen hardbottom study sites located in southwest Onslow Bay (SWOB) and Wilmington-East Call Area (WECA) that were assessed seasonally. Artificial reefs contain a description of the vessel type, length, and history.

Name	Code	Description	Lat.	Long.	Reef Type	Depth	Location
Alexander Ramsey	ALEXR	Liberty ship (441' long) sunk in 1974 as part of NC Artificial Reef Program (AR-370)	34.1753	-77.7520	Artificial	Intermediate	SWOB
Hyde	HYDE	USACOE dredge (215' long) sunk in 1988 as part of NC Artificial Reef Program (AR-386)	33.9575	-77.5572	Artificial	Intermediate	SWOB
John D. Gill	JGILL	Tanker (528' long) sank in 1942 when torpedoed by U-*158*	33.8663	-77.4817	Artificial	Intermediate	SWOB
Cassimir	CASSI	Freighter (390' long) sank in 1942 after collision with another freighter	33.9656	-77.0303	Artificial	Deep	SWOB
Dallas Rocks	DALRK		34.2320	-77.6323	Natural	Intermediate	SWOB
200 / 200 Ledge	200.200		34.1321	-77.3606	Natural	Deep	SWOB
23 Mile Ledge	23MLE		33.9992	-77.3778	Natural	Deep	SWOB
5 Mile Ledge	5MLED		34.1022	-77.7508	Natural	Intermediate	SWOB
Raritan East	RARIT	Freighter (251' long) sank in 1942	33.5417	-77.9484	Artificial	Intermediate	WECA
City of Houston	CITYHO	Passenger freighter / steamer (290' long) sank in 1878 during a storm	33.4052	-77.7120	Artificial	Deep	WECA
Unknown Wreck 1	BMPKS		33.3940	-77.8780	Artificial	Deep	WECA
Unknown Wreck 2	HBYRD		33.4818	-78.0017	Artificial	Deep	WECA
Thumb Ledge	THUMB		33.5125	-77.8855	Natural	Intermediate	WECA
Hammerhead Ledge	HAMRH		33.5219	-77.8765	Natural	Intermediate	WECA
Lightning Bolt Ledge	LIGHT		33.4774	-77.8927	Natural	Deep	WECA
Bumpy Ledge	BUMPY		33.4606	-77.8776	Natural	Deep	WECA

Fish counts included total abundance and abundance by size class (small fish 1-10 cm; medium fish 11-29 cm; large 30-49 cm; apex predators 50+ cm). As per our survey design, we aimed to conduct two fish transects on each reef, but several times only one survey was conducted due to sea conditions. When two belt transects were conducted at a hardbottom site during a sampling season, the fish abundances were averaged to avoid pseudoreplication (Hurlbert 1984). Fish abundances were calculated at the finest taxonomic resolution possible (e.g., species), as well as for families and functional groups. Functional groups reflected the trophic ecology of each species and included carnivores, herbivores, invertivores, omnivores, piscivores, and planktivores. Metrics were also calculated for fish within the snapper-grouper complex because of management importance. In addition to fish abundance, we calculated species richness (S), Shannon-Wiener diversity (H’), and evenness (J).

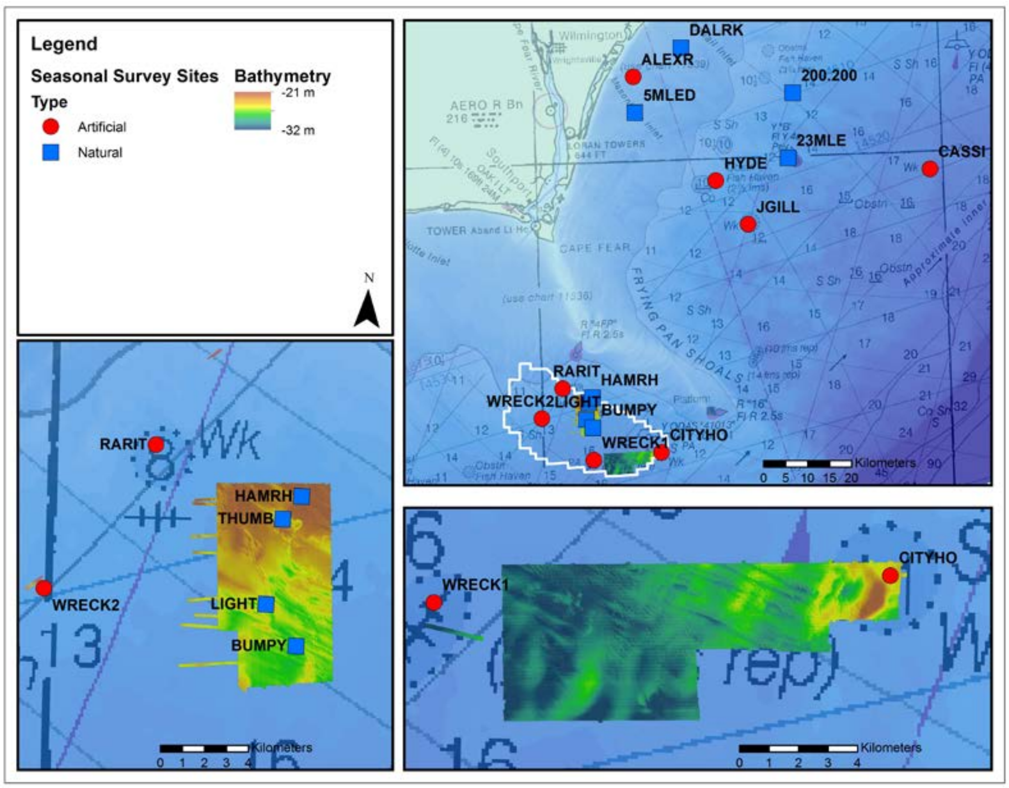

Figure 2-12. Locations of hardbottom study sites used for seasonal habitat assessments.

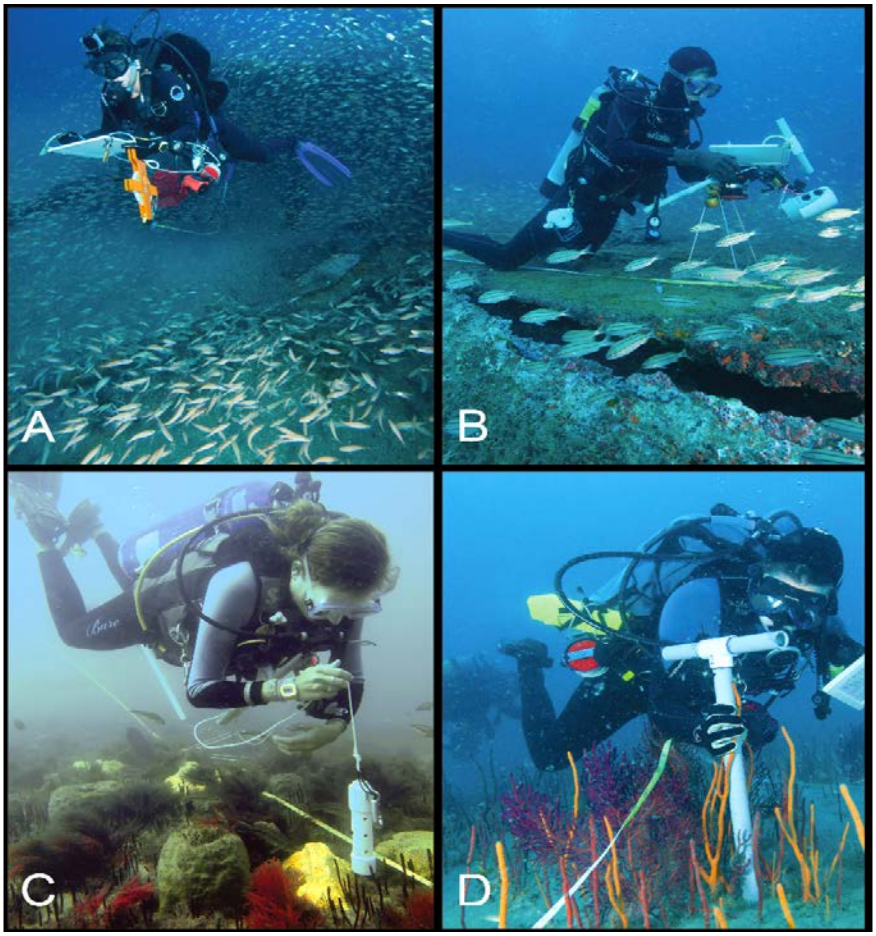

Figure 2-13. Survey methods for seasonal assessments of hardbottom habitat and biological associates: A) fishes along a belt transect; B) benthic community in a photoquadrat; C) structural complexity using a water level logger; D) sediment depth using a T-rod.

2.4.2.2. Benthic Community Assessments

To evaluate effects of hardbottom complexity and sediment dynamics on benthic communities composed of benthic invertebrates and macroalgae, we conducted photoquadrat surveys of percent cover (Bohnsack 1979). Eleven 25 cm x 25 cm photoquadrats (Figure 2-13B) were obtained along each 30 m transect every 3 m between 0 m and 30 m with an Olympus E-PM1 twelve megapixel digital camera, Olympus PT-EP06 underwater housing, Ikelite DS161 Substrobe, and underwater framer with an attached ruler. The underwater framer was attached to the camera housing to ensure that the distance between the camera lens and the photoquadrat was consistent among photos. Two images of each quadrat were taken to provide duplicate versions if needed (e.g., if one photo was not in focus). Because transects were randomly established during each sampling season, specific photoquadrat sites were not revisited.

To analyze the digital images, CoralNet software (Beijbom et al. 2012) was used to overlay 100 stratified random points on each photoquadrat image. The 100 points were stratified such that the image was divided into five rows and five columns of cells. In each cell, four points were randomly generated. The organism present at each point was identified to the lowest taxonomic level possible by CoralNet using a machine-learning algorithm. Each point identified by the algorithm was then verified or corrected by trained analysts. If multiple layers of epibiota were present, the topmost layer was identified. Percent cover was calculated at the lowest taxonomic level possible and also summed for phyla and functional group for each photoquadrat and averaged for each sampling season at each hardbottom site to prevent pseudoreplication (Hurlbert 1984). Points on each quadrat that had been identified as transect hardware, fish, or unclear were removed, and the total number of points was scaled back up to 100 points per quadrat so that all quadrats could be compared.

2.4.2.3. Structural Complexity

To document how structural complexity affects fish community metrics, such as composition and diversity, we measured the contour of each reef using an Onset HOBO U20 Titanium Water Level Logger (U20-001-02-Ti) containing a pressure-transducer that records fine-scale variation in depth, from which bottom elevations were inferred. As per methods in Dustan et al. (2013), a single diver swam over the reef with the logger suspended from a line and positioned as close to the substrate as possible (Figure 2-13C). The logger was moved ~ 10 cm per second over the length of each 30 m transect. The logger was raised 1 m above and rapidly lowered back down to the substrate surface in a spike motion five times at the start and end of each transect and three times every 5 m between these endpoints. Because the logger records continuously during each dive, these spikes were used to identify each transect within the data stream and calibrate the distance surveyed. During post-dive processing, the distance calibration spikes were removed from each file using Microsoft Excel, and the raw pressure recorded by the pressure-transducer was converted from units of psi to m, assuming that atmospheric pressure was 1 atmospheres, corresponding to the water depth. If the sampling rate differed from the target rate of ~ 10 cm per second, then the transect length was scaled to 30 m so that transects could be compared.

For each transect, the contour of the hardbottom reef was visualized by plotting transect distance against water depth. The average, minimum, and maximum depths were calculated for each transect. The vertical relief of each transect was calculated as the difference between the minimum and maximum depth. Digital reef rugosity (DRR) (Dustan et al. 2013) was calculated as the standard deviation of depths along each transect. An alternative measure of rugosity was calculated as the ratio of the actual surface contour distance to the linear transect distance as:

$$C = D / L$$

where C = rugosity, L = linear distance of transect (m), and D = distance of transect following the natural surface contour (m) (Risk 1972, McCormick 1994). The distance of the natural surface contour (D) was calculated as the sum of the hypotenuses between every two successive depth measurements recorded by the water level logger. To visualize the distribution of complexity values across reefs, Gaussian based kernel density (Sheather and Jones 1991) was estimated using the ‘stats’ package (R Development Core Team 2014).

The spatial variability of each transect was visualized with variograms. Variograms are a spatial analysis technique that decomposes the spatial variability in a transect among distance classes (Legendre and Fortin 1989, Legendre and Legendre 2012). The distance classes corresponded to every measurement of depth (m) separated by 10 cm through to 300 cm (30 m), or the entire transect distance (e.g, 10 cm, 20 cm, 30 cm… 280 cm, 290 cm, 300 cm). The variance attributed to each of these distance classes is called the semivariance. The semivariance was calculated as:

$$\gamma(d) = 1 / (2N(d)) \sum_{i=1}^{W(d)} (y_i - y_{i+d})^2$$

where $\gamma(d)$ is the semivariance at distance class d, N(d) is the number of pairs for separation of distance class d, y_i is the depth at location i and y_{i+d} is the depth at location i plus the distance class value d, and W(d) is the final location of the transect that corresponds to distance class d (Isaaks and Srivastava 1989, Legendre and Legendre 2012). The semivariance was plotted against distance classes up to 15 m (half the transect length). This ensured that we plotted the spatially structured component of each transect. The resulting variograms depict the spatial scale over which the complexity of each reef varied.

2.4.2.4. Sediment Cover

To document how changes in sediment cover across a range of habitat complexity, we measured sediment depth using a hollow 2 cm diameter PVC rod with graduated markings to the nearest cm (Figure 2-13D). Sediment depth measurements were obtained every three meters along the same transect that fish and structural complexity were sampled, and after fish sampling for that transect was completed. The sediment measurements were obtained at the same locations as each photoquadrat image.

Sediment cover data were maintained at the level of each measurement for comparison with benthic community assessment data. Sediment data were also averaged over multiple transects when a hardbottom site was surveyed more than once in a sampling season. The average, maximum, minimum, and range of sediment cover were calculated for each site per sampling period. Standard deviation was also calculated to indicate how permanent (low standard deviation) or ephemeral (high standard deviation) sediment cover changed on hardbottom reefs across the seasons.

2.4.2.5. Water Temperature

To document the influence of seasons on the fish and benthic communities, we measured water temperature on each transect using the same Onset HOBO U20 Titanium Water Level Logger (U20-001-02-Ti) that we used to measure structural complexity. The water level logger recorded water temperature every second over the duration of each transect. Back in the laboratory, raw temperature values were used to calculate the average, maximum, and minimum temperature (^{o}C) over each transect. When multiple transects were conducted in the same sampling season, the water temperatures were averaged.

2.4.3. Analyses of Seasonal Assessments

Analyses of data from seasonal assessments were conducted using R (R Development Core Team 2014) with an alpha value of 0.05. Correlation analyses were conducted using the 'ecodist' package (Goslee and Urban 2007) to determine correlations between environmental variables. Collinear and redundant variables were removed from further analyses based on prior ecological knowledge. For structural complexity, we retained the variable for digital reef rugosity. For sediment dynamics, we retained the standard deviation of sediment cover. For temperature, we retained the average temperature. Shapiro-Wilk normality tests were conducted to determine if the environmental variables were normally distributed. Violations of normality were corrected by appropriately transforming variables and corrections were visualized with histograms. Species data for both fish and the benthos were square-root transformed to reduce the contribution of rare species and abundant species.

Potential differences in fish community composition on natural and artificial hardbottom were examined with Analysis of Similarities (ANOSIM). ANOSIM tests for differences in community composition based on ranked pairwise similarity values between samples (Clarke 1993, McCune and Grace 2002). ANOSIM was conducted on the resemblance matrix based on Bray-Curtis distance. The specific drivers of differences detected with ANOSIM were determined with Similarity Percentage Analysis (SIMPER, reef type). SIMPER determines how individual biological response variables, such as species, families, or trophic groups, within the larger multivariate dataset contribute to the overall Bray-Curtis dissimilarity (Clarke 1993). Similar to ANOSIM, SIMPER is based on pairwise comparisons (Clarke 1993). Both ANOSIM and SIMPER were conducted using the 'vegan' package (Oksanen et al. 2013). The influence of geographic location (study area vs. Onslow Bay) and season (fall, spring, summer) on fish community composition were also examined with SIMPER.

Nonmetric multidimensional scaling (nMDS), an ordination technique used to summarize patterns in the structure of multivariate datasets (Shepard 1962, Kruskal 1964, Legendre and Legendre 2012), was performed separately for the fish community and benthic community data. The samples were mapped into an ordination space, such that the ecological distances between samples were ordered by rank terms. These analyses were conducted on all data, as well as for subsets of data by reef type and location, such that groups of samples that were different according to ANOSIM could be visualized separately. First, Bray-Curtis distances were calculated on the square-root transformed data to summarize pairwise distance among samples (Goslee and Urban 2007). The Bray-Curtis distance measure is appropriate because it helps overcome the problem of joint absences in species data (Goslee and Urban 2007). The resulting matrix of Bray-Curtis distances was used in a step-down procedure with 60 ordinations to select the appropriate number of ordination axes based on stress values (Goslee and Urban 2007). Non-metric multidimensional scaling ordination was conducted for two axes. Since nMDS is a numerical approximation technique, twenty iterations were run to compare solutions. The best of the twenty ordinations was selected based on minimum stress and corresponding R^2 values. The chosen ordination was rotated with principal components analysis (PCA) to force the first axis of ordination to contain the most variance so that axes could be interpreted by relative importance (McCune and Grace 2002, Legendre and Legendre 2012). To ensure that the relationship between ordination distance and Bray-Curtis distance was linear, a Shepard diagram was created. Biplots containing samples, species, and environmental vectors were produced to visualize the relationships in ordination space to discern compositional patterns. More specifically, the samples were projected into ordination space to understand their distribution. Species were projected on top of the samples as weighted average scores (Oksanen et al. 2013). Correlation vectors for environmental variables were also plotted, such that there was one correlation vector for each variable and the length of each vector was scaled to the magnitude of the correlation.

Influences of structural complexity on fish metrics, including abundance, richness, species diversity, and evenness, were tested with generalized linear models and mixed effects models. Linear models were fit with the ‘lm’ function with digital reef rugosity as the continuous predictor variable. Linear mixed effects models were fit using the ‘nlme’ package (Pinheiro et al. 2013) to account for reef type, location, and season and to determine the effect of the predictor (structural complexity) on the response variable (e.g., abundance, richness, species diversity, evenness). Both linear models and mixed effects models were fit to the benthic data similarly to the fitting process used for the fish data, with the exception that benthic models also included sediment dynamics (standard deviation of sediment depth).

We used permutational analysis of variance (PERMANOVA; Anderson 2001) to determine the statistical significance of structural complexity, sediment dynamics, and seasonal water temperature on the fish and benthic communities using the ‘vegan’ package (Oksanen et al. 2013). PERMANOVA is a permutation-based technique that, unlike ordination techniques used previously, explicitly tests hypotheses to provide a test of significance (Anderson 2001). More specifically, PERMANOVA uses variance partitioning to test the response of a multivariate dataset to one or more factors (Anderson 2001). The PERMANOVAs used Bray-Curtis distance between square-root transformed data and 1,000 permutations. For the fish community, the PERMANOVA model was conducted for all reefs, accounting for reef type (artificial vs. natural), structural complexity (digital reef rugosity), sediment cover (sediment standard deviation), and water temperature. PERMANOVA’s were also run separately for natural and artificial reefs for complexity and sediment. For the benthic community, PERMANOVA was conducted for all reefs, accounting for differences in reef type (natural vs. artificial), geographic location (study area in Long Bay vs. Onslow Bay), complexity, sediment, and water temperature, as well as separately for reef types and locations.

To understand effects of structural complexity, sediment dynamics, water temperature, and water depth on the benthic invertebrate and macroalgal community, we used principal components analysis (PCA). PCA is an indirect ordination technique that detects and graphically displays structure in multivariate data by finding a transformation matrix that provides a new projection of the data (McCune and Grace 2002, Legendre and Legendre 2012). More specifically, the new projection is found by constructing a new coordinate system where the new axes, the principal component axes, are combinations of the original axes. The new coordinate system is further selected by rotating the axes to determine the most parsimonious projection of the data. PCA was conducted on the correlation matrix of environmental variables (complexity, sediment, temperature, depth). Eigenvalues, proportion of variance, and scree plots were examined to determine how many principal components (PCs) to retain to explain the variance in the environmental data. To interpret the ecological nature of the PC axes, correlations of variable loadings, biplots, and sample projections were examined.

To examine potential correlations of structural complexity and sediment dynamics with fish and benthic community structure, we conducted canonical correspondence analysis (CCA) using the 'vegan' package (Oksanen et al. 2013). CCA is an indirect ordination technique that constrains the species by making the ordination axes functions of environmental variables (Ter Braak 1986, Legendre and Legendre 2012). Biotic cover of the major benthic communities (e.g., macroalgae phyla, other invertebrates, substrate) was projected into the CCA ordination space to discern compositional patterns. Vectors of the abundance of fish functional groups and environmental variables (complexity, sediment, temperature, depth) were overlaid, such that they were scaled to the magnitude of correlation. The resulting CCA plots allowed us to visualize how complexity and sediment influenced the benthic and fish communities.

3. Results

3.1. Sidescan Sonar

Sidescan sonar data were translated from the range of intensities received by the towfish. For this survey, interpretation follows conventional SSS display, with lighter colors representing areas of higher return, i.e. clean coarse sands, hardbottom, wrecks, biomass in the water column, or features facing perpendicular to the swath angle. Darker colors represent areas with more absorption, i.e. softer material such as silt or muds, algal mats, or shadows of objects with relief.

Sidescan survey operations were performed 24 hours a day, while being monitored continuously by a trained survey technician. The warm, saline waters associated with the Gulf Stream embayment and shoal features on the inner shelf of Long Bay introduced water density structure and some refraction artifacts to the outer swaths of the SSS data, mostly in the deepest parts of the survey area and when seas approached or exceeded ~2 m. These artifacts are visible as lighter to white colored “squiggly” lines (Figure 3-1).

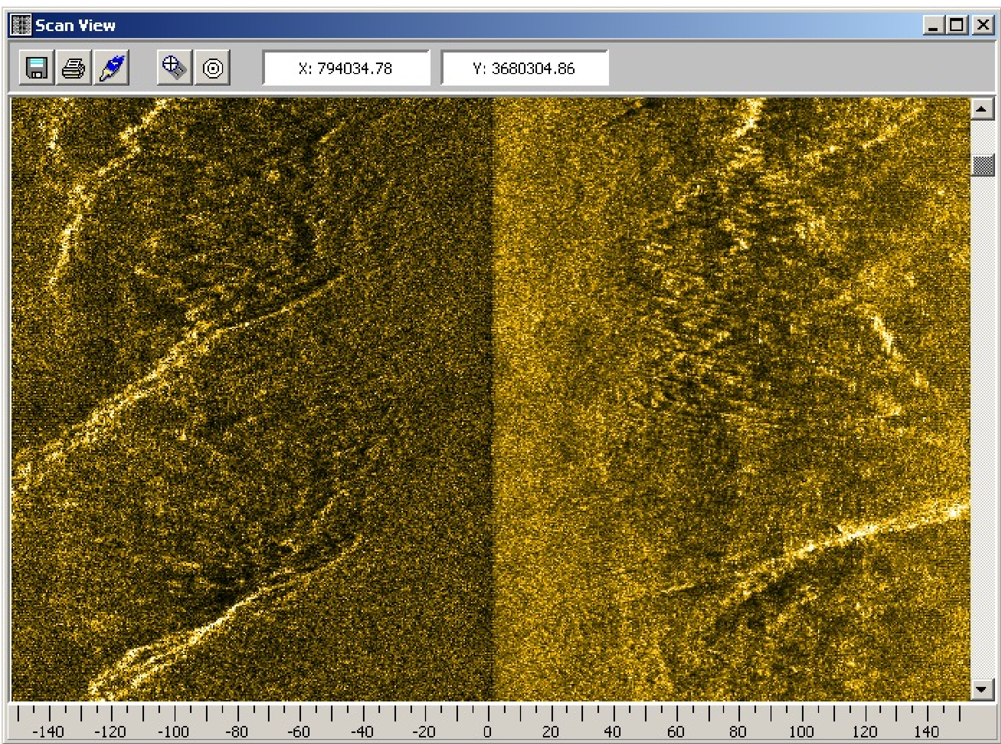

Figure 3-1. Refraction artifact observed in portions of sidescan sonar imagery.

Towfish layback calculations and positioning accuracy varied with degrading sea conditions; however, sidescan imagery is generally in good agreement with the multibeam bathymetry (Figure 3-2).

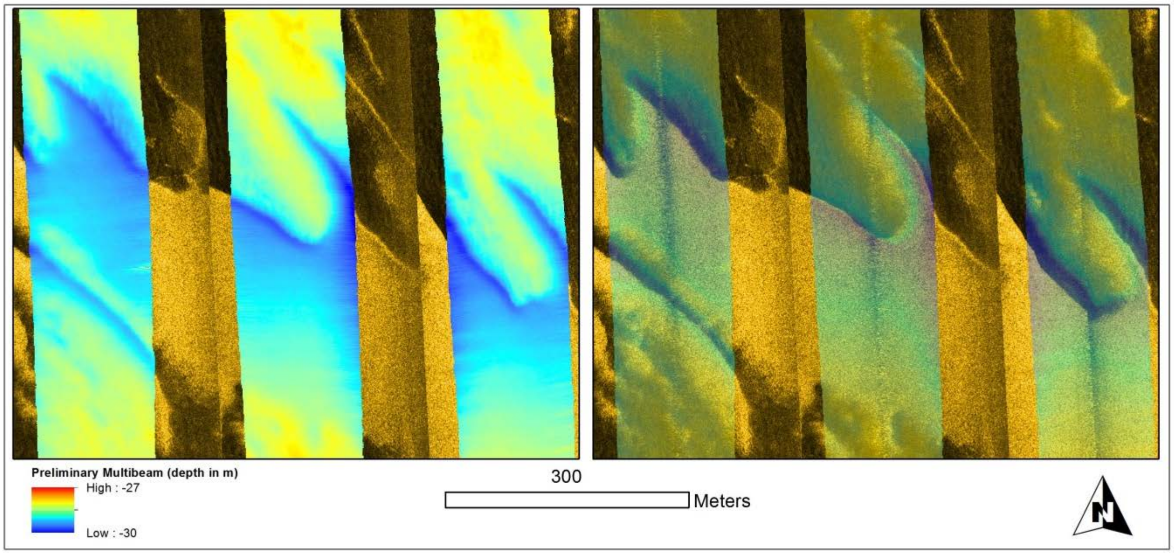

Figure 3-2. Side scan sonar imagery, overlaid by multibeam bathymetry. The two images are the same, but with the multibeam bathymetry semi-transparent in the image to the right.

Overall, SSS swath coverage maintained ~115% throughout the survey. Data quality is considered good and adequate for seafloor habitat mapping and object detection down to ~2 m (Figure 3-3 to Figure 3-7). Four classes were identified by visual inspection from the SSS imagery: coarse sands, outcrops or hardbottom, wrecks, biomass in the water column. There were 342 additional targets marked during the processing stages. As specified in Table 8, the remaining targets were identified as morphological, biological, morphological/biological, or unknown. “Biological” refers to features such as dark patches correlated with features such as algal or grass mats, as well as anomalies identified in the water column related to schools of fish. “Morphological” refers to geological features, i.e. outcrops, scours, or unique bedform features. “Morphological/biological” refers to areas that reveal a combination of the two. “Unknown” refers to anomalies in the side scan sonar record or features identified that have no interpretation as of now, but are worthy of documenting for reference. However, it should be noted that these point features do not sufficiently correlate to the actual, physical size of the recorded features. Additionally, some features span across-swath of multiple survey lines, and might be targeted more than once, specifically hardbottom. These features were most prominent in two areas, located in the north and south-central portion of the survey area, and a few scattered in between these areas (see Figure 3-4 and Figure 3-5). It was determined that digitizing the apparent features into a polyline shapefile that would more accurately describe the nature of the seafloor morphology. When comparing the north and south clusters of targets, the southern area appears to be covered by thin blankets of sediment, revealing a NE-SW trend of outcrops. Most of these features are 10 – 200 m in length with 0.2 – 0.5 m relief. The northern cluster appears to be less scoured, showing outcrops that are either spatially sparse or related to relatively fewer yet larger-scale features than the southern cluster, reaching up to 1 km in linear length with 1 – 2 m relief. Shipwrecks that were already charted or present in the Automated Wreck and Obstruction Information System (AWOIS) database were tagged and referenced to the closest mark on the nautical chart or in the AWOIS database (Figure 3-4 and Table 3-1) or new wrecks (Table 3-2).

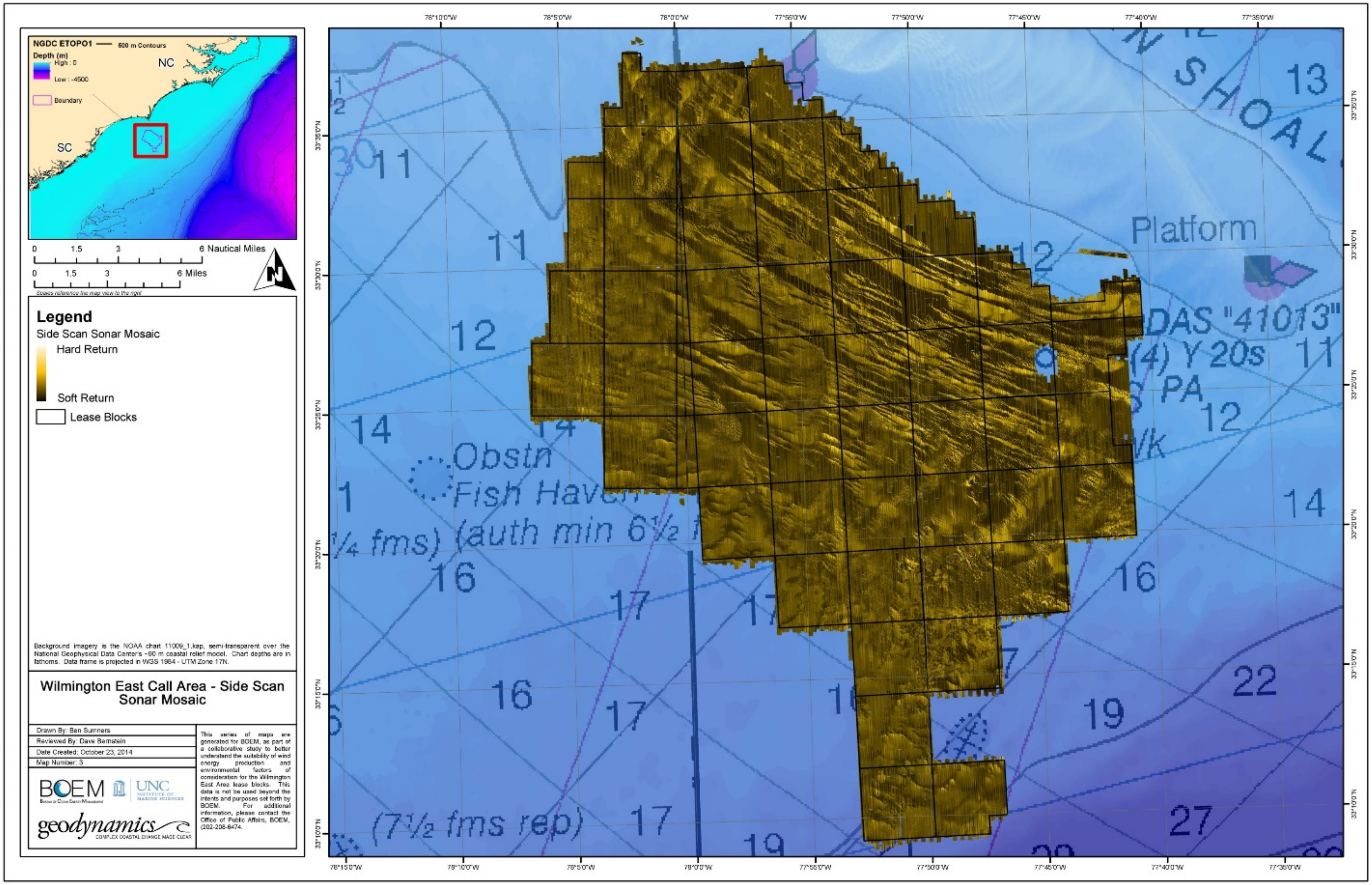

Figure 3-3. Results of the sidescan sonar mosaic, overlaid by OCS lease blocks.

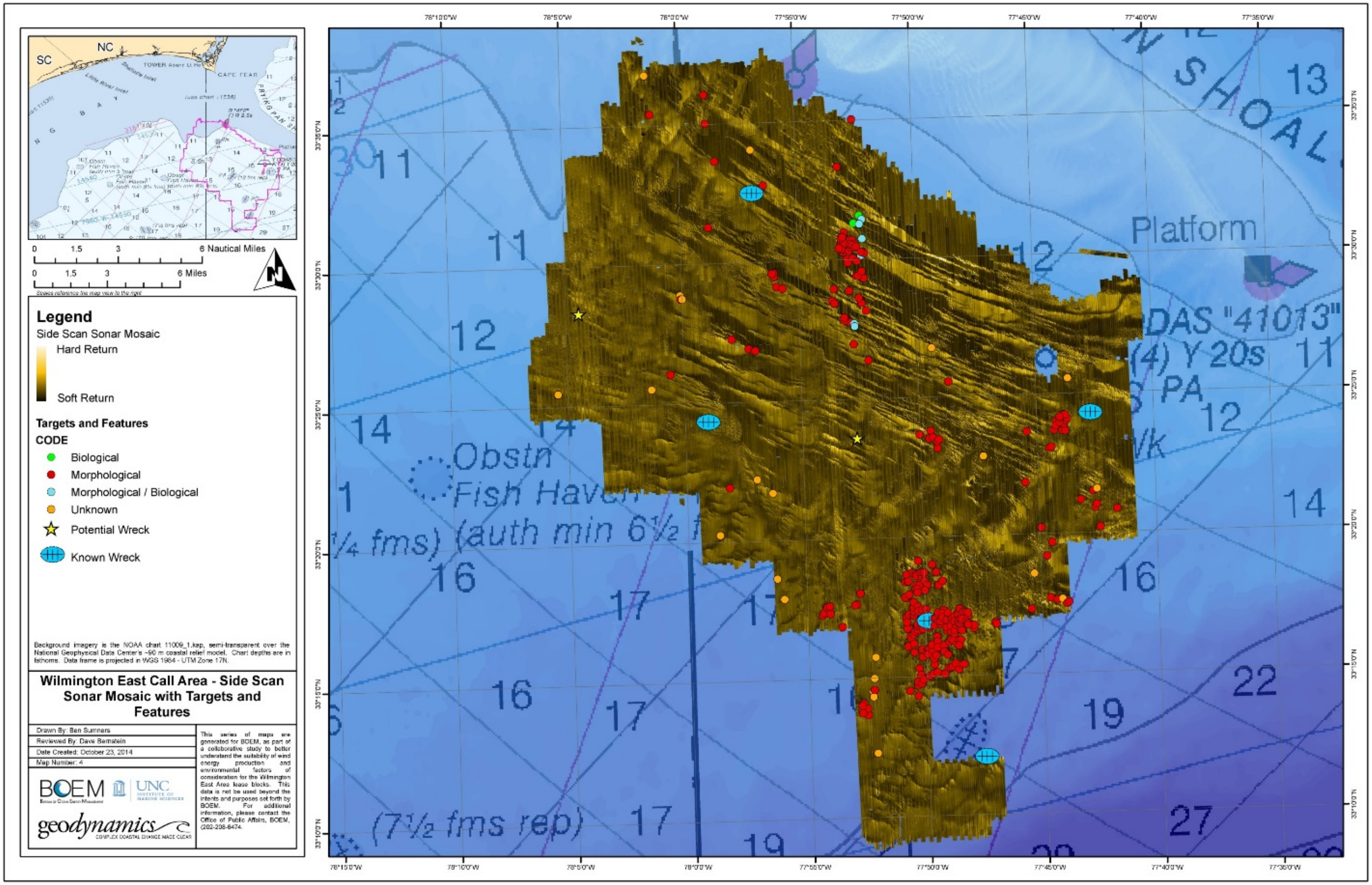

Figure 3-4. Results of the sidescan sonar target and feature database, overlaid on the sidescan sonar mosaic.

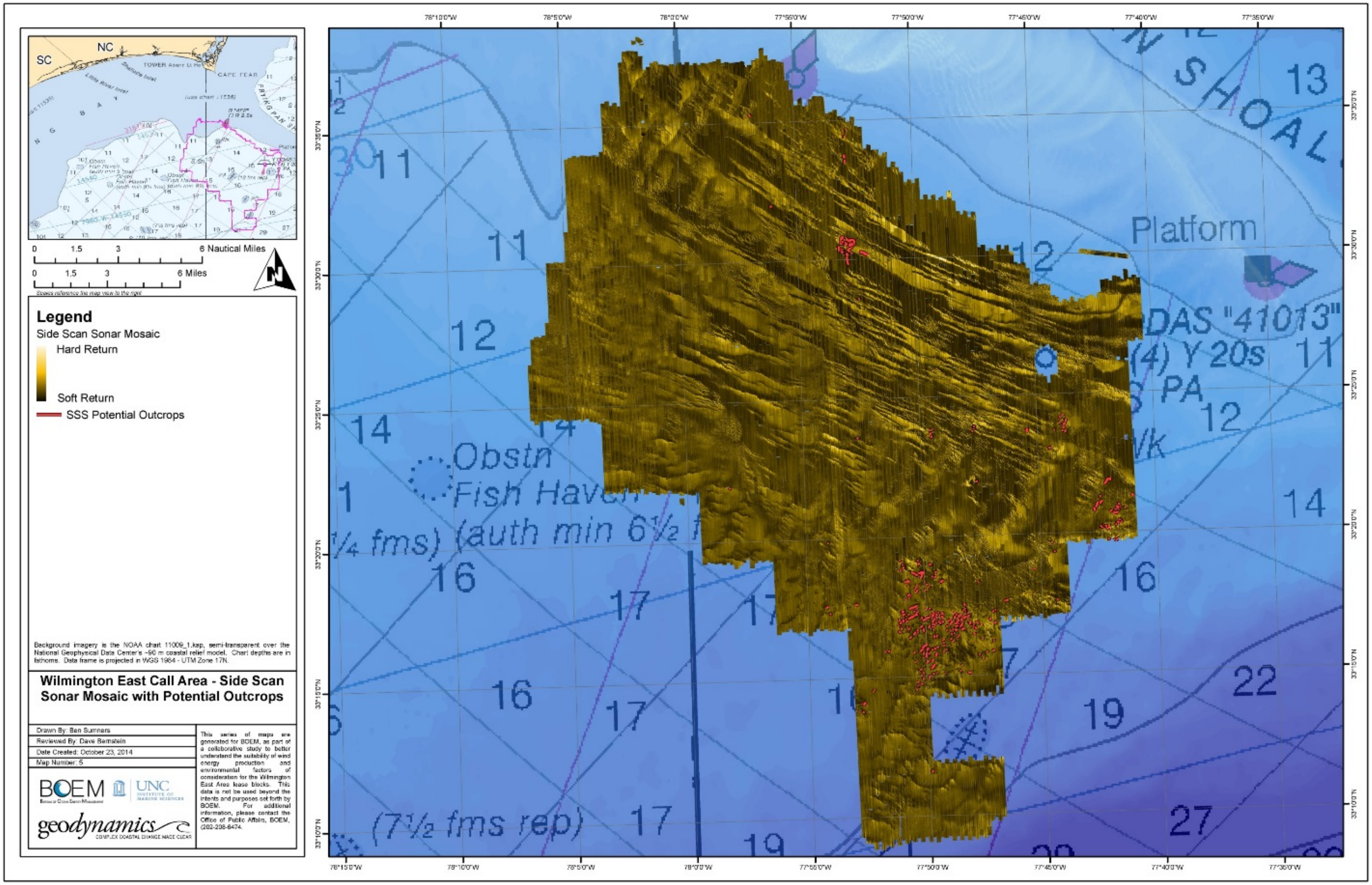

Figure 3-5. Results of the digitized potential outcrops, overlaid on the sidescan sonar mosaic.

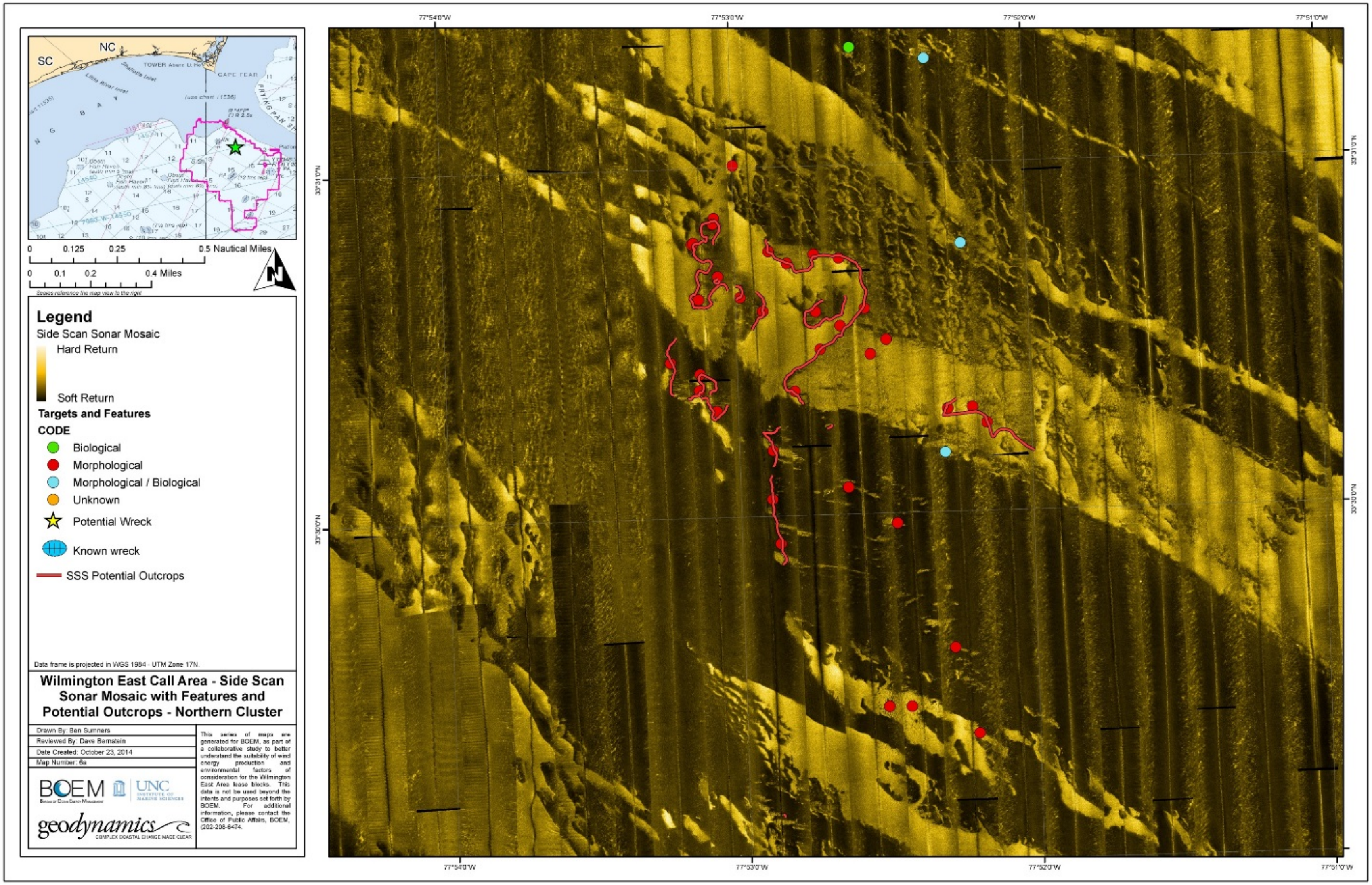

Figure 3-6. Close-up view of a cluster of features identified in the northern part of the survey area, overlaid by digitized outcrop line.

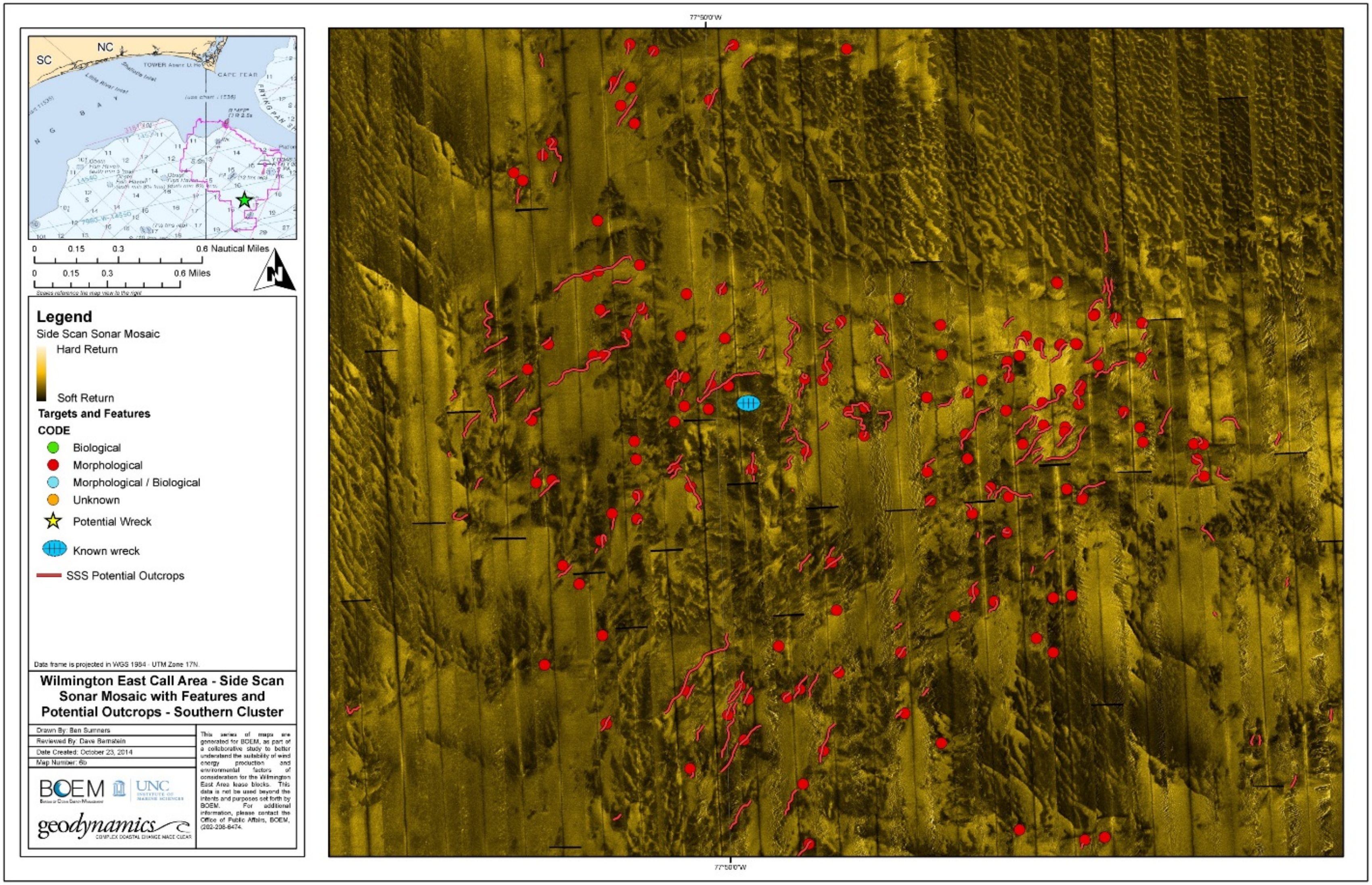

Figure 3-7. A zoomed in view of a cluster of features identified in the southern part of the survey area, overlaid by digitized outcrops.

3.2. Multibeam Echosounder

The NOAA Ship *Nancy Foster* provided a good platform to collect bathymetry throughout the survey area using the hull-mounted Reson 7125 V1/V2. As the ship's sonar and navigation equipment had previously been coordinated by a center line survey, the MBES survey equipment performed with excellent agreement, commonly surveying with <10 cm artifacts in post-processed data. However, some unforeseen system errors relating to the timing and synchronization between the motion sensor and multibeam echosounder arose over the course of the survey, especially during the second survey in early September 2013. Major efforts were attempted to resolve the issue, including complete system reboots, system integration reviews, component replacements, alternative acquisition methods, alternative sonars, and satellite calls to system manufacturers. This issue occurred mid-survey line and would not be resolved until a full system reboot. The primary goal of the project was to collect 110% SSS coverage and the decision was made to continue the survey while any and all attempts were made to fix the issue, as to avoid having gaps in SSS coverage due to limited ship time. This issue manifested itself as a variable timing discrepancy between the motion sensor and the acquisition sonars, but did not affect SSS acquisition. Artifacts in the multibeam data appeared as "wobbles", where motion and timing correctors became misaligned but with no detectable offset or pattern, creating a motion artifact that could not be resolved in post-processing. Multibeam data quality was assessed by reviewing in CARIS software, line by line, and manually trimming portions of lines or removing complete lines. Surfaces with motion artifacts beyond 0.5 m, generally beyond the scale of the features being investigated, were considered "poor" and removed. "Marginal" data still have some artifacts, mostly around 0.2 – 0.3 m, but seafloor features are still discernable and provided in the final dataset shown in Figure 3-8. Figure 3-9 illustrates this information geographically, showing where data were good, marginal, or areas without lines where poor data were removed.

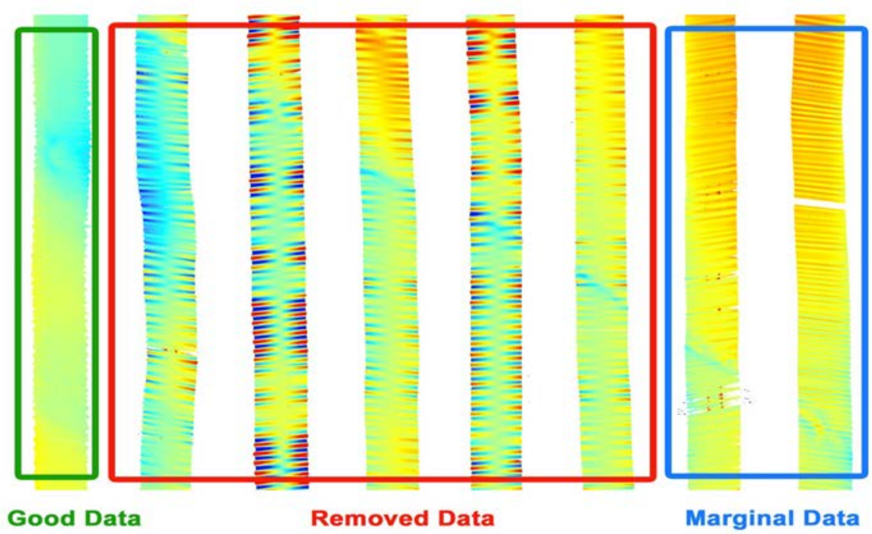

Figure 3-8. Image showing the degree of artifact associated with the multibeam system and the classification of data quality.

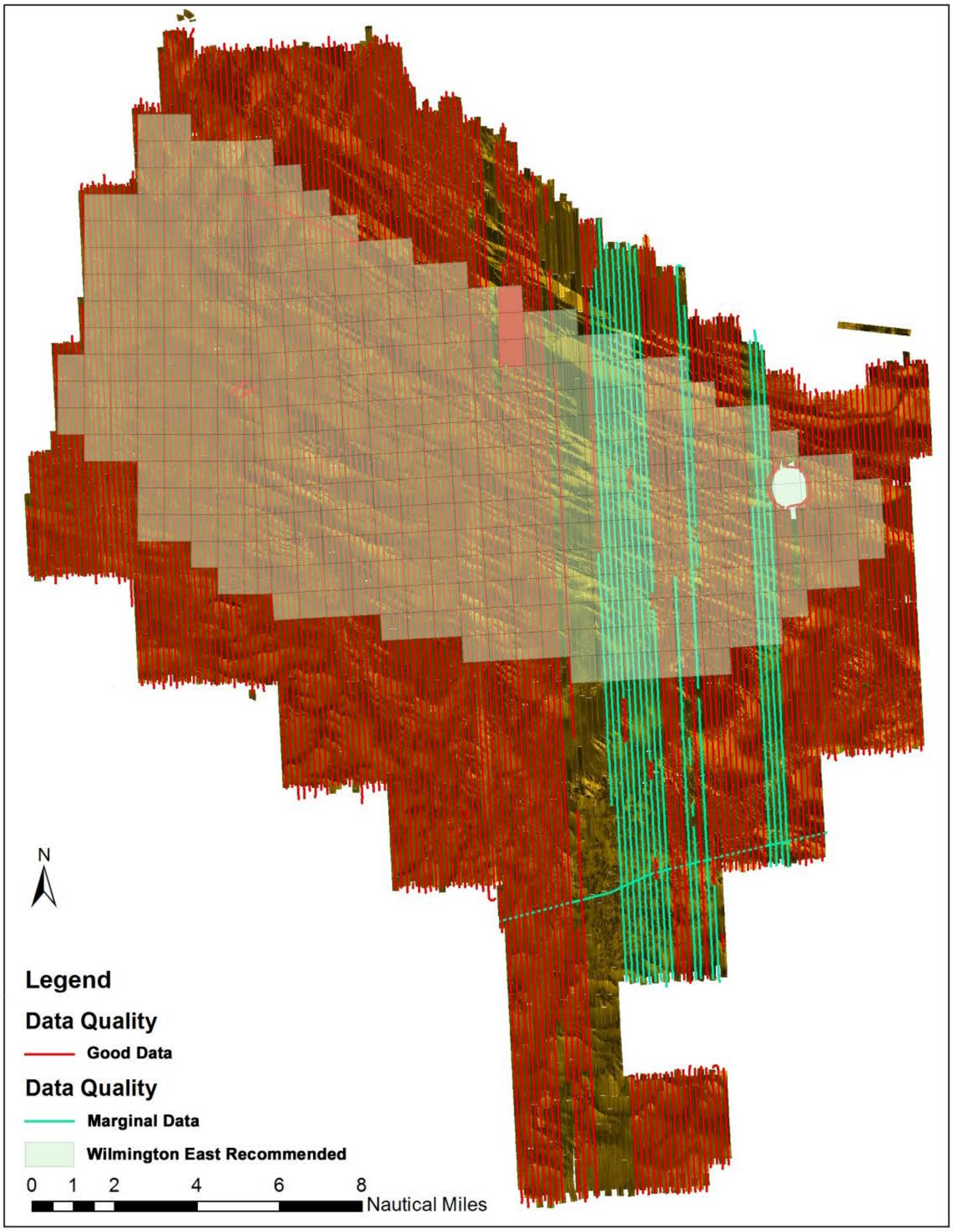

Figure 3-9. Image showing the distribution of multibeam data quality and portions of multibeam data that were removed or not logged due to system error.

3.2.1. Maps and Data Products

The multibeam sonar data collected during the sidescan sonar survey show a southward gradient in depth, but also show variation in relief (Figure 3-10). The delineated outcrops were used to focus a high-resolution multibeam sonar survey to better characterize the relief around two clusters of outcrops. The MBES surveys provide an enhanced interpretation of the seafloor and confirm the formation of ledges and outcrops that were identified by the analysis of the sidescan sonar imagery (Figure 3-11 to Figure 3-16). Overall, the SSS and MBES sonar data provide a great deal of information about the seafloor and presence of archaeological features within the study area. Two additional sites were identified as potential wrecks as there were not previously known wrecks in the immediate vicinity. The site referred to as “6537k” and “6537k_1” were investigated in Survey 4, and confirmed as a wreck, however it is still unclear if this is a previously known site (Table 3-2). These datasets provide the baseline data for future interpretations, assessments, and developments in the understanding of benthic habitats of the North Carolina OCS.

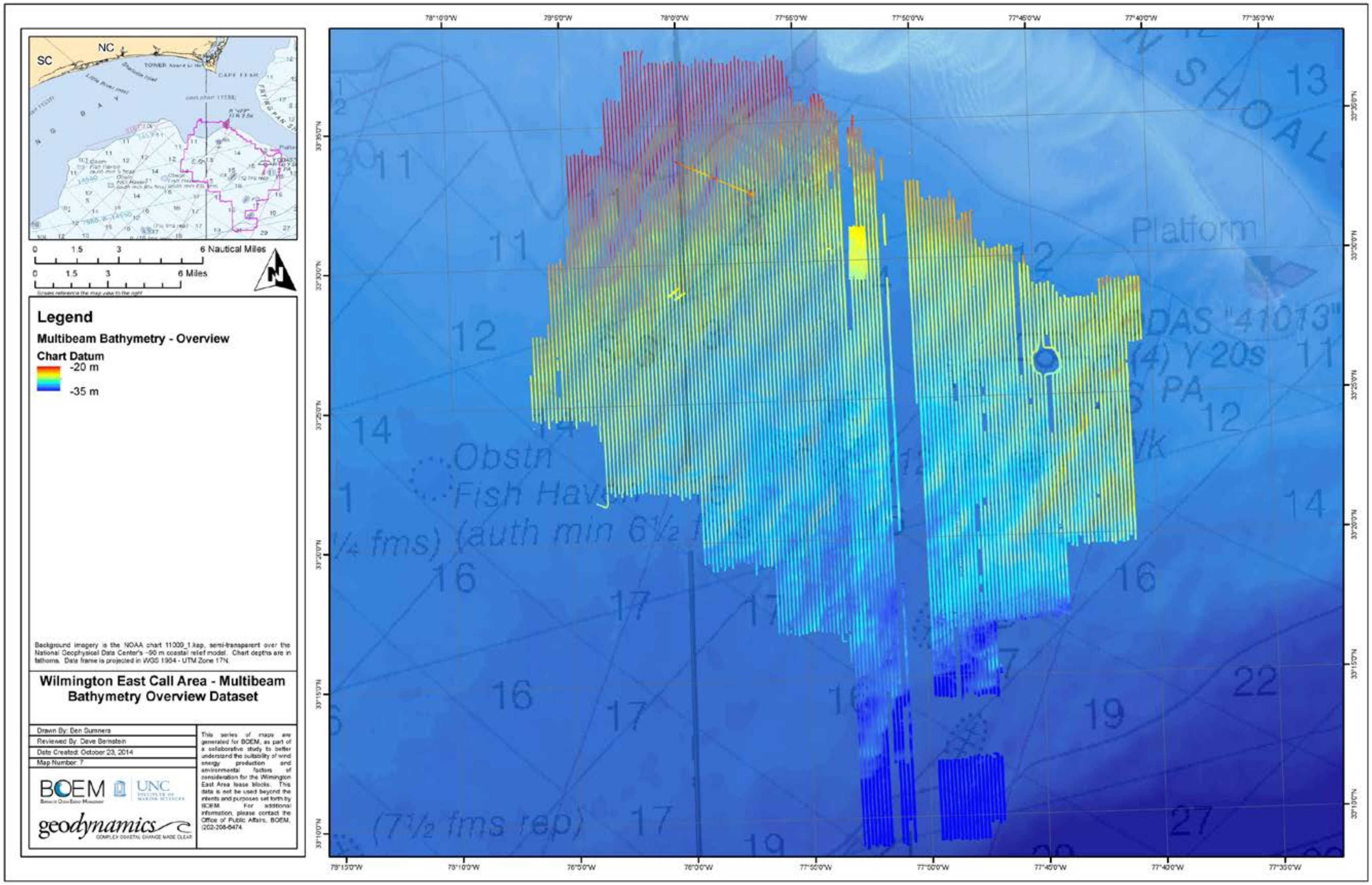

Figure 3-10. Results of the multibeam bathymetry dataset referred to as the "overview" data.

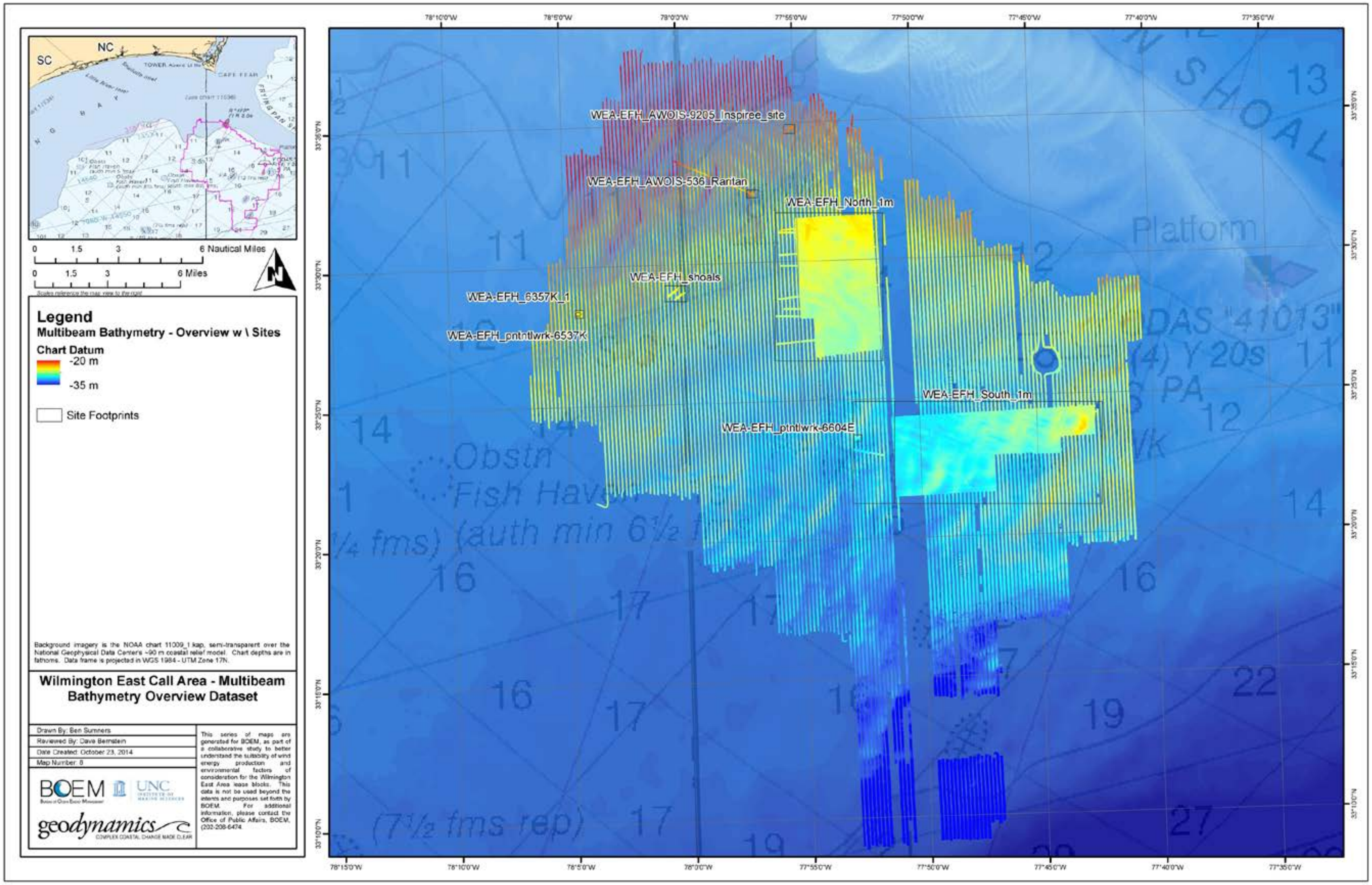

Figure 3-11. Results of the "overview" multibeam bathymetry dataset with the "sites" overlaid and labelled for reference.

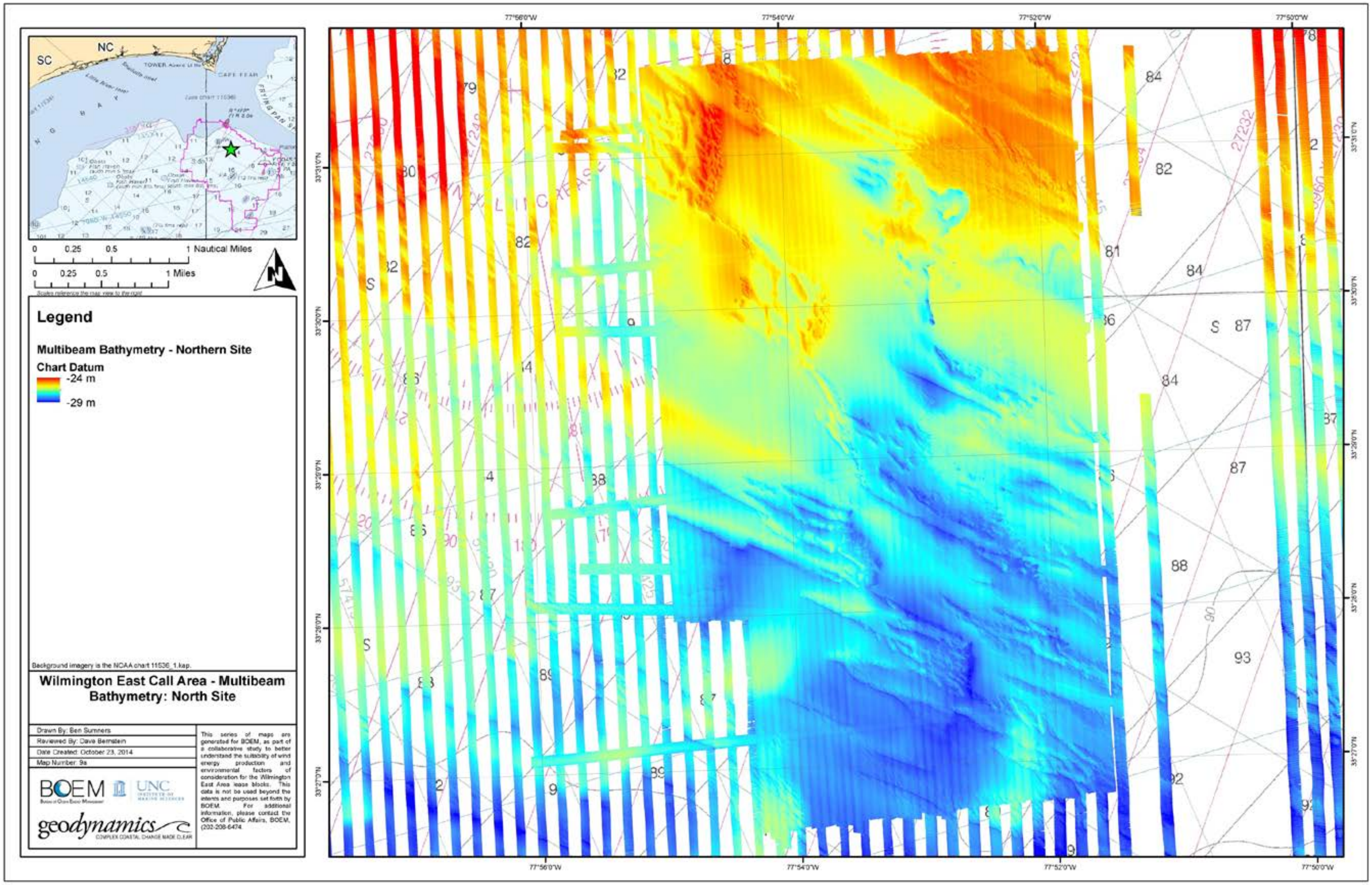

Figure 3-12. Map displaying bathymetry at the full coverage area referred to as the "north" site, overlaid on the "overview" bathymetry.

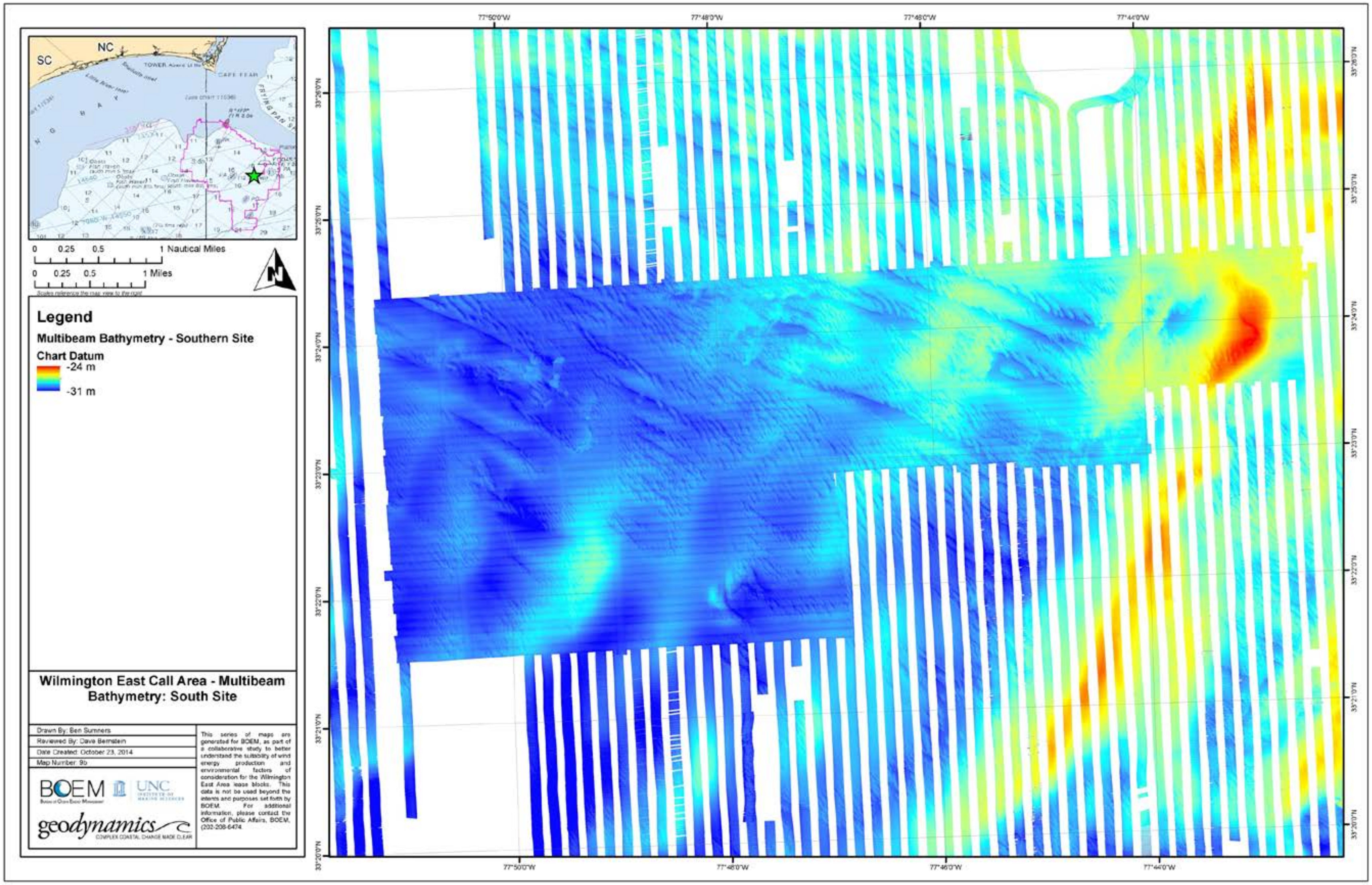

Figure 3-13. Map displaying bathymetry at the full coverage area referred to as the “south” site, overlaid on the “overview” bathymetry.

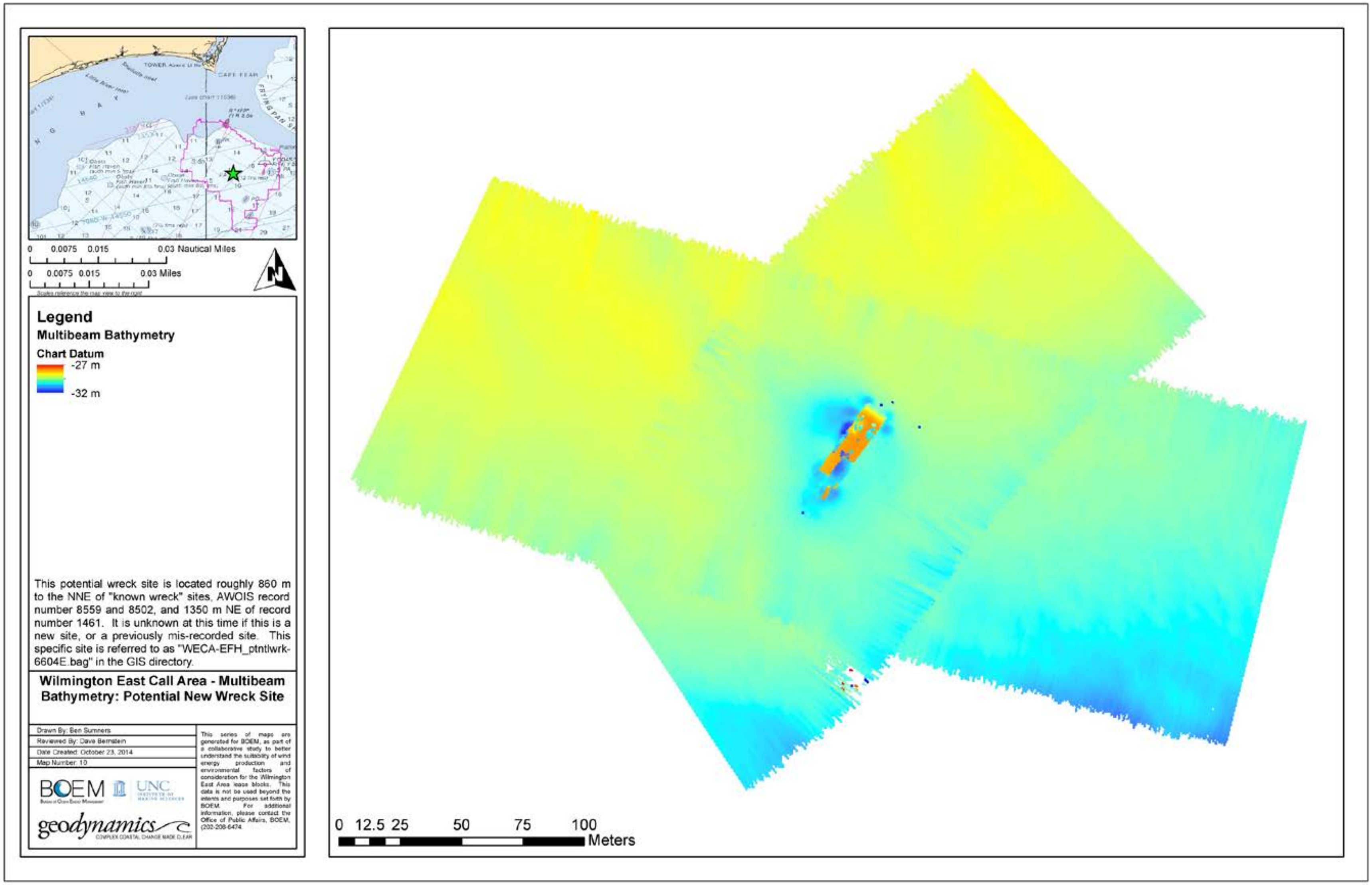

Figure 3-14. Map displaying bathymetry over a wreck site roughly 1 km from known, documented AWOIS wreck sites in the south central portion of the survey area.

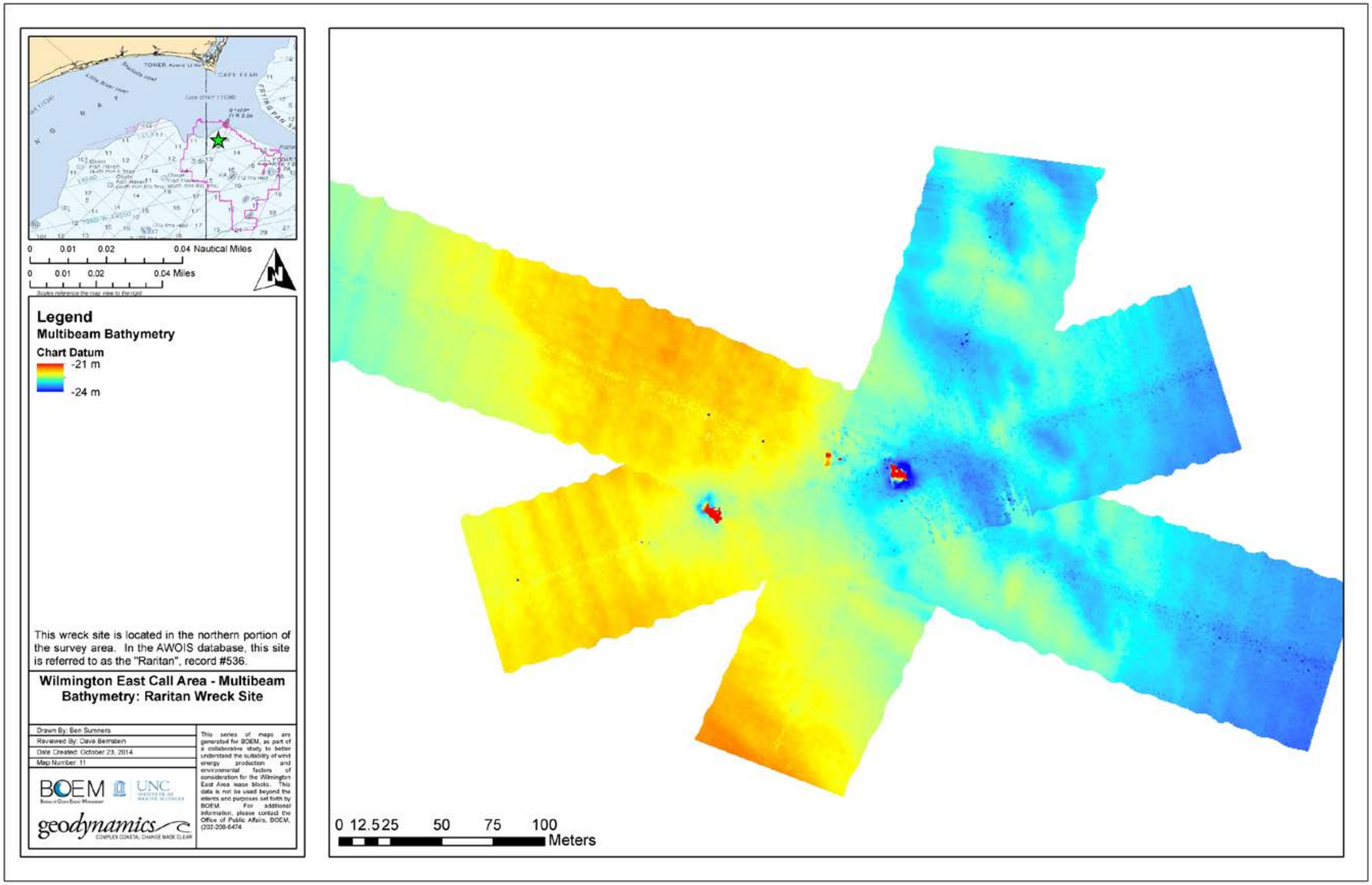

Figure 3-15. Map displaying bathymetry over the AWOIS wreck site referred to as the "Raritan".

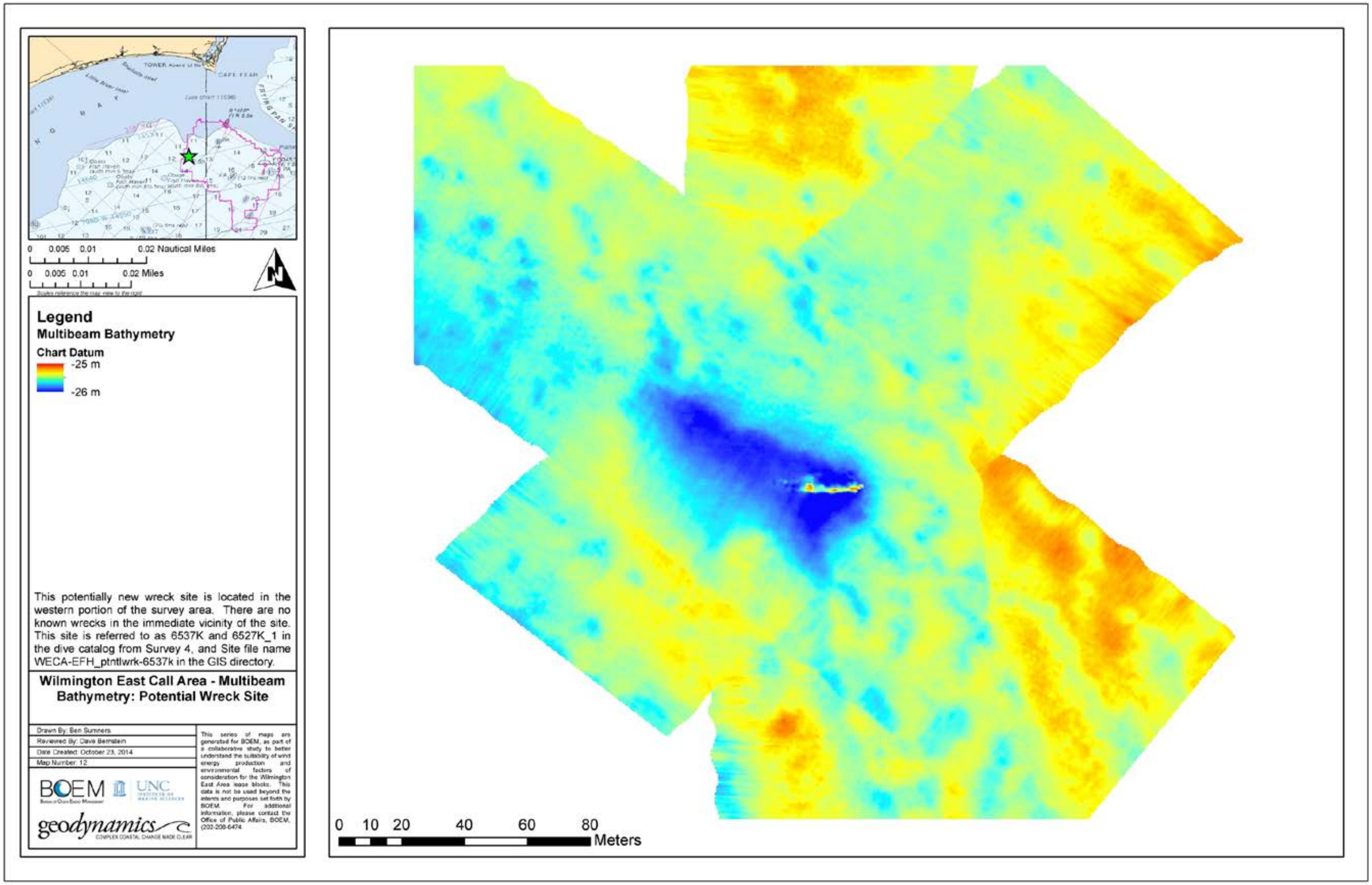

Figure 3-16. Map displaying bathymetry over a potentially new wreck site, referenced as 6537K in the dive catalog.

Table 3-1. Table describing known wrecks targeted during the project. Latitude and Longitude in WGS84.

Target Name	Latitude	Longitude	Comments	Survey	Block Number
15:39:15_184_feature	33.5418	-77.948349	Length: 17.6m Width: 4.5m possible wreck - confirmed, "RARITAN" wreck in AWOIS, two piles, record #10102	Leg 1	6402
07:31:48_25	33.4054	-77.7116191	Height: 1.1 Length: 59.3 Width: 13.0 City of Houston wreck, record# 9692	Leg 3	6607F
23:03:39_39	33.2019	-77.7924855	Height: unclear Length: 53.3 Width: 3764027.8 AWOIS shipwreck name, "Ore Freighter", record #1389	Leg 3	
21:30:42_150_feature	33.2837	-77.8311155	Height: 2.3 Length: 57.5 Width: 14.6, 573 m from "YDS 68 USS" wreck, record# 8501	Leg 2	6755
Lady_Margaret_wreck	33.406	-77.9837805	Lady Margeret Wreck, assigned post-processing; rubbly site, about 5-15 m wide, record# 2484	Leg 1	6602A

Table 3-2. Table displaying potential new wreck sites targeted during the survey.

Target Name	Latitude	Longitude	Comments	Survey	Block Number
09:17:27_8_feature	33.3938	-77.8780922	Length: 51.6 Width: 7.3 very hard return, unkown feature, roughly 860 m NE from "known wreck" site in AWOIS, record #8502	Leg 2	6604
13:16:44_160_feature	33.4726	-78.0740811	Height: 0.9 Length: 15.6 Width: 2.6 potential wreck; site referred to as ""6537k_1"" later in dive log	Leg 1	6537K

3.3. Mapping Fish Densities Using Splitbeam Echosounder

Two (38 kHz and 120 kHz) or three (38 kHz, 120 kHz and 200 kHz) frequency SBES systems were used for the surveys in 2013 and 2014. Only the output from the 120 kHz frequency was analyzed. Data from the other frequencies were used to help interpret targets that were likely plankton and discernable in the 38 kHz signal.

Fish distributions varied across the four survey missions and three survey designs. We observed individual fish scattered throughout the watercolumn, or distributed in layers near the seafloor. We also detected and mapped dense schools of fishes of a variety of shapes and dimensions (Figure 3-17).

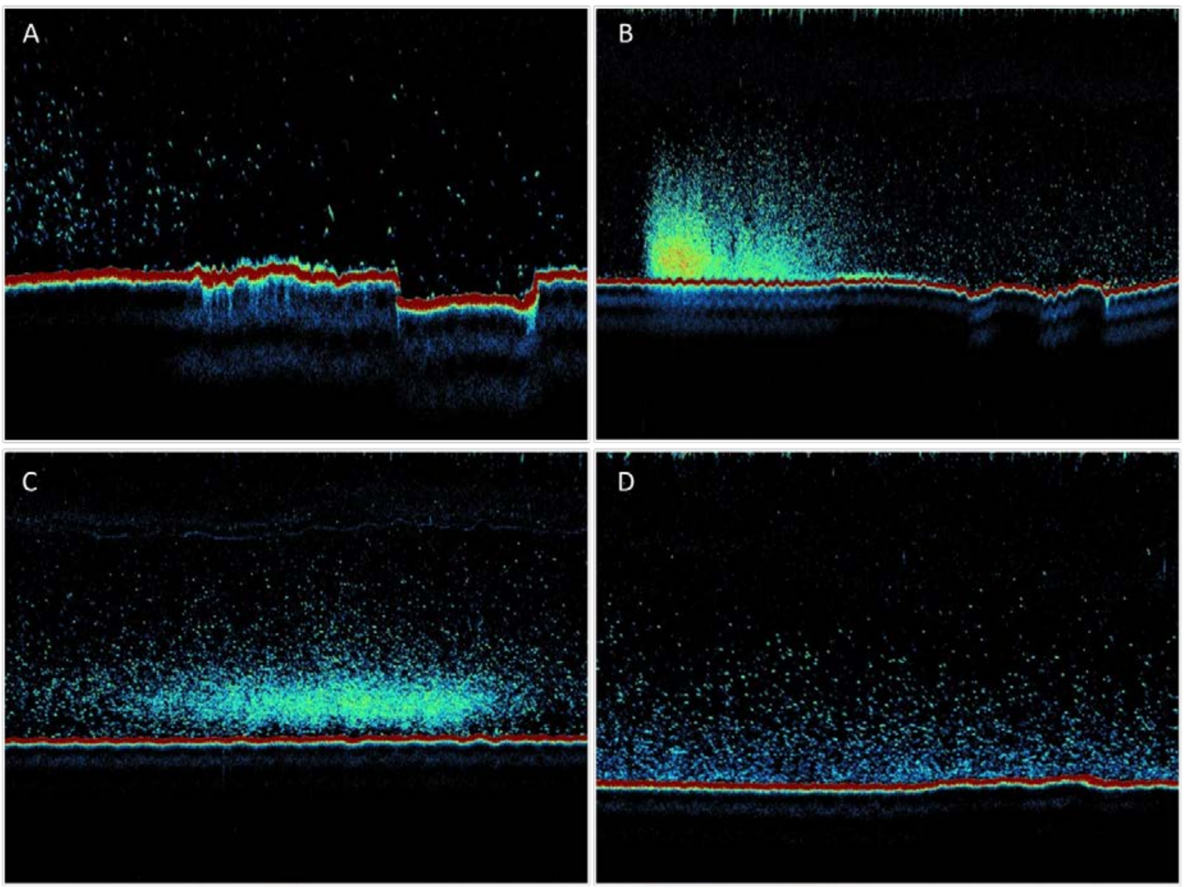

Figure 3-17. Example splitbeam echosounder echograms showing the seafloor (red) and individual fish (green-yellow-orange) near a ledge (A) or fish schools in the water column (green-yellow-orange) over a mixed hardbottom (B) or unconsolidated bottoms (C & D).

Diel patterns in the magnitude of densities observed were evident over the 24-hour surveys in 2013 and 2014. In 2013, total density, which included densities of some very large schools of small fish, were observed primarily between dawn and dusk (Figure 3-18). In contrast, small fish densities were greatest during the overnight (dusk to dawn) periods, likely related to presence of small planktivores and their associated vertical migration and feeding behaviors (Figure 3-18). Densities of medium and large size classes were higher between dawn and dush (Figure 3-18).

The pattern was similar for 2014 despite the focus of surveys conducted primarily during dusk to dawn periods (data not shown).

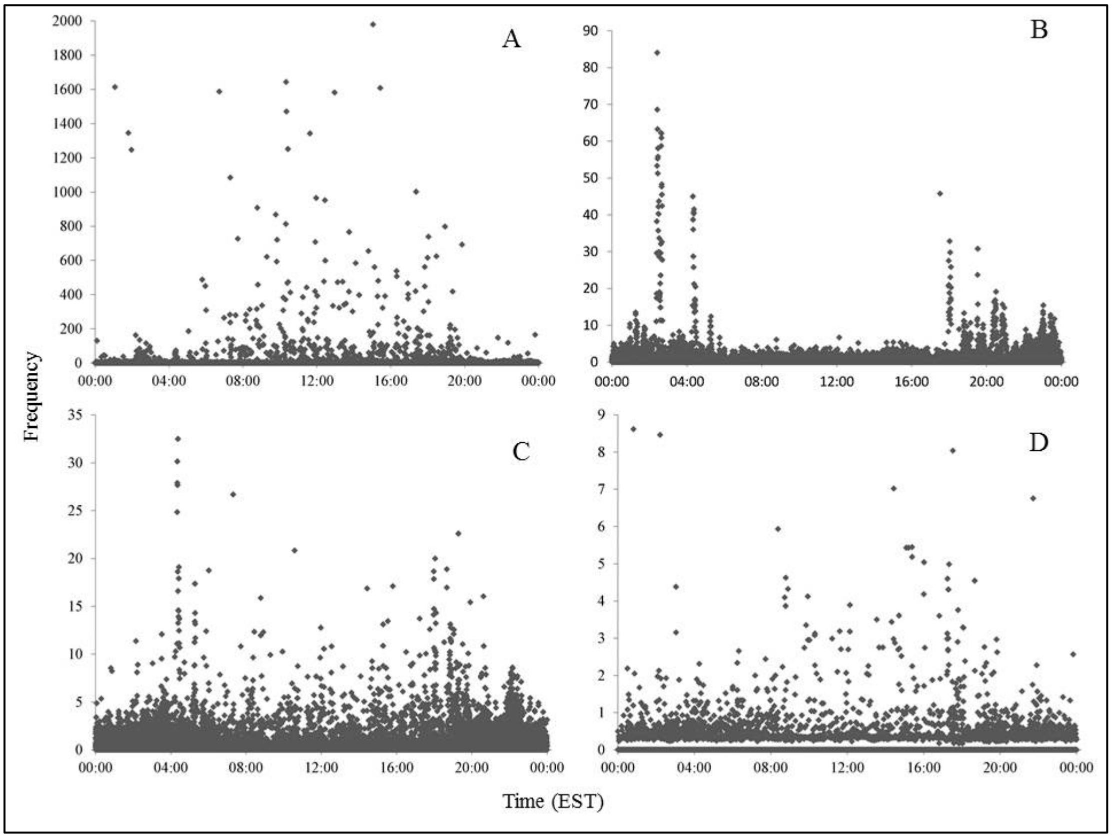

Figure 3-18. Diel patterns of densities for SBES surveys in 2013 according to size classes. A) total densities of all sizes, B) small size class (<12cm), C) medium size class (12-29 cm) and D) large size class (>29 cm).

The following summaries are given for all fish detected during SBES surveys. Length frequency distributions inferred from individual fish target strengths were dominated by small fish less than 10 cm or about -45 dB (Figure 3-19). The detections of fish included depth in the water column and depth of the seafloor, which is used to calculate depth above seafloor to characterize vertical distributions. In 2013 and 2014, we plotted the distance above seafloor separately by day (between dawn and dusk in local time) and night to qualitatively compare diel distributions by size classes. In 2013, small fish (less than 12 cm) were distributed throughout the water column during both day and night surveys, though differing in magnitude of densities. Medium size classes (12 to 29 cm) were more concentrated within 5-10 m of the seafloor during the day and throughout the water column at night. Large fish were generally found within 5 m of the seafloor, though were also scattered as much as 20 m above the seafloor at night (Figure 3-20). The surveys conducted during the day in 2014 were focused over ledge or mixed hardbottom habitats. The vertical distributions of fish over these habitats were much closer to the seafloor for all size classes compared to the night surveys during 2014 that covered the broad distribution of seafloor habitat types. Vertical distributions at night were similar across fish sizes for both the 2013 and 2014 surveys.

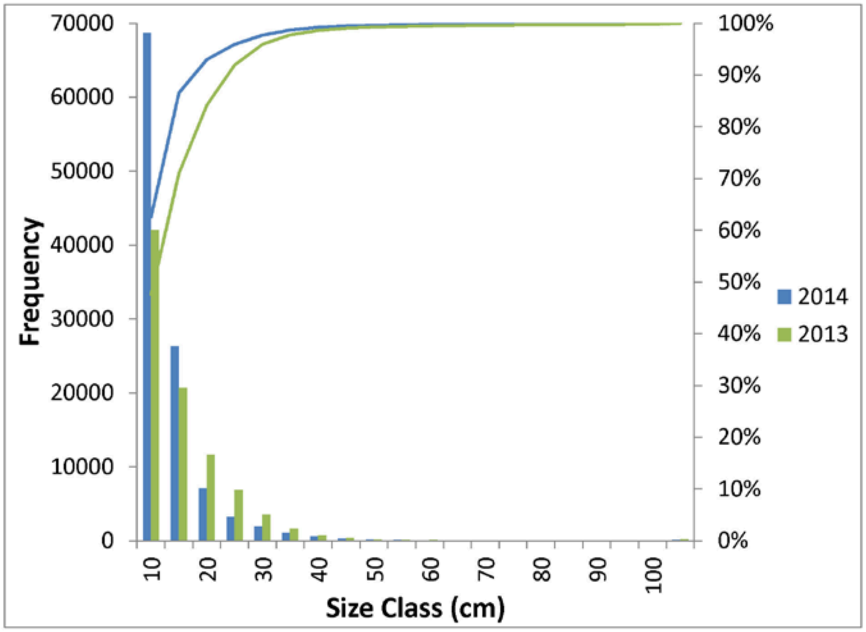

Figure 3-19. Length (TL) frequency distribution and cumulative proportions for fish detected during all SBES surveys in 2013 and 2014.

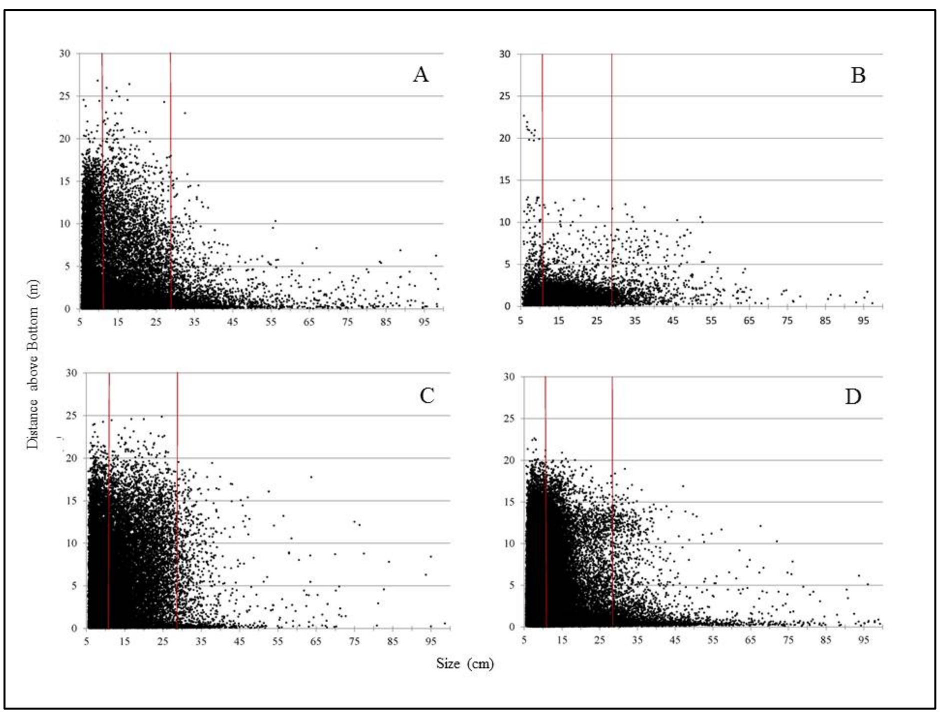

Figure 3-20. Distance above the seafloor for individual fish detected during SBES surveys for 2013 day (A) and night (B) and 2014 day (C) and night (D). Fish sizes in cm are estimated from acoustic target strength. Red vertical bars indicate divisions of pre-determined size classes for small fish (<12 cm), medium fish (12 to 19 cm) and large fish (>29 cm).

3.3.1. Distribution of Fish Densities

3.3.1.1. 2013 Surveys of the Wind Energy Planning Area

Spatial distribution of fishes in the wind energy planning area varied depending on size classes, time of survey, and underlying seafloor floor features. Densities for small (length <12 cm) and medium size classes (12 cm < length < 29 cm) of fish were broadly distributed, with some areas of high density likely explained by the time survey (Figure 3-21 and Figure 3-22), most notably on the eastern margin of the planning area and other portions of the survey that appear as north-south bands of higher density values. Other areas of high densities were evident in the north central and southern regions of the planning area, especially for the medium size classes. These regions were identified in the seafloor mapping as clusters of ledges and mixed hardbottom seafloor habitats. Densities of large fish were an order of magnitude lower than the densities for small and medium fish (Figure 3-23). The distributions of large fish were more organized in clusters than the small or medium size classes. Distribution of fish schools were similar to the large fish and organized into clusters that overlapped with the high densities of medium and large fish (Figure 3-24).

The spatial structure for total fish density (all size classes and schools) was similar in day and night survey periods in 2013. Spatial autocorrelation was evident in the geostatistical variogram out to 1300 and 1400 m for day and night, respectively. Interpolation maps for total fish density were visually similar to the point maps for medium, large and school densities (Figure 3-25). In contrast, while there were clusters of large fish densities visible on the map, the variation between adjacent density measures along and between survey transects were highly variable resulting in a very short range in spatial autocorrelation indicative of spatial structure that was at a smaller scale than our 100-m binned observations and resulted in a interpolation map that shows localized hotspots (Figure 3-26). Using the Getis-Ord Gi* measure to detect hotspots in large fish densities, significant hotspots were evident in the north-central and southern region of the wind energy planning area, visually similar to the distribution of high densities as shown in the point maps for large fish size classes (Figure 3-27). The largest cluster of hotspots was in the southern region of the original wind energy planning area, outside the reduced WEA (shown as white outline in Figure 3-27).

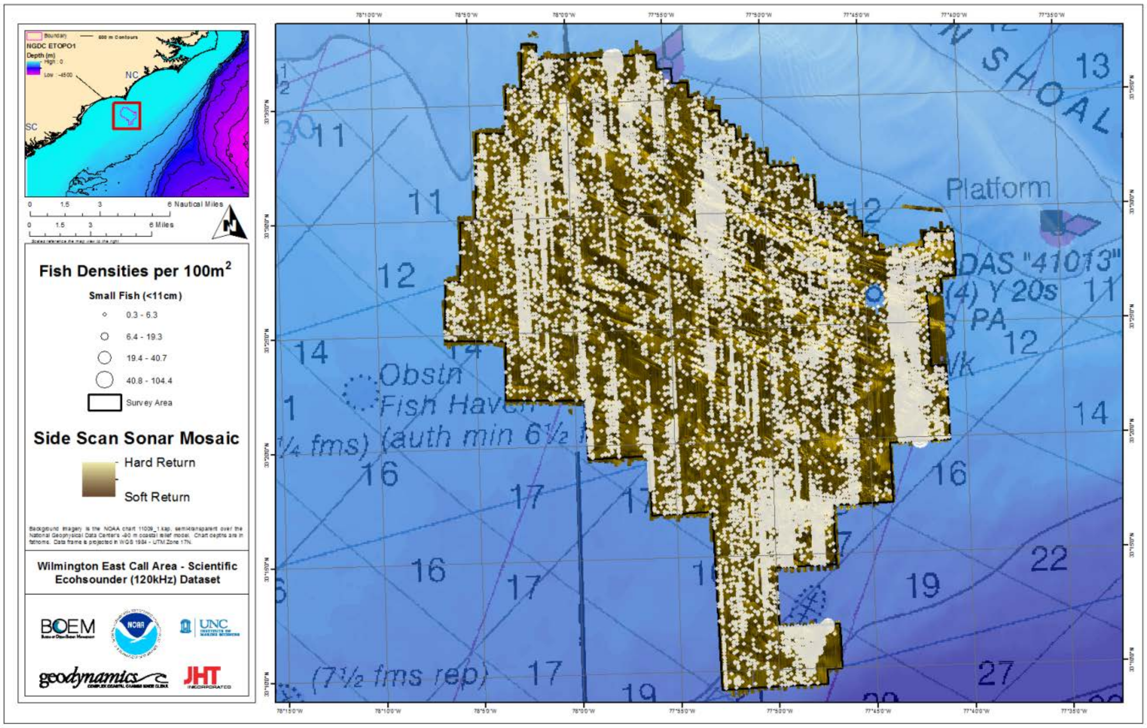

Figure 3-21. Distribution of fish densities for small size classes (length <12 cm) from SBES surveys in 2013 over entire wind energy planning area. White symbols are proportional in size to relative density.

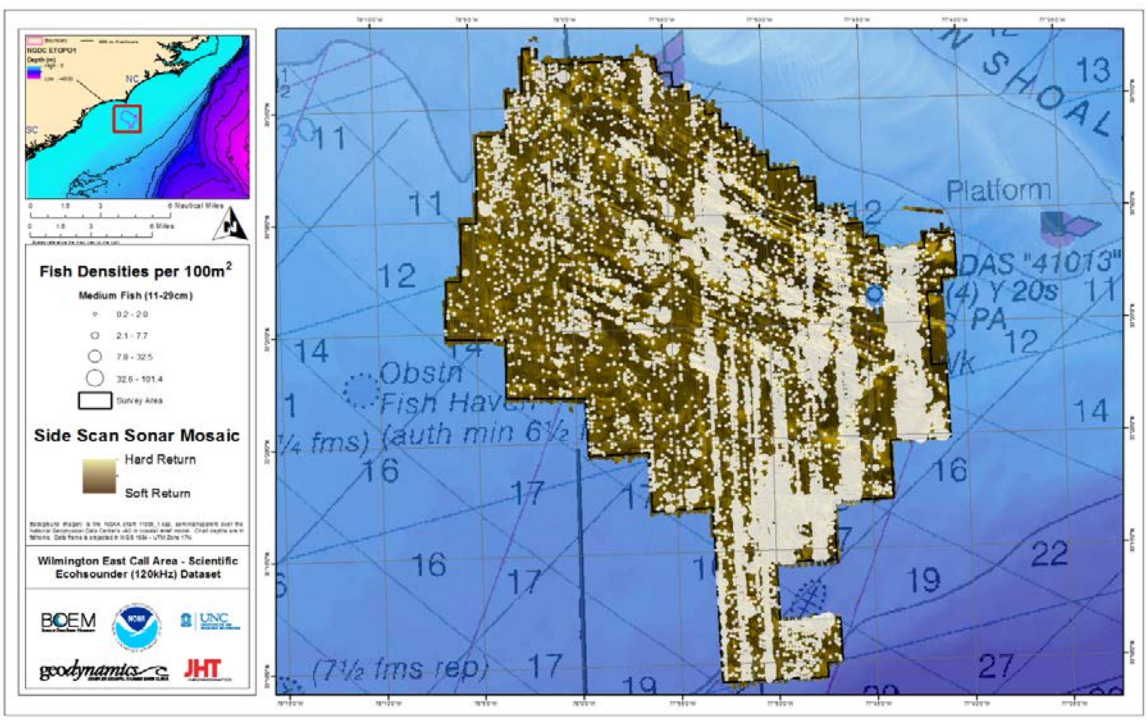

Figure 3-22. Distribution of fish densities for medium size classes (length 12-29 cm) from SBES surveys in 2013 over entire wind energy planning area. Size of white symbols are proportional to relative density.

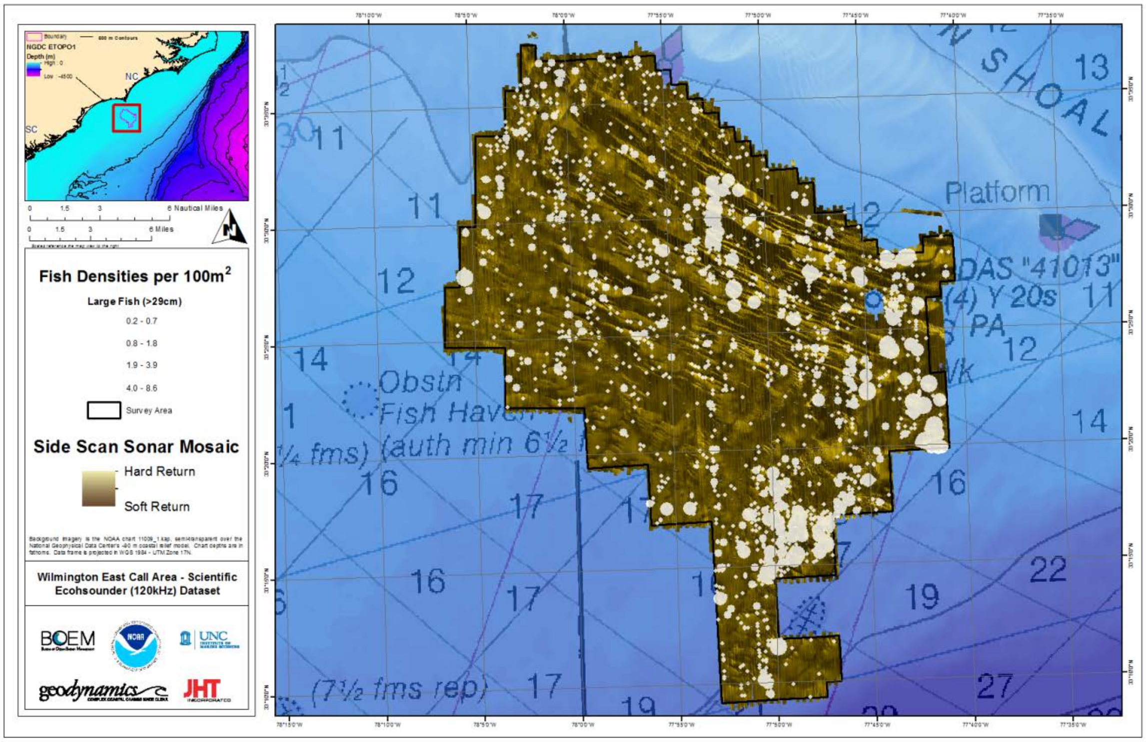

Figure 3-23. Distribution of fish densities for large size classes (length >29 cm) from SBES surveys in 2013 over entire wind energy planning area. White symbols are proportional in size to relative density.

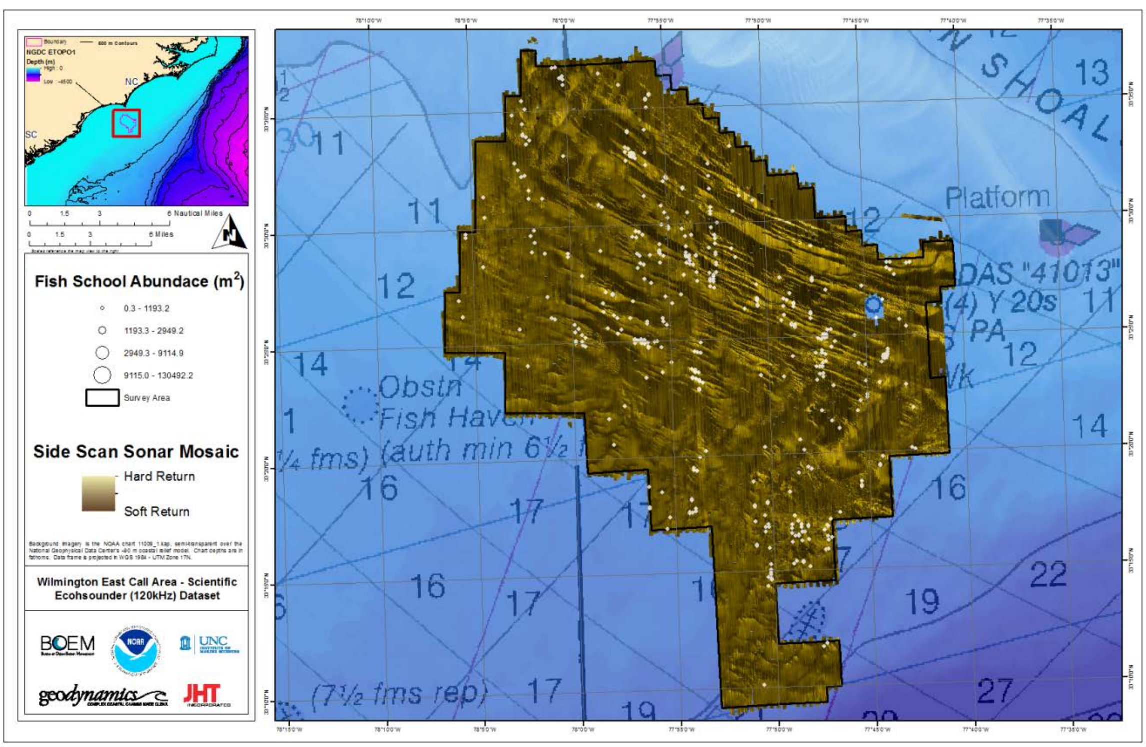

Figure 3-24. Distribution of fish densities in fish schools from SBES surveys in 2013 over entire wind energy planning area. White symbols are proportional in size to relative density.

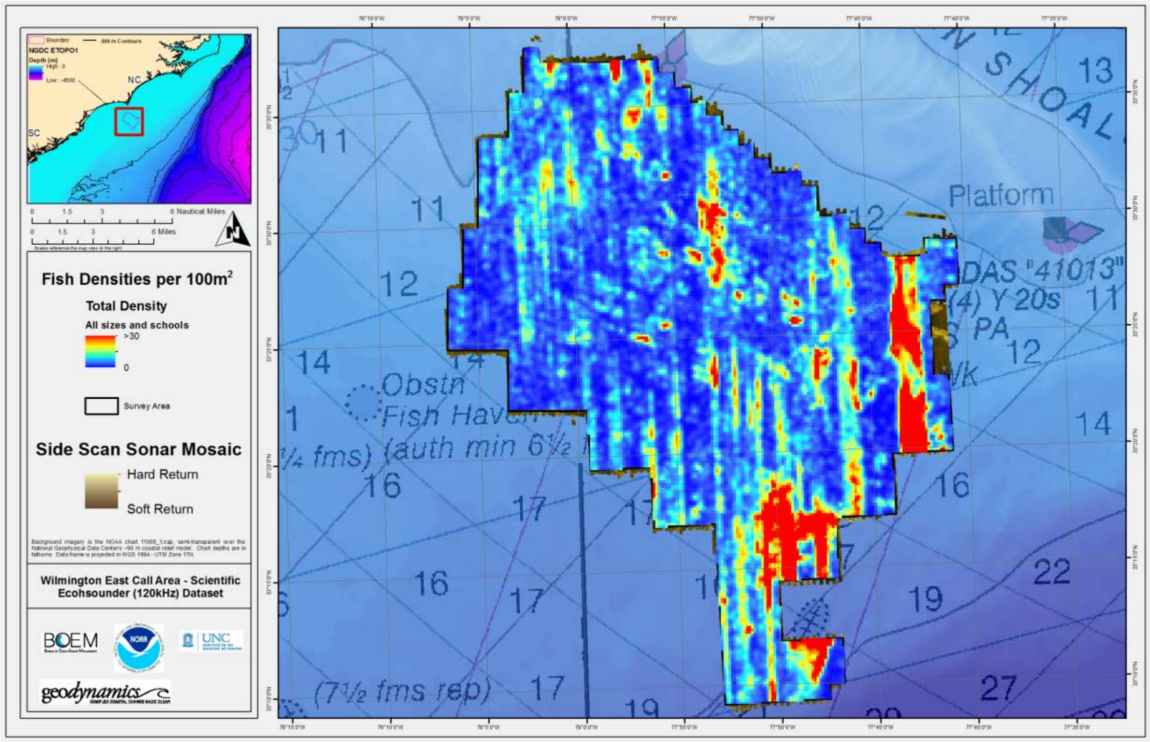

Figure 3-25. Kriging interpolation of total fish density, including all size classes and fish schools, in the wind energy planning area from surveys conducted in 2013. Densities are scaled from blue (zero) to red (high).

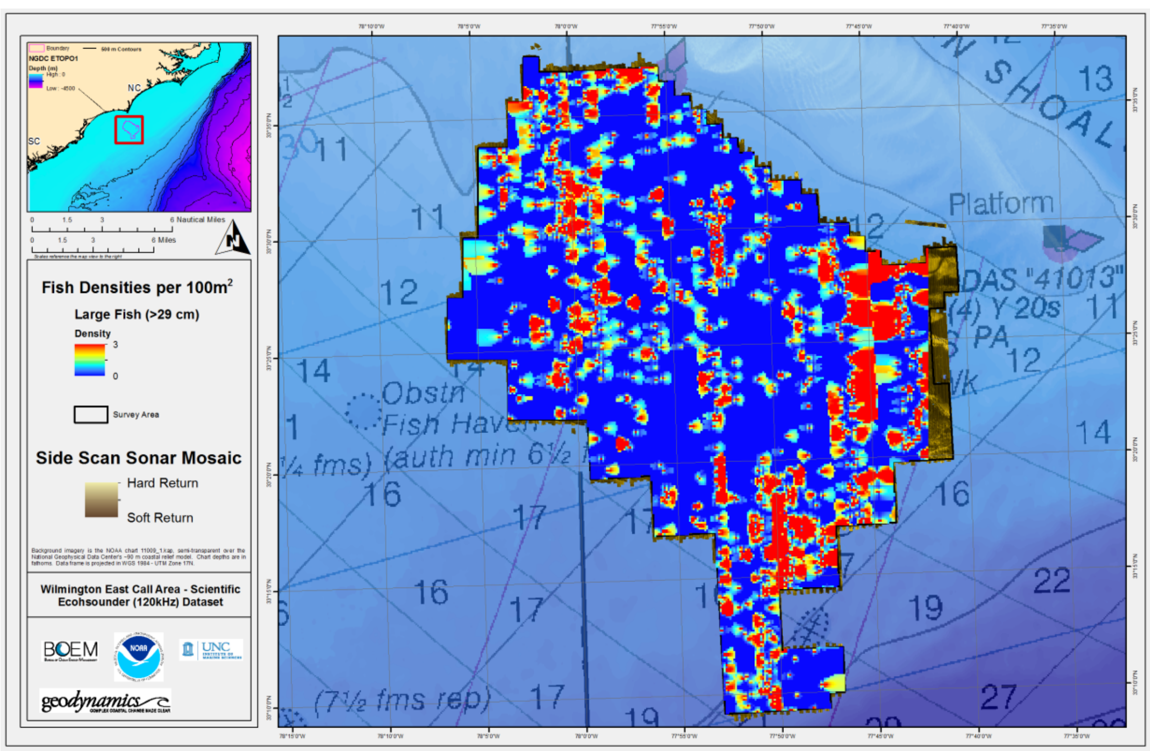

Figure 3-26. Kriging interpolation of large fish size classes (length >29 cm), in the wind energy planning area from surveys conducted in 2013.

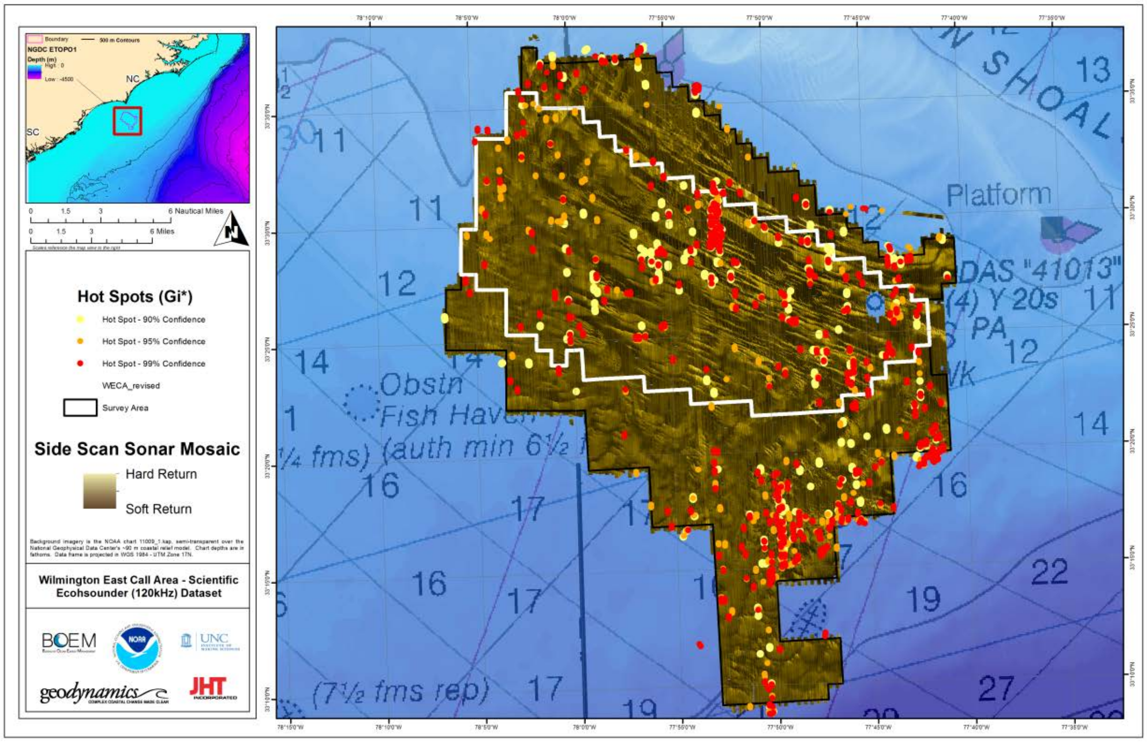

Figure 3-27. Significant hotspots for large fish size class densities in the wind energy planning area from surveys conducted in 2013. The hotspot Gi* p-value is shown in 3 levels, >90% (yellow), >95% (orange) and >99% (red) indicating increase likelihood of clusters of high fish densities compared to random. The revised wind energy area is shown as a white border over the side scan sonar mosaic.

3.3.1.2. 2014 Surveys of the Study Area

The MBES and SBES surveys conducted in 2014 were focused on areas in the revised wind energy area that were identified by clusters of potential hardbottom habitats or high fish densities. Similar to the pattern of distribution in 2013, the distribution of fishes varied by size. Because we focused on the areas with the highest fish density, it was not surprising that the metrics that described spatial distribution of densities varied between 2013 and 2014. Areas of non-zero densities (present area) and selectivity indices were higher in 2014 surveys, especially for densities of large fish. Average densities in present areas did not vary by year or survey (Table 3-3).

The survey lines dictated by the multibeam survey were more closely spaced, resulting in higher resolution observations. The small and medium fish size classes were again broadly distributed, with “bands” of high densities along survey transects in the data likely driven by elevated densities observed during dusk and dawn and especially in the northern region (Figure 3-28 and Figure 3-29). Where “bands” of high density did not obscure other patterns, there were higher densities of small and medium fish size classes in the southeast region of the southern focus area. Distribution of large fish size class densities were clustered in the southeast region of the north focus area and the north-central and southeast of the south focus area (Figure 3-30). Fish schools were relatively rare and sparsely distributed in the 2014 surveys (Figure 3-31).

Geostatistical interpolations for total fish densities in 2014 largely reflected the spatial patterns in the small and medium fish size class densities (Figure 3-32). Range of spatial autocorrelation was 890 m in the north focus area and 1200 m in the south focus area. Geostatistical interpolation of large fish size class densities captured the same pattern of distribution as the point density maps, with spatial autocorrelation ranges of 1200 m in the north focus area and 430 m in the south focus area (Figure 3-33). The shorter range of spatial autocorrelation in the south focus area is explained by the patchy pattern observed in large fish densities. Hotspot analysis using Geti-Ord Gi* metrics discovered clusters of hotspots in the southeast region of the north focus area and north-central and southeast region of the south focus area (Figure 3-34). The hotspots in the north focus area and south focus area were in similar regions as found in the 2013 surveys. The surveys in 2013 were conducted over several months (June – November 2013) and the 2014 surveys were conducted in May 2014. The consistency of hotspots observed over the two surveys suggests important habitat or water quality features in these locations.

Table 3-3. Summary metrics for spatial distribution of fish densities for two survey years and designs across day and night and size classes. See text for methods of computing present area (PA) and selectivity index.

Year	Survey	Time	Size Class	Present Area (PA)	Density in PA (Fish per 100m^2)	Selectivity Index
2013	Wind Energy Planning Area	Day	Total	39.1%	7.78	0.97
			Large	4.7%	0.70	0.98
			Med	15.7%	1.28	0.93
			Small	30.9%	0.80	0.74
		Night	Total	51.5%	2.80	0.86
			Large	5.9%	0.54	0.96
			Med	22.1%	1.15	0.82
			Small	36.0%	1.51	0.86
		Both	Total	44.1%	5.40	0.95
			Large	4.7%	0.62	0.97
			Med	23.6%	1.17	0.89
			Small	31.9%	1.09	0.85
2013	Wind Energy Area	Day	Total	39.4%	10.87	0.97
			Large	4.1%	0.63	0.97
			Med	15.7%	1.30	0.93
			Small	32.0%	0.70	0.80
		Night	Total	46.1%	2.29	0.88
			Large	5.5%	0.50	0.96
			Med	30.1%	1.00	0.84
			Small	29.2%	0.85	0.84
		Both	Total	42.2%	6.75	0.96
			Large	5.1%	0.57	0.97
			Med	22.1%	1.12	0.89
			Small	30.2%	0.76	0.82
2014	North Focus Area	Night	Total	87.0%	15.76	0.87
			Large	13.7%	0.63	0.91
			Med	68.1%	1.84	0.70
			Small	74.3%	5.47	0.75
	South Focus Area	Night	Total	79.7%	6.88	0.80
			Large	17.7%	0.59	0.89
			Med	62.5%	1.57	0.68
			Small	68.2%	2.67	0.68

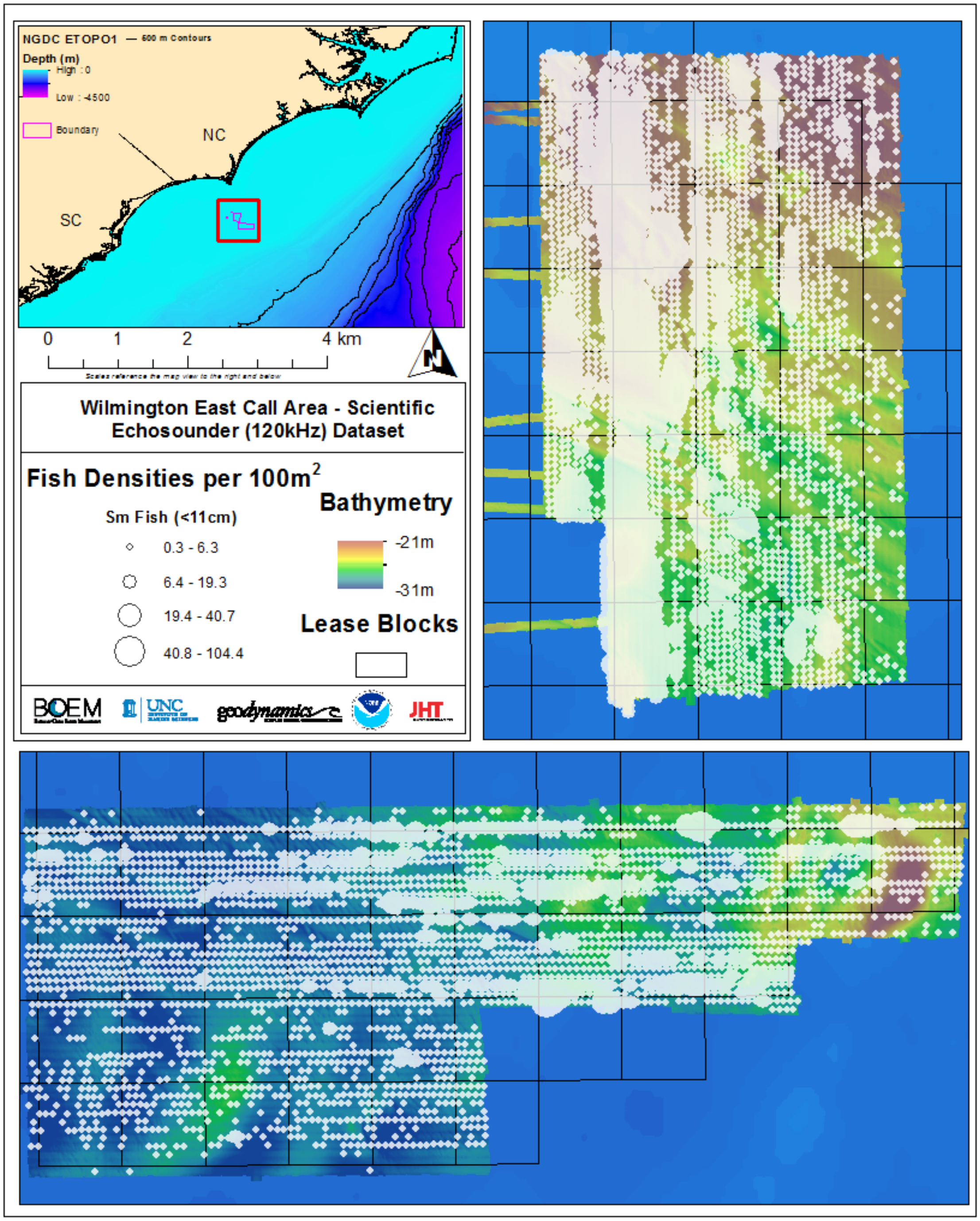

Figure 3-28. Distribution of densities for small fish size class (<12 cm) in the areas selected for high resolution multibeam surveys in the wind energy area. White dots are proportional to densities in fish per 100m^2 and displayed over the bathymetry derived from the multibeam survey. WEA lease blocks are shown for reference.

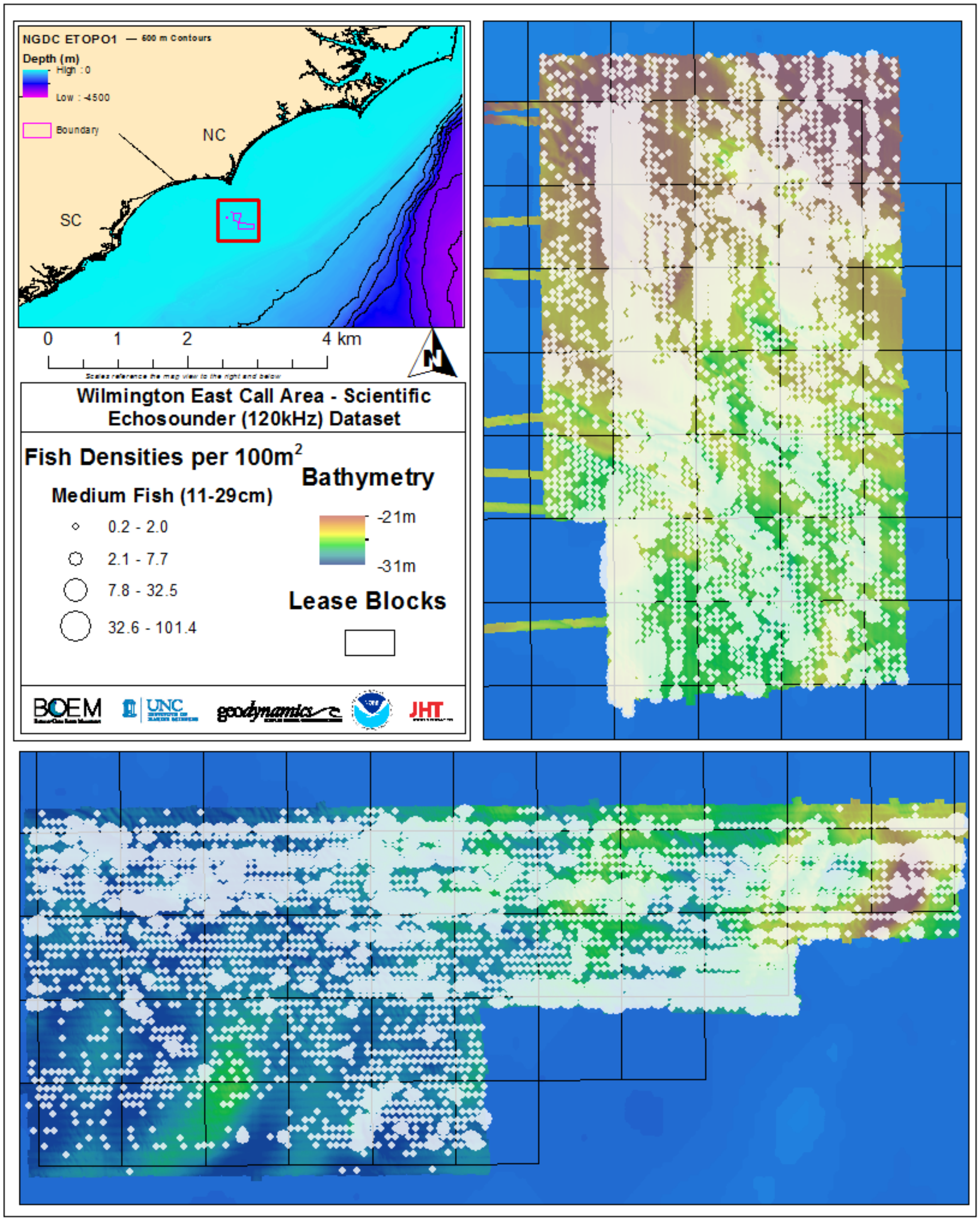

Figure 3-29. Distribution of densities for medium fish size class (12 cm < length < 29 cm) in the areas selected for high resolution multibeam surveys in the wind energy area. White dots are proportional to densities in fish per 100m^2 and displayed over the bathymetry derived from the multibeam survey. WEA lease blocks are shown for reference.

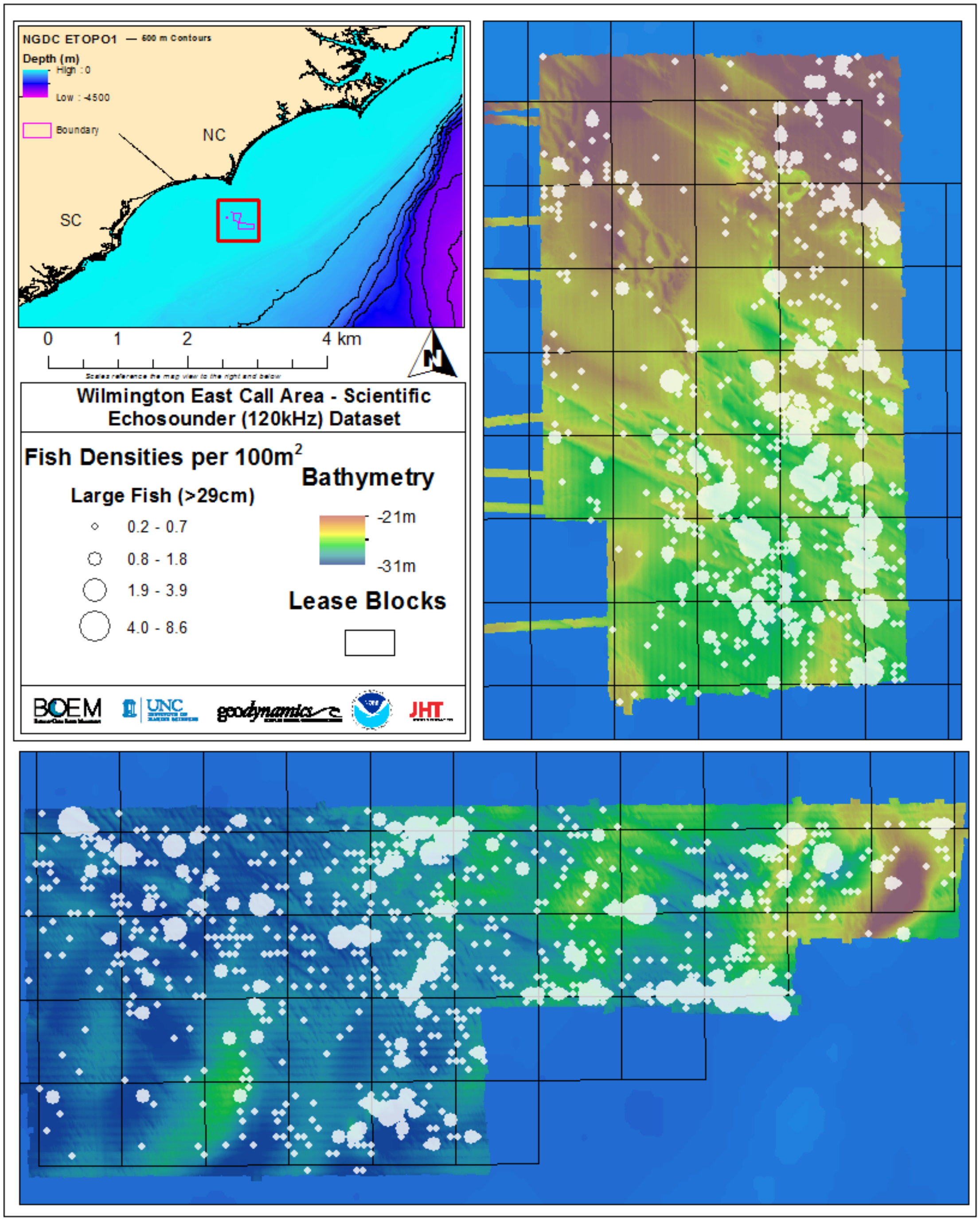

Figure 3-30 .Distribution of densities for large fish size class (length >29 cm) in the areas selected for high resolution multibeam surveys in the wind energy area. White dots are proportional to densities in fish per 100m^2 and displayed over the bathymetry derived from the multibeam survey. Wind energy lease blocks are shown for reference.

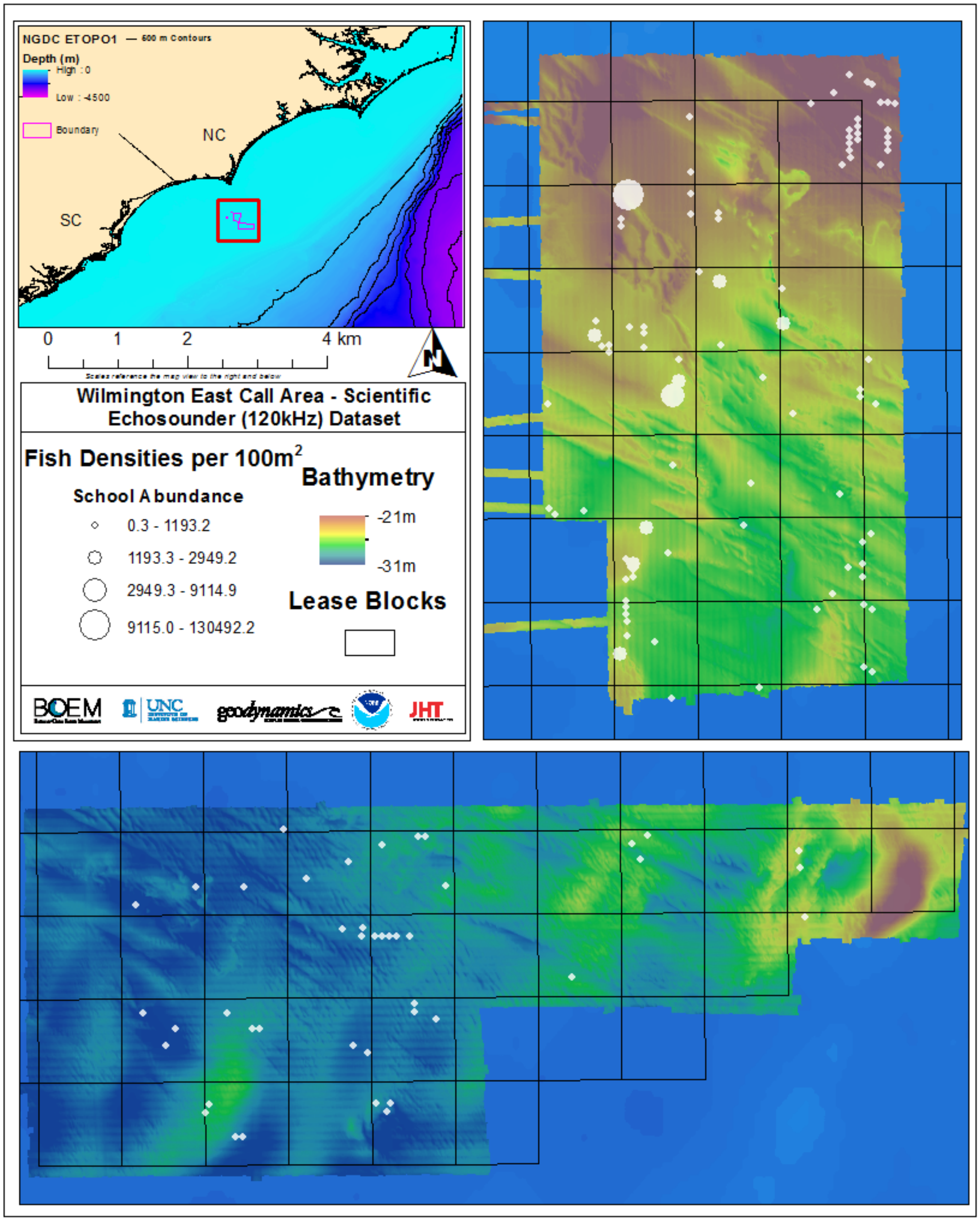

Figure 3-31. Distribution of densities for fish schools (all size classes of fish not discernable as individual fish) in the areas selected for high resolution multibeam surveys in the wind energy area. White dots are proportional to densities in fish per 100m^2 and displayed over the bathymetry derived from the multibeam survey. WEA lease blocks are shown for reference.

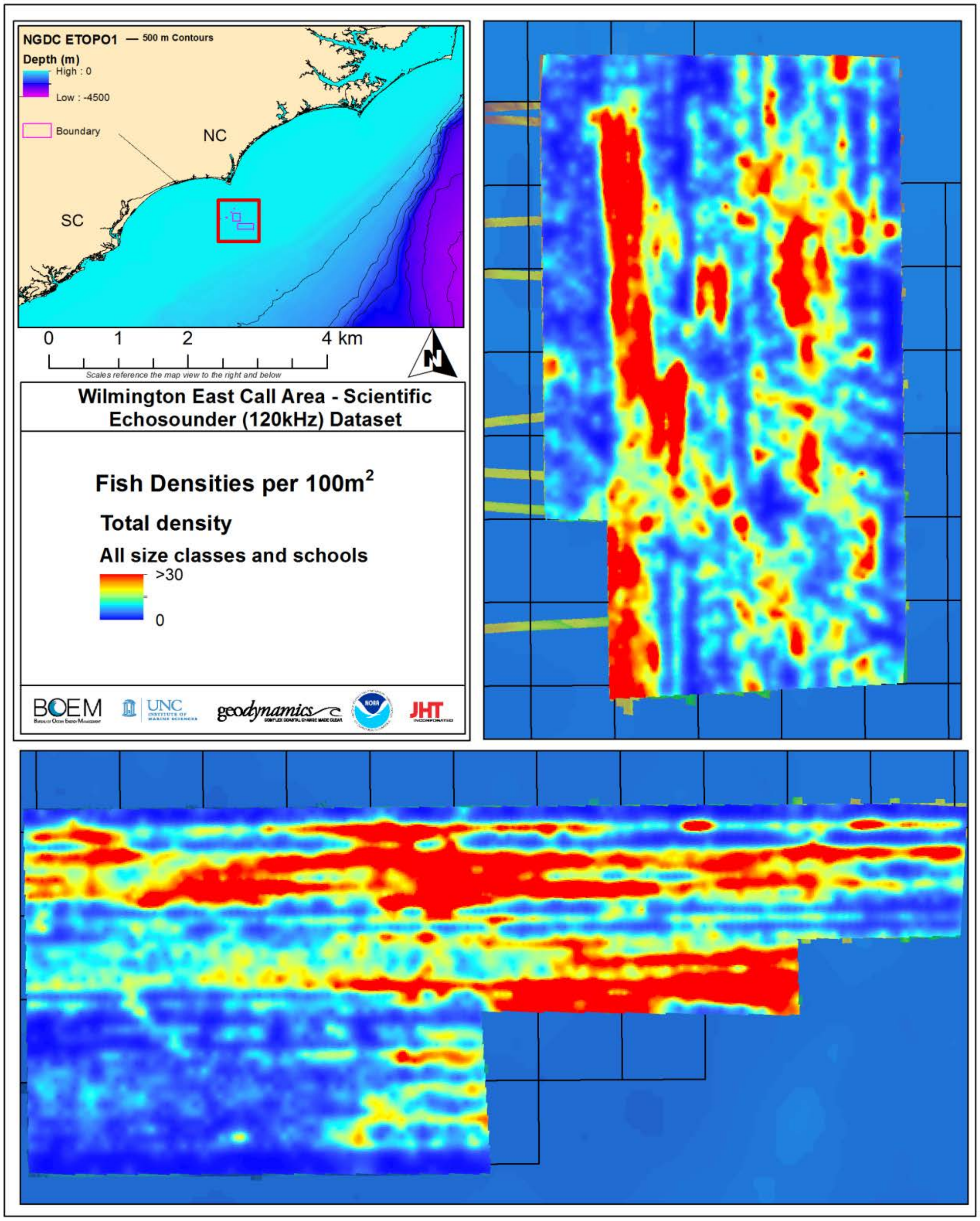

Figure 3-32. Kriging interpolation of total fish densities (all size classes, including fish schools) in areas selected for high-resolution multibeam survesy in the wind energy area. Densities are scaled according to blue (low) to red (high) color range.

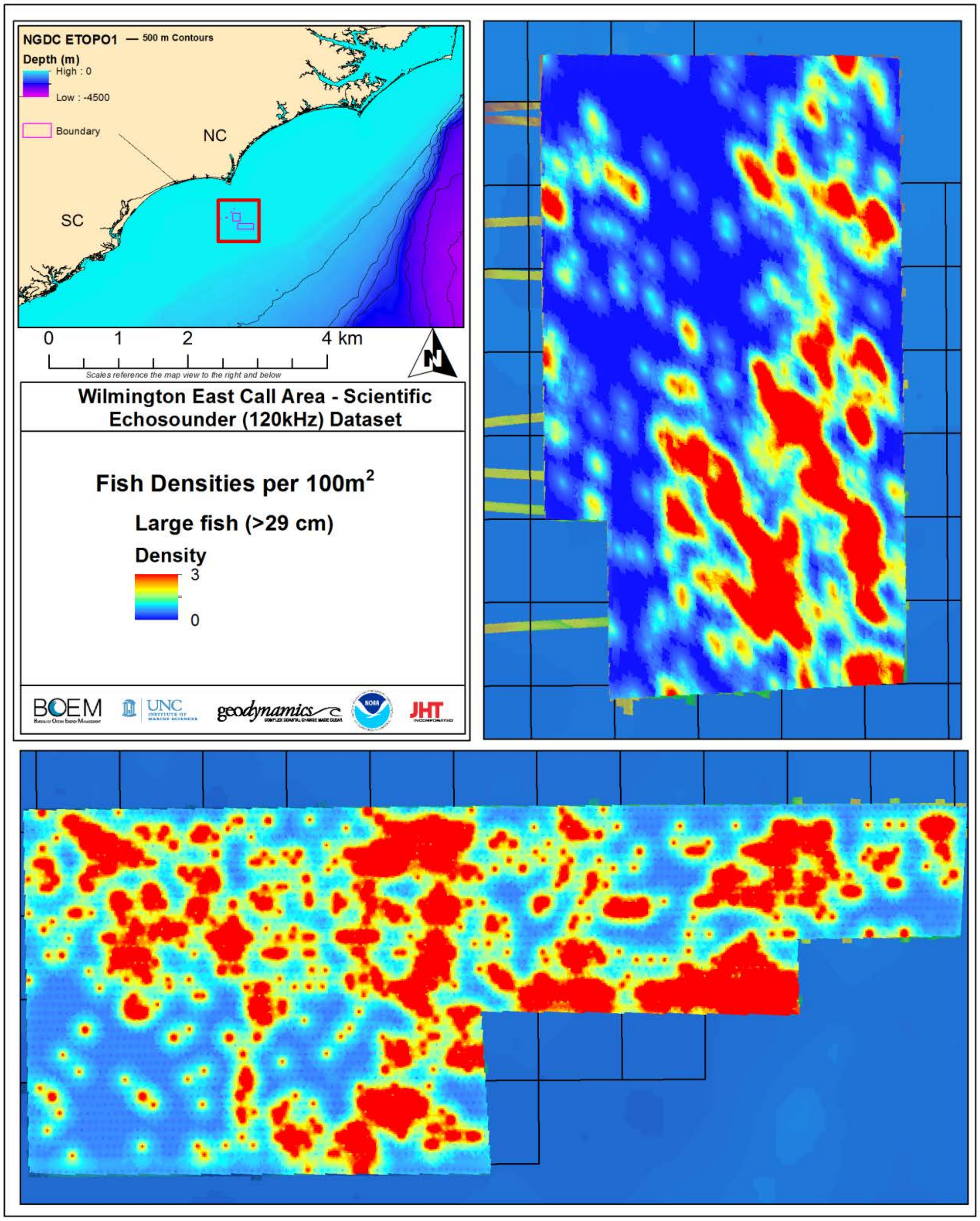

Figure 3-33. Kriging interpolation of large fish densities in focus areas selected for high-resolution multibeam survesy in the wind energy area. Densities are scaled according to blue (low) to red (high) color range.

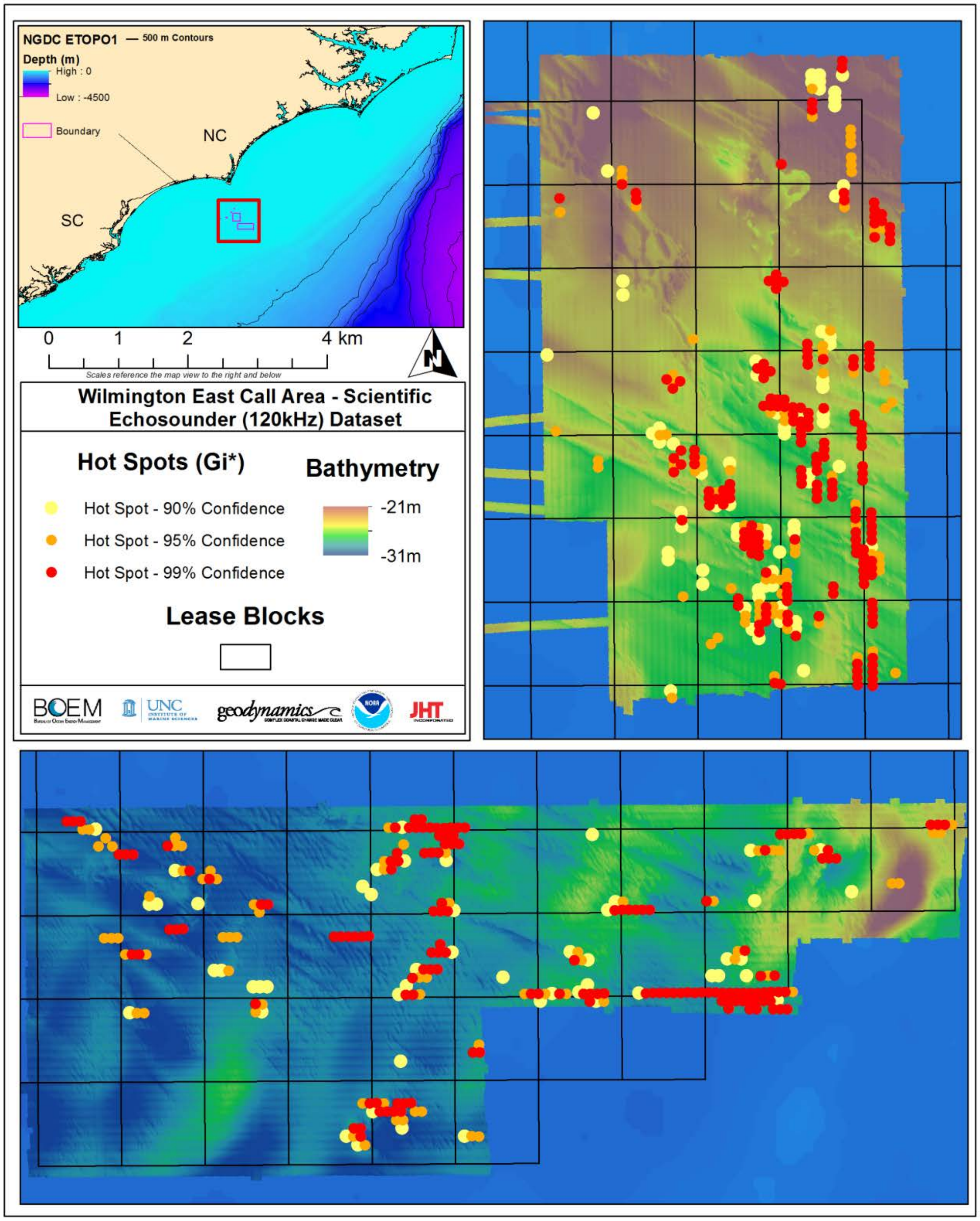

Figure 3-34. Significant hotspots for large fish size class densities in the focus areas of wind energy area from surveys conducted in 2014. The hotspot Gi* p-value is shown in 3 levels, >90% (yellow), >95% (orange) and >99% (red) indicating increase likelihood of clusters of high fish densities compared to random.

3.3.2. Distribution of fish in relation to hardbottom habitats

Seventeen SBES surveys were conducted over 28 selected dive stations and paired in time with diver visual surveys (Figure 3-35). The surveys were conducted over a range of habitat relief inferred from sidescan sonar and multibeam sonar imagery and confirmed as hardbottom or not by diver observations. Individual fish were detected during the day on high-relief ledge hardbottom features while few fish were detected over low-relief seafloor adjacent to the ledges (Figure 3-36). In contrast, fish were more broadly distributed around ledges at night (Figure 3-37). Distances from hardbottom features were measured for each detected fish, coded by fish size class (small, medium or large). Cumulative frequency histograms of the distance from ledge hardbottom features show 80% of the large fish were within 150 m of the feature and 100% were within 500 m (Figure 3-38).

Individual fish detected during the night SBES surveys were analyzed similarly by measuring distance from hardbottom features. In contrast to day surveys, night MBES surveys in 2014 (conducted within 9 days of the diver assessments and daytime SBES surveys) show a broader distribution of fish in relation to ledge features. Even large fish were distributed more than 900 m from the ledge features (Figure 3-38); however, inspection of selected sites still show generally fewer large fish in low-relief habitats adjacent to hardbottom ledges. In contrast, small fish were distributed over broad spatial ranges across the seafloor.

The design of the night MBES surveys in 2014 complicated the interpretation of the detection and distribution of fish relative to hardbottom features. The spacing of lines and orientation were dictated by the MBES surveys and not with respect to the orientation of the ledge features. Analysis of the distribution of fish relative to mixed hardbottom habitats was not informative due to the inability to accurately define the edge of this habitat type from MBES or SBES and define a distance between fish and habitat.

Fish densities mapped during SBES surveys over dive stations were positively and significantly correlated with diver observations when compared at small spatial extents. Aggregating fish detected using SBES within 25m of the dive survey transect location was the only statistically significant and positive correlation (Figure 3-39). Correlations with other spatial extents were not significant, suggesting relatively high variability and patchiness in fish distribution over hardbottom habitat features.

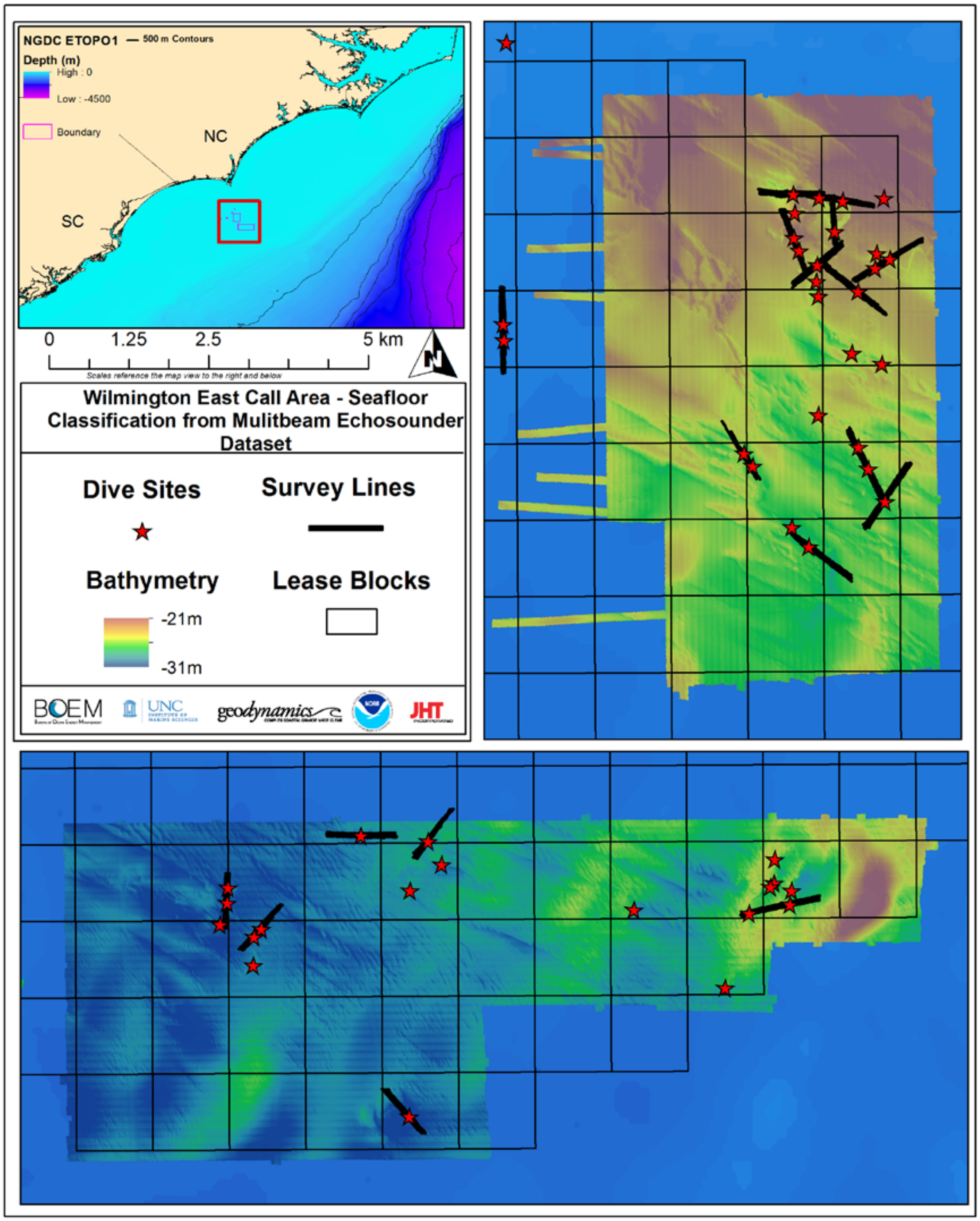

Figure 3-35. SBES Survey lines (black lines) over selected hardbottom features (color scaled from red-shallow to blue-deep). The survey lines were about 1.5 km in length, centered on a selected diver visual station.

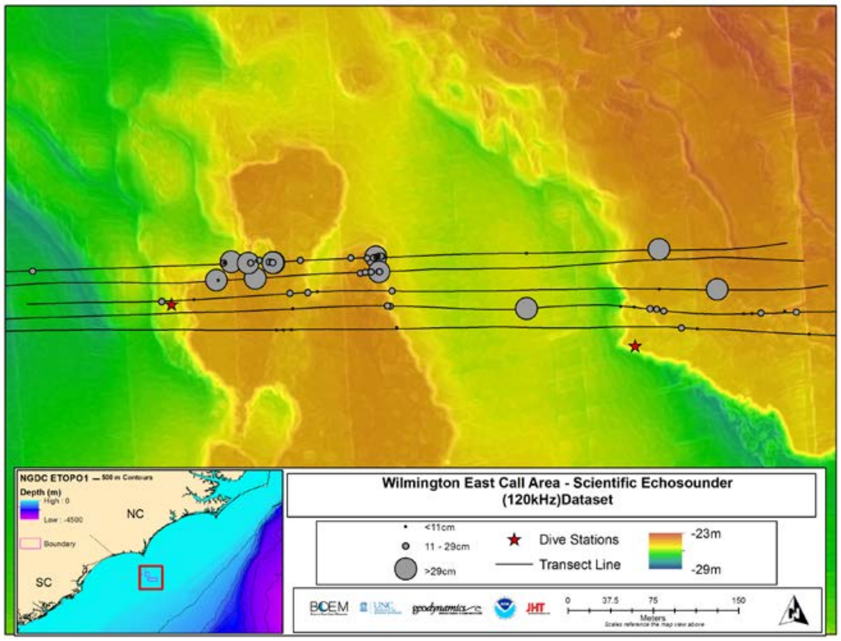

Figure 3-36. Example SBES survey lines (black lines) over a set of diver stations on high-relief ledge hardbottom habitats (red stars). Bathymetry base layer is shown as orange (shallow) to deep (blue). Individual fish are shown as black circles.

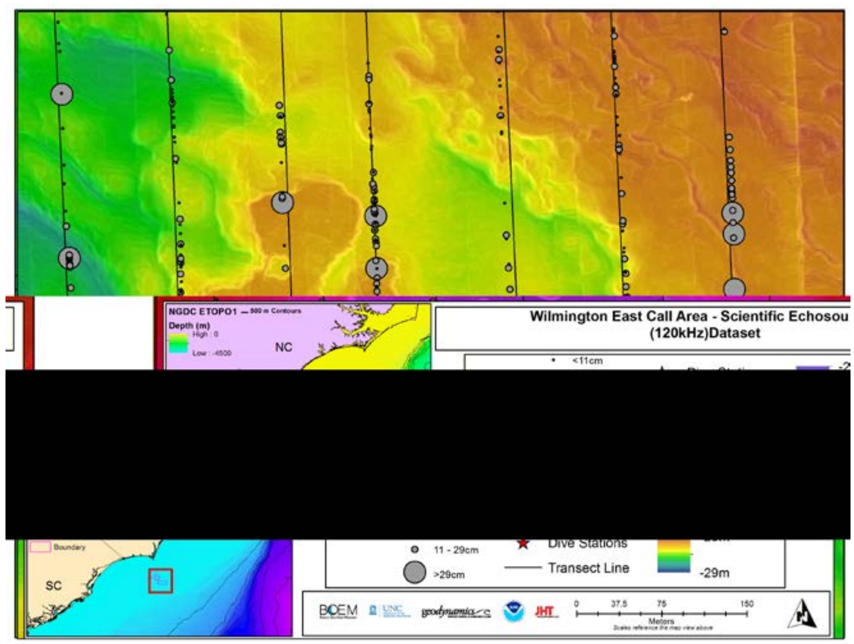

Figure 3-37. Example of SBES survey during night MBES mapping in north focus area in 2014. Bathymetry is shown as in Figure 3.4.11A. Individual fish are scaled according to size class: small (<12 cm), medium (12-29 cm) and large (>29 cm).

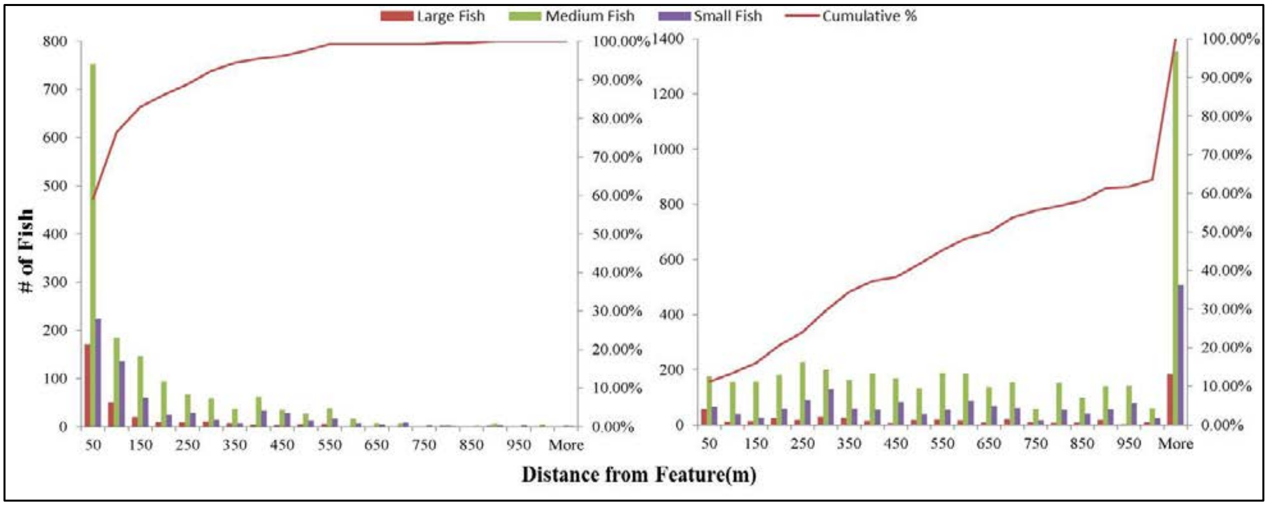

Figure 3-38. Frequency of fish by distance from ledge features by size class (bars) and cumulative proportion of distances from features for large fish (red line) for day surveys (left) and night surveys (right) conducted in 2014.

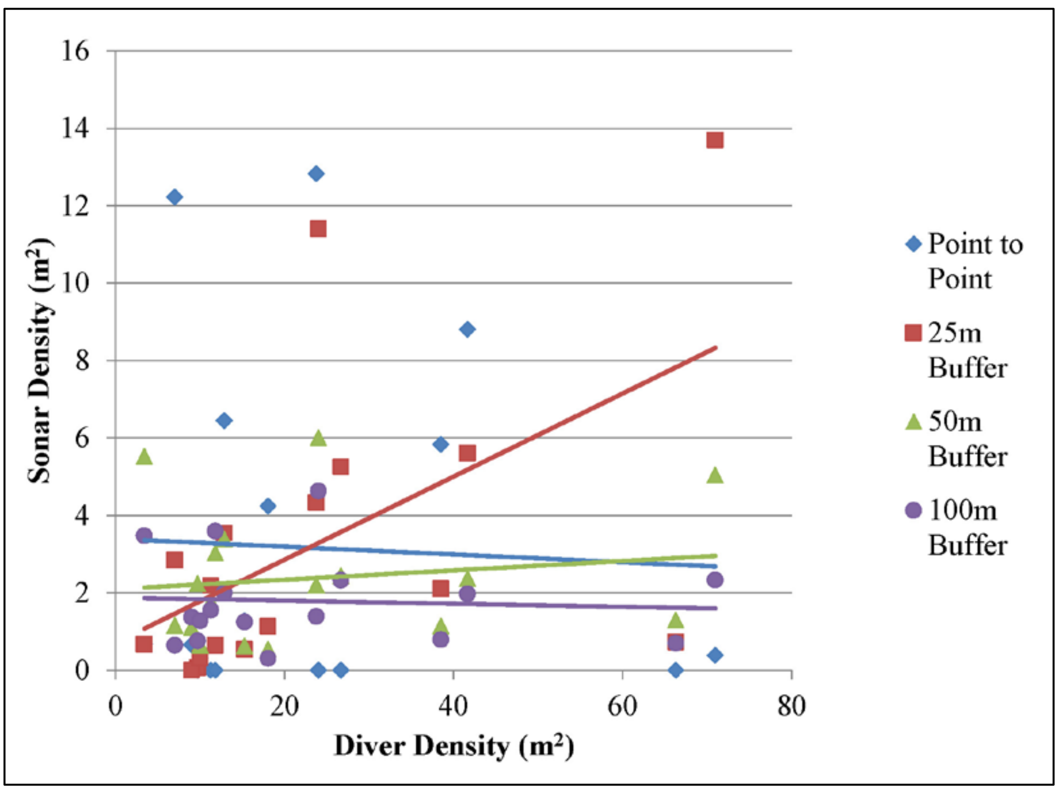

Figure 3-39. Correlation between diver densities for large fish (>29 cm) along transects and densities from sonar (SBES) surveys. Sonar densities were related to diver densities at four spatial extents indicated by colored symbols. Point to point compares the sonar density value in closest proximity to diver station. The buffers are an average of all sonar density values within 25, 50 or 100m radius of the dive station.

3.3.3. Modeling Acoustic Fish Densities Relative to Seafloor Complexity

For every GAM model of fish abundance by size class, both fish of other size classes and environmental predictors together explained more deviance than environmental predictors alone. Significant environmental predictors for every model were latitude and longitude, indicating spatial autocorrelation and schooling behavior. For large fish in the overall survey area, additional significant environmental predictors included EK60 bottom return, depth, slope, and slope change (Deviance explained 15.45%, adj $r^2 = 0.0739$; Figure 3-40). For large fish in the North survey area, significant environmental predictors included depth and multibeam backscatter, an indicator of the hardness and roughness of the seafloor (Deviance explained 22.5%, adj. $r^2 = 0.0953$). For large fish in the South Focus area, significant environmental predictors included multibeam backscatter, slope, slope change and depth (Deviance explained 16.9%, adj. $r^2 = 0.106$). For medium fish in the overall survey area, significant environmental predictors included EK60 return, depth, and slope change (Deviance explained 17.5%adj r^2 0.0813; Figure 3-41). For medium fish in the North Focus area, significant environmental predictors included EK60 return, depth, multibeam backscatter (Deviance explained 22.8% adj r^2 0.116), and in the South survey area, significant predictors included depth, slope, and multibeam backscatter (Deviance explained 25.3% adj r^2 0.232). For small fish in the overall survey area, significant environmental predictors included EK60 return, and depth (Deviance explained 34.2%, adj r^2 0.264; Figure 3-42). In the North survey area, significant environmental predictors included depth and EK60 return (deviance explained, 42.7%, adj r^2 0.334) and in the South area, significant environmental predictors included depth and multibeam backscatter (Deviance explained 22.5%, adj $r^2$0.132).

Depth, relief (i.e. slope, slope change), and habitat classification (i.e. EK60 return, multibeam backscatter) clearly influence the location of fish densities. Most of the models showed an association between fish and habitat classification, as represented by either multibeam backscatter or EK60 return. Larger fish exhibited a more detectable relationship with relief. For example, in the overall area, fish within the larger size class were associated with slope and slope change, whereas medium fish were only associated with slope, and small fish were not associated with either. Many relationships are nonlinear, except for slope which increase linearly with fish biomass in large and medium size classes. Fish associations with fish in other size classes were stronger than fish associations with environmental features. One potential explanation for this pattern is nocturnal fish foraging away from hardbottom or that fish species may be represented by more than one size class.

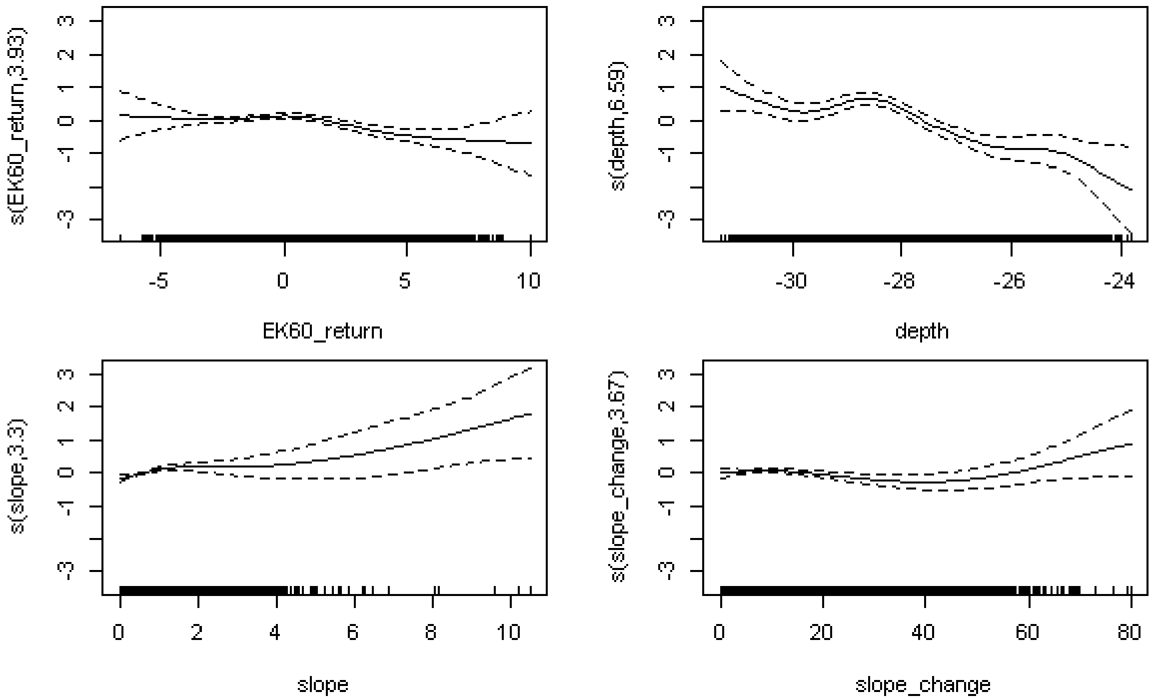

Figure 3-40. Smoothed relationships (y-axis) between SBES fish in the large size class with environmental variables for the combined North and South survey areas.

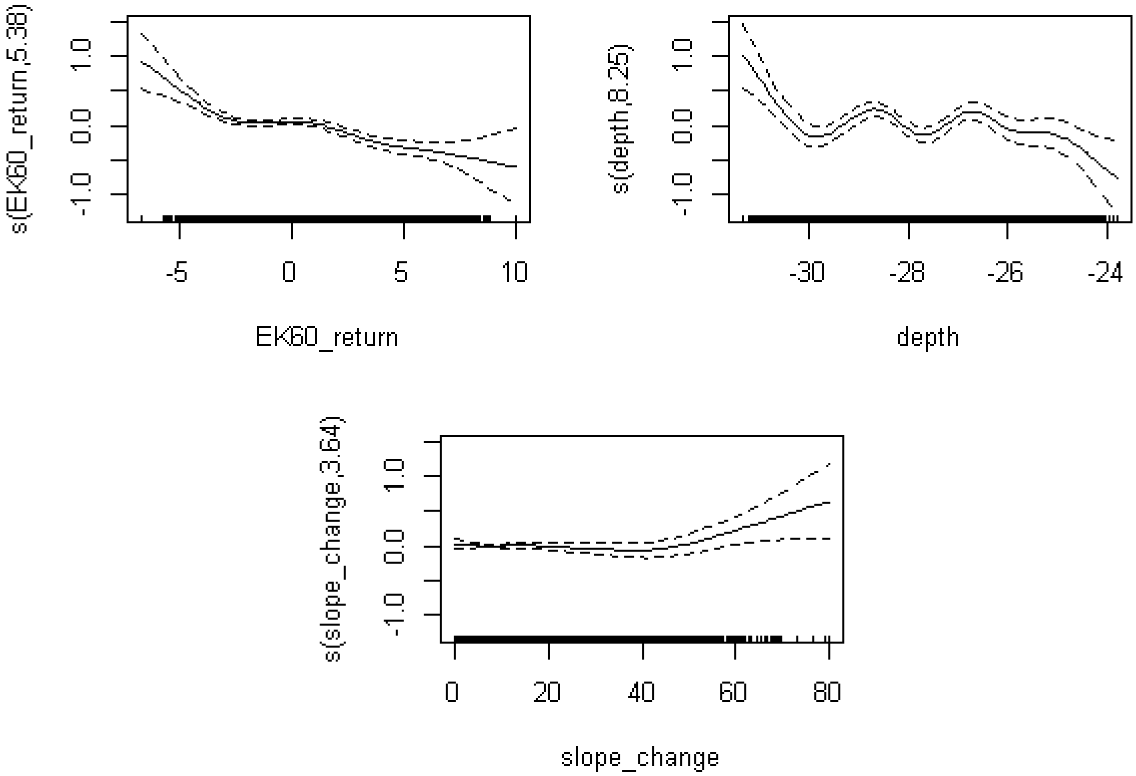

Figure 3-41. Smoothed relationships (y-axis) between SBES fish in the medium size class with environmental variables for the combined North and South survey areas.

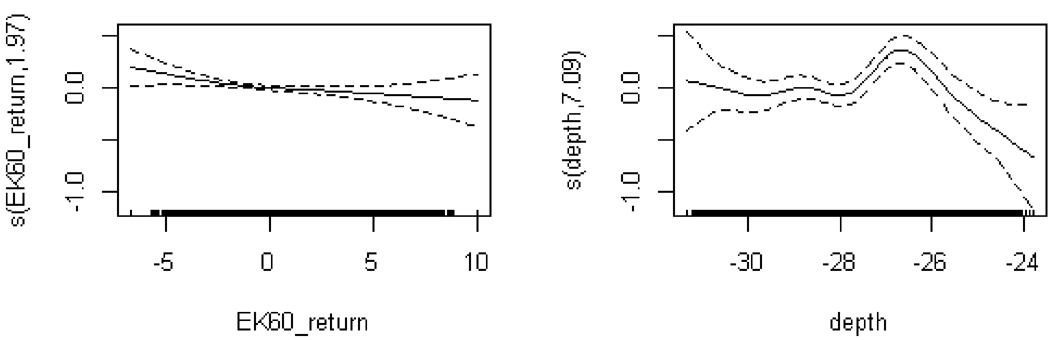

Figure 3-42 Smoothed relationships (y-axis) between SBES fish in the small size class with environmental variables for the combined North and South survey areas.

3.4. Diver Assessments of Benthic Habitat and Fish Communities

During the nine day research cruise in May 2014 aboard the NOAA Ship *Nancy Foster,* a total of 57 sites were surveyed using benthic methodologies (n = 52 hardbottom biological survey, 5 unconsolidated sediment ground –validation; Figure 3-43). Within hardbottom surveys, ledge and mixed hardbottom/sand were the dominant habitat types (Figure 3-44 and Table 3-4). Not all survey types were conducted over each hardbottom site; sample sizes varied within survey types due to field logistical constraints (e.g. weather, limited bottom time, depth limitations; Table 3-4). At the five unconsolidated sediment (sand) sites, divers did not characterize habitat, but instead provided additional ground-validation of sidescan and multibeam bathymetric classifications.

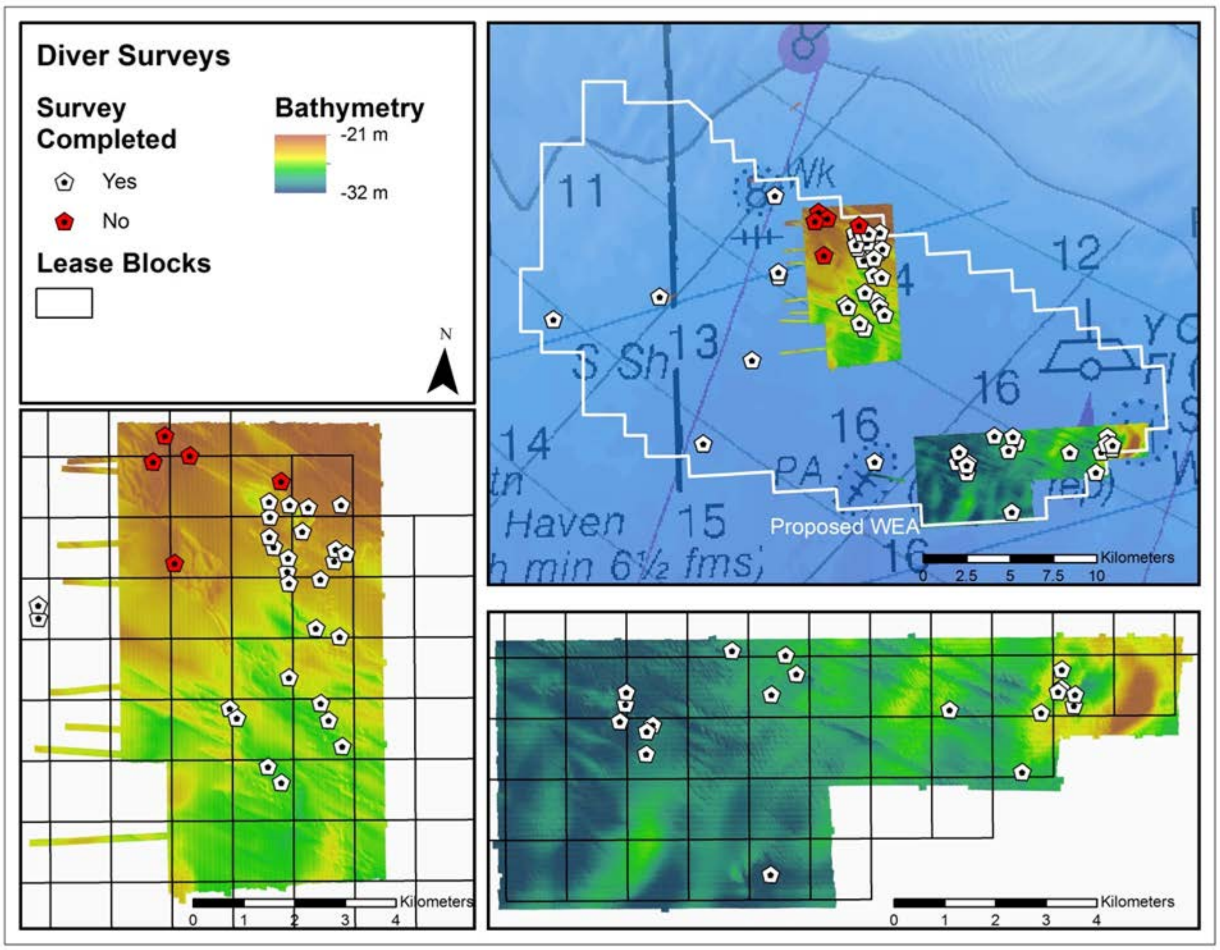

Figure 3-43. Sites surveyed during the May 2014 diver surveys of the potential wind energy area off Wilmington, NC. Fish and line point intercept methods were conducted at all surveyed sites (white symbols, N = 52). Red symbols indicate where divers encountered sand, no hardbottom, and a survey was not completed (n = 5).

Table 3-4. Diver site summary table. * indicates survey was conducted at the site; however, sample size was less than required minimum (5 points for topography, 40 points for LPI) and data were not used in further analyses. Site names are assigned according to wind energy lease block number and site replicate within the block.

Site	Latitude	Longitude	Conspic.	Cryptic	Topo	LPI	Photo quad	Macro Inv.	Habitat type	Depth (ft)	Crevice - hole	Turtles
6605E_4	33.395332	-77.82569	x	x	x*	x			ledge	101	Yes	No
6607E_1	33.39921	-77.73421	x	x	x*	x	x	x	ledge	94	Yes	No
6605J_3	33.391761	-77.81986	x	x	x		x		mixed HB/sand	103	No	No
6605H_3	33.401390	-77.78970	x	x	x	x			ledge	99	Yes	No
6537K_1	33.472549	-78.07438	x	x	x	x		x	wreck	84	No	No
6454I_4	33.513065	-77.88581	x	x	x*	x	x		mixed HB/sand	86	No	No
6504A_1	33.498672	-77.88120	x	x	x	x			ledge	92	Yes	No
6454M_1	33.503131	-77.88150	x	x	x	x			ledge	93	Yes	Yes
6504M_2	33.466011	-77.88478	x	x	x	x			mixed HB/sand	98	Yes	No
6606H_1	33.395423	-77.73770	x	x	x	x	x		ledge	91	Yes	No
6454I_3	33.510414	-77.88551	x	x	x	x	x		mixed HB/sand	89	No	No
6605J_1	33.386569	-77.82111	x	x	x	x	x	x	mixed HB/sand	97	Yes	No
6607E_4	33.399799	-77.73358	x	x	x	x	x		ledge	98	No	No
6606L_1	33.384799	-77.7414	x	x	x	x			mixed HB/sand	96	Yes	No
6454M_3	33.505065	-77.88464	x	x	x	x	x	x	ledge	87	Yes	No
6607E_3	33.398750	-77.73061	x	x	x	x	x	x	ledge	94	Yes	No
6454J_2	33.512233	-77.87746	x	x	x	x	x	x	ledge	87	Yes	No
6503A_1	33.491458	-77.93411	x	x	x	x			mixed HB/sand	88	Yes	No
6454M_4	33.506858	-77.88553	x	x	x	x	x	x	ledge	89	No	No
6604E_1	33.393768	-77.87799	x	x	x*	x*		x	wreck	98	Yes	No
6605J_2	33.390583	-77.82109	x	x	x	x	x		mixed HB/sand	100	Yes	No
6454N_6	33.504196	-77.86927	x	x	x	x	x		mixed HB/sand	88	No	No
6605D_1	33.404651	-77.79206	x	x	x	x	x	x	mixed HB/sand	99	No	No
6605H_1	33.397613	-77.79492	x	x	x	x			mixed HB/sand	98	Yes	No
6607E_5	33.403148	-77.73352	x	x	x	x	x		mixed HB/sand	92	No	No

Site	Latitude	Longitude	Conspic.	Cryptic	Topo	LPI	Photo quad	Macro Inv.	Habitat type	Depth (ft)	Crevice - hole	Turtles
6454M_2	33.500797	-77.88161	x	x	x	x			mixed HB/sand	91	Yes	No
6454N_4	33.502834	-77.87168	x	x	x	x			mixed HB/sand	91	No	No
6607E_2	33.396789	-77.73081	x	x	x	x	x		mixed HB/sand	93	Yes	No
6588H_1	33.405860	-77.98380	x	x	x	x		x	mixed HB/sand	96	Yes	No
6552D_1	33.448497	-77.95206	x	x	x	x	x		ledge	96	Yes	No
6453A_1	33.533561	-77.93485	x	x	x	x		x	ledge	81	Yes	No
6454N_7	33.504909	-77.87148	x	x	x	x	x		pavement	88	Yes	No
6454J_1	33.512786	-77.87049	x	x	x	x			mixed HB/sand	84	Yes	No
6504B_2	33.499507	-77.87454	x	x	x	x			mixed HB/sand	90	Yes	No
6454I_2	33.512626	-77.88144	x	x	x	x			mixed HB/sand	90	Yes	No
6504J_2	33.477485	-77.87390	x	x	x	x			ledge	96	Yes	No
6504E_1	33.481925	-77.88077	x	x	x	x			mixed HB/sand	93	Yes	No
6504J_1	33.474498	-77.87214	x	x	x	x			mixed HB/sand	96	No	No
6503L_1	33.476215	-77.89314	x	x	x	x	x		mixed HB/sand	96	Yes	No
6504I_1	33.474514	-77.89161	x	x	x	x	x		mixed HB/sand	97	Yes	No
6504B_3	33.490760	-77.87529	x	x	x	x	x	x	pavement	87	No	No
6538H_1	33.482734	-78.00814	x	x	x	x	x	x	mixed HB/sand	87	Yes	No
6504M_1	33.463245	-77.88185	x	x	x	x			mixed HB/sand	96	Yes	No
6503A_2	33.493751	-77.93424	x	x	x	x			pavement	87	Yes	No
6504J_3	33.469924	-77.86914	x	x	x	x	x		mixed HB/sand	97	No	No
6504B_1	33.489368	-77.87019	x	x	x	x	x		mixed HB/sand	95	No	No
6605C_2	33.405246	-77.80340	x	x	x	x	x		ledge	102	Yes	No
6454N_2	33.5079	-77.8786	x	x		x	x		ledge	88	Yes	No
6605I_1	33.39223	-77.82684	x			x	x		mixed HB/sand	102	No	No
6605E_5	33.39746	-77.82561	x			x			ledge	105	Yes	Yes
6655D_1	33.36563	-77.79426	x			x	x	x	mixed HB/sand	105	No	No
6606G_1	33.39556	-77.75709	x	x		x			ledge	98	No	No

Table 3-5. Number of sites surveyed by each survey method and minimum and maximum site depths (m) for each habitat type. * indicates adjusted survey site totals due to small sample size. This is the number of sites analyzed.

Habitat type	Conspicuous	Cryptic*	Topo*	LPI*	Photo Quad	Macro-Inv	Max depth	Min depth
Ledge	18	17	13	18	10	6	32	23
Mixed HB/Sand	29	27	27	28	16	5	32	21
Pavement	3	3	3	3	2	1	27	26
Artificial	2	2	1	1	0	2	30	24
Overall	52	47	44	50	28	13	32	21

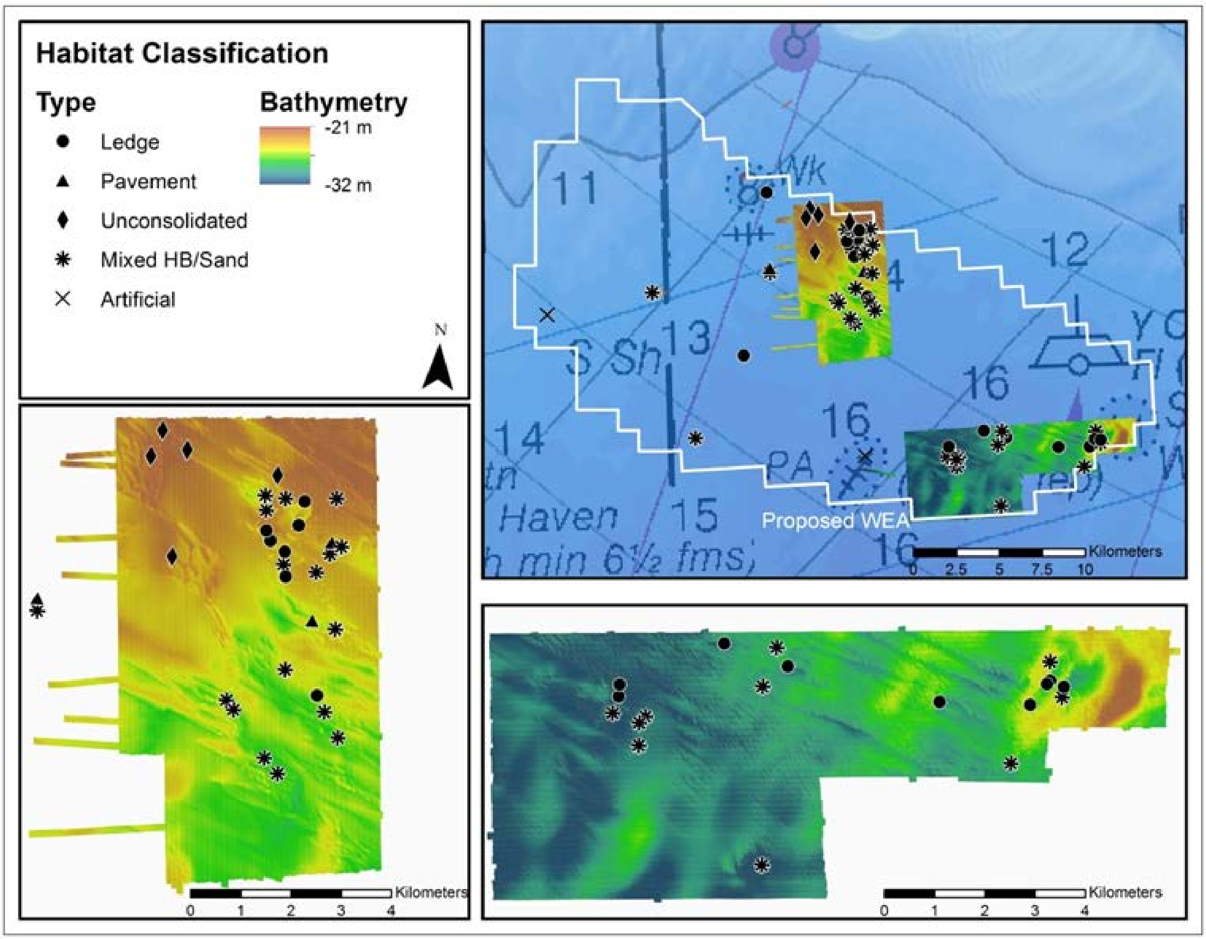

Figure 3-44. Habitat type documented by diver surveys in May 2014.

3.4.1. Diver Assessments of Benthic Habitat

3.4.1.1. Topographic complexity surveys

Within the survey area, overall mean abiotic (hardbottom) height was 19.7 cm, with a range of site-level mean heights of 2.6 - 88.3 cm (N = 43 sites) (Figure 3-45). Mean height by habitat type ranged from 6.9 cm in pavement habitats to 67.8 cm at artificial reef sites. Some very high abiotic relief was recorded in both ledge and artificial sites, while pavement and mixed HB/sand habitats were more uniformly low in relief. Ledge habitat relief was significantly higher than mixed HB/sand habitats (t (13.7) = -4.14, p = 0.001); due to small sample sizes, differences between other habitat types were not tested.

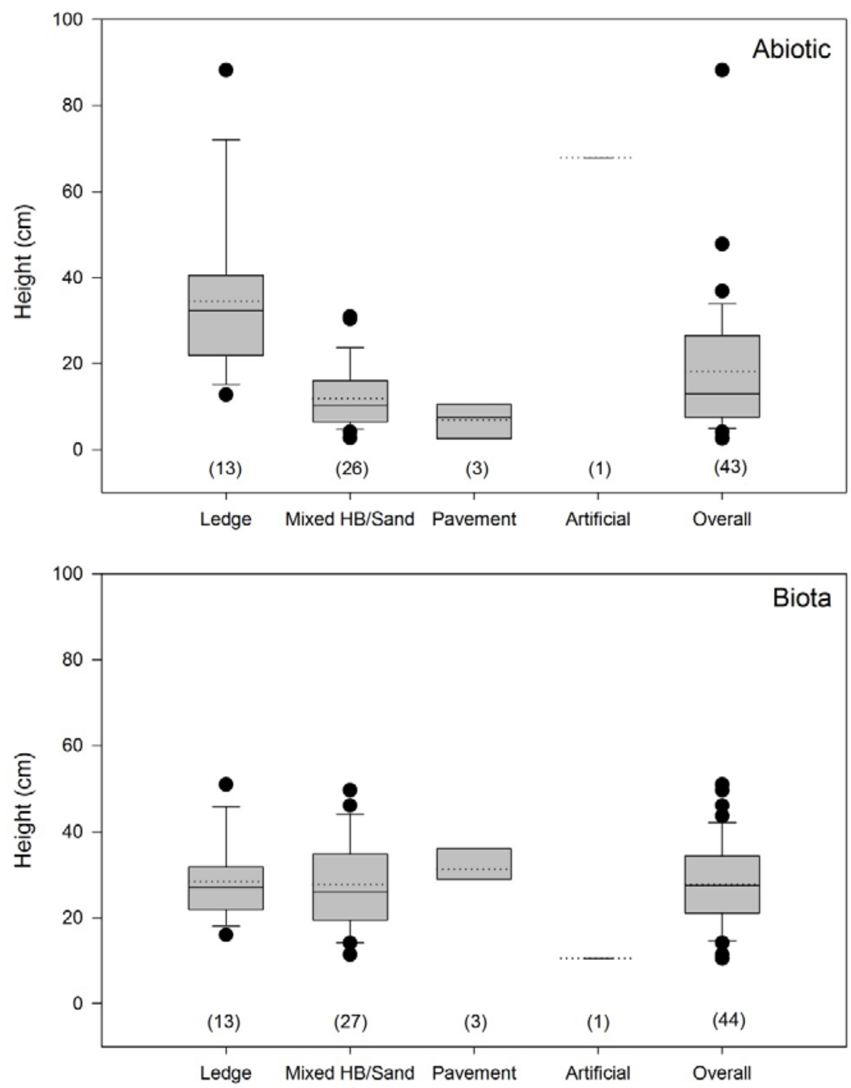

Figure 3-45. Hardbottom and biota height (cm) by habitat type and across all sites combined. Mean height shown by dashed line, individual outliers presented as circles. Sample sizes by habitat type are in parentheses.

Overall mean biotic height was 27.8 cm, with a range between 10.5 – 51 cm (N = 44 sites). Biotic height was similar between ledge and mixed HB/sand habitats (Figure 3-45). Some sites had high biotic heights (> 40 cm; Figure 3-45). For all of the survey sites combined, overall biotic height was significantly greater than abiotic height (t (65.9) = -2.64, p = 0.01). Combined abiotic and biotic heights describe the total site complexity, with the greatest complexity being in artificial habitats, followed by ledge and mixed HB/sand habitats. The total site complexity of ledge habitat was more comparable to artificial habitats than biotic or abiotic structure alone, however our sample size was small and data for biotic complexity was incomplete in artificial habitats.

Individual biota height measurements ranged from 2 – 136 cm (soft coral and macroalgae respectively). Of the 806 habitat biota height values recorded, soft coral was most frequently recorded (n = 520 records) followed by sponge (n=108) and macroalgae (n = 69). Soft coral height was greatest (32.9 ± 0.6 cm) followed by sponge (21.0 ± 0.9) and macroalgae (20.8 ± 2.5). Few biotic species group differences were identified between ledge and mixed HB/sand habitats (Figure 3-46), only hydroids were taller in ledge than in mixed HB/sand habitats (Z = 2.16, p = 0.03). Although some individual measurements were quite tall (e.g. *Sargassum* species at 136 cm.), there was no significant difference in macroalgae, soft coral, other, or sponge heights between ledge and mixed HB/sand habitats.

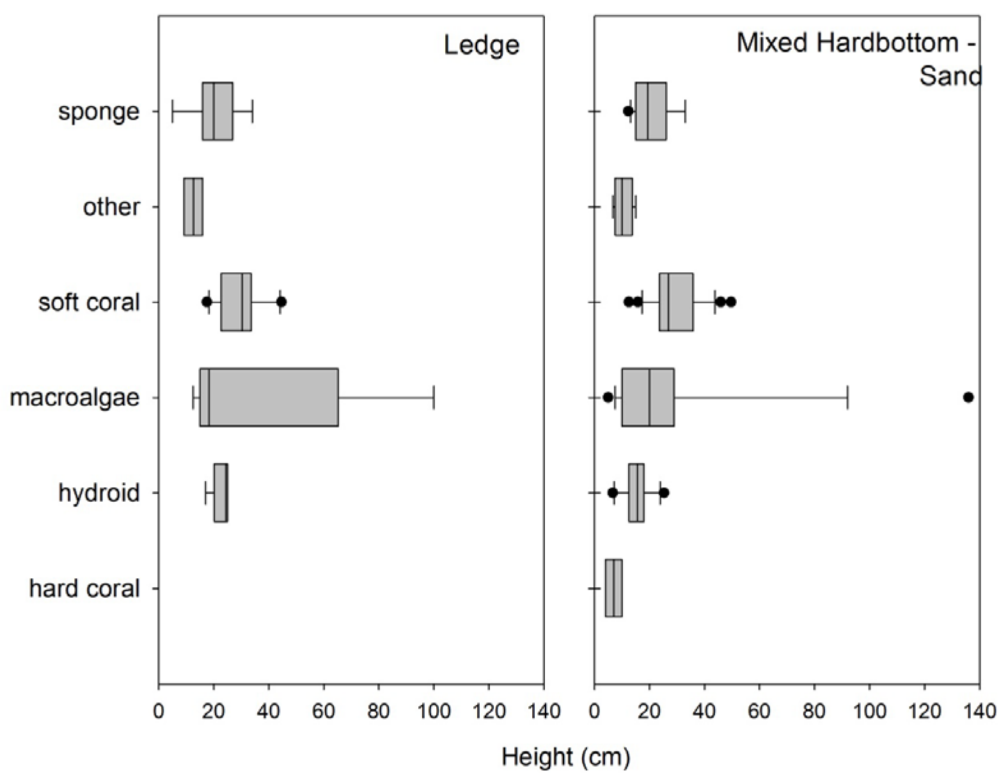

Figure 3-46. Biota height (cm) by general biota category for ledge and mixed hardbottom-sand sites. Mean biota height shown by dashed line, individual outliers presented as circles.

Divers reported bottom water temperatures between 17.5 - 23°C, macroalgal heights measured for this study appeared representative of a winter algal community rather spring and fall conditions, when offshore NC communities are dominated by large (>15 cm) fleshy macroalgae (C.A. Buckel, unpublished data from Onslow Bay, NC). The observed macroalgae community was low in height and species diversity, and indicators of a spring algae bloom were not observed however sampling a few months later would have likely documented a greater amount of structure from macroalgae.

3.4.1.2. Line Point Intercept (LPI) surveys

Abiotic cover at surveyed sites was dominated by hardbottom (rock) and sand substrates (Table 3-6). Both substrates contributed a similar amount of benthic cover, and no significant differences were found between the two (Figure 3-47). Rubble cover was less than sand ($Z = 8.26$, $p < 0.0001$) and hardbottom ($Z = -8.35$, $p < 0.0001$) (Table 3-6, Figure 3-47). Hardbottom cover was significantly greater on ledge than mixed HB/sand (t ($df = 44$) $= -4.75$, $p < 0.0001$) while sand cover was significantly greater on mixed HB/sand than ledge habitats (t ($df = 33$) $= 4.8$, $p < 0.0001$). There was no significant difference in rubble cover between these two habitat types.

Table 3-6. Mean abiotic percent cover (SE) by habitat type and for all sites combined.

Habitat Type	N Sites	Hardbottom	Sand	Rubble
Ledge	18	64.5 (5.4)	33.1 (5.4)	2.3 (0.8)
Mixed HB/Sand	28	33.9 (3.8)	65.3 (3.8)	0.8 (0.3)
Pavement	3	42.8 (15.4)	57.2 (15.4)	0 (0)
Artificial	1	3.5	61.4	35.1
Total	50	44.9 (3.7)	53.1 (3.7)	2.0 (0.8)

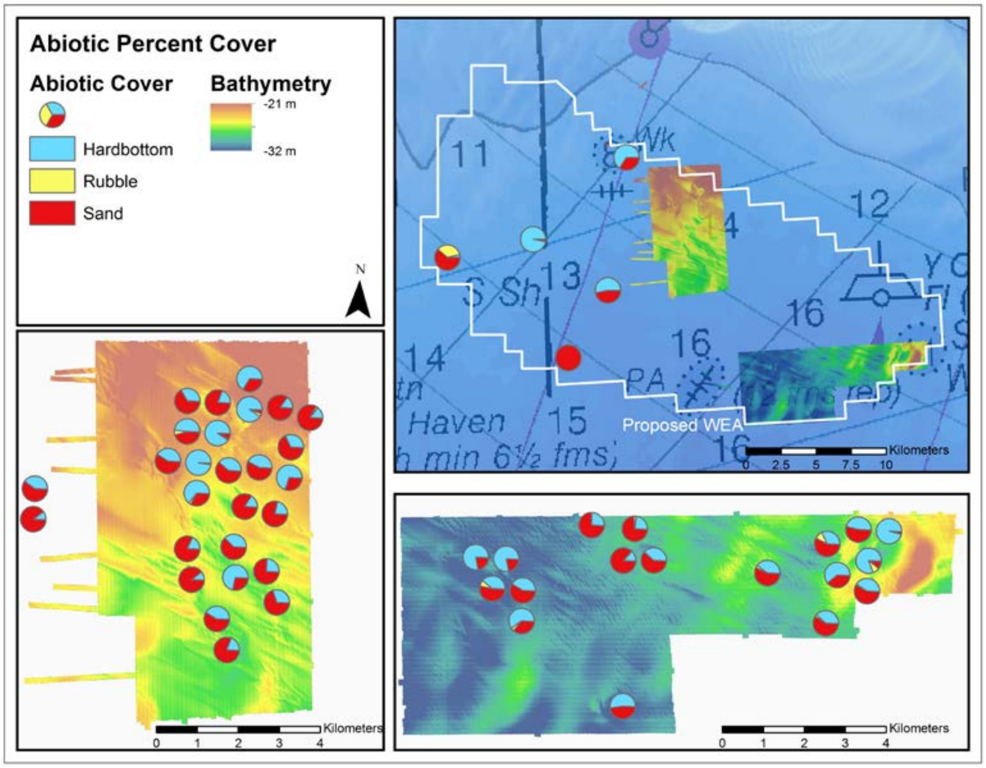

Figure 3-47. Percent cover of hardbottom, rubble and sand at diver surveyed sites in May 2014.

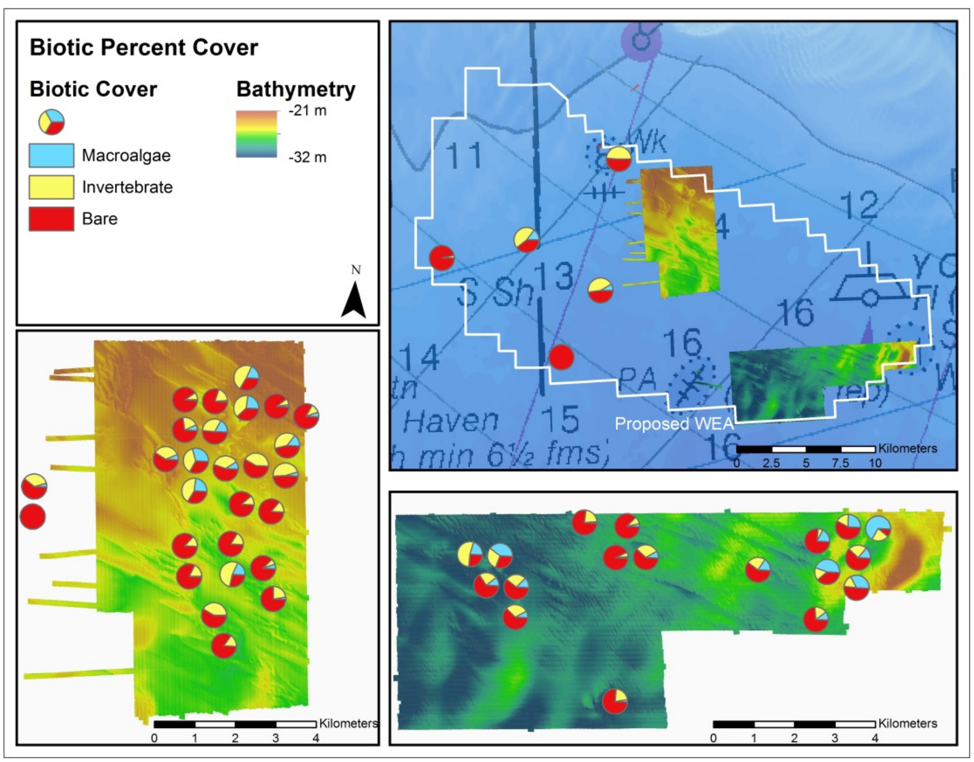

Figure 3-48. Percent cover of macroalgae, invertebrates, and bare substrate at diver surveyed sites in May 2014.

Biotic cover, quantified by LPI, was composed primarily of bare substrate (63.3 ± 3.1%), followed by invertebrates (26.1 ± 2.0%), and macroalgae (13.5 ± 2.1%) (Figure 3-48, Figure 3-49). Cover of these three bottom types differed significantly ($F = 121.68$, $p < 0.0001$) with each group being significantly different ($p = < 0.001$) from the others following a sequential Bonferroni correction. Bare substrate cover was greater than macroalgae and invertebrate cover in all surveyed habitats (Figure 3-49). Macroalgae ($t = -3.3$, $p = 0.0033$) and invertebrate ($t = -2.9$, $p = 0.0052$) cover was higher and bare cover was lower ($t = 4.6$, $p < 0.0001$) within the ledge habitat compared to the mixed HB/sand habitat. Due to small sample sizes statistical differences could not be examined between the other habitat types.

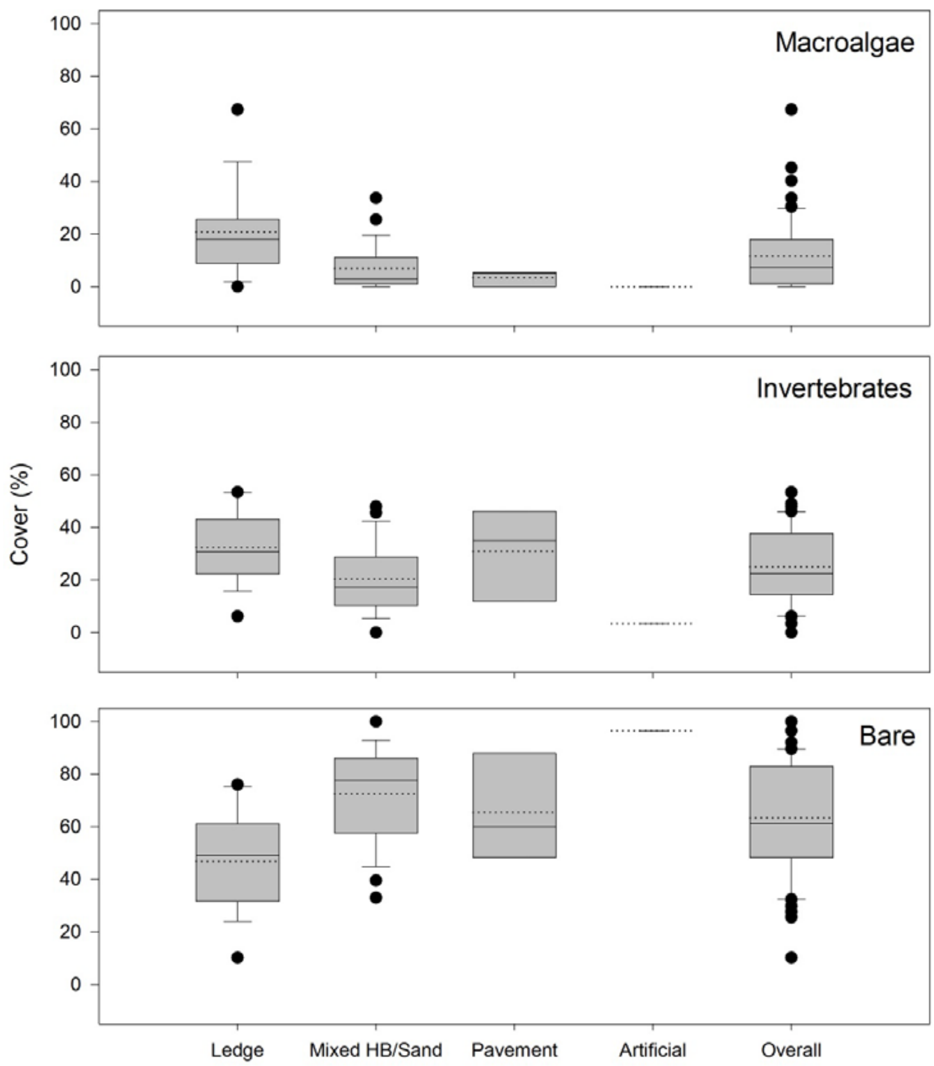

Figure 3-49. Benthic cover of macroalgae, invertebrates, and bare substrate by habitat type and all sites combined. Mean cover shown by dashed line, individual outliers presented as circles. Sample sizes by habitat type are provided in Table 3-3.

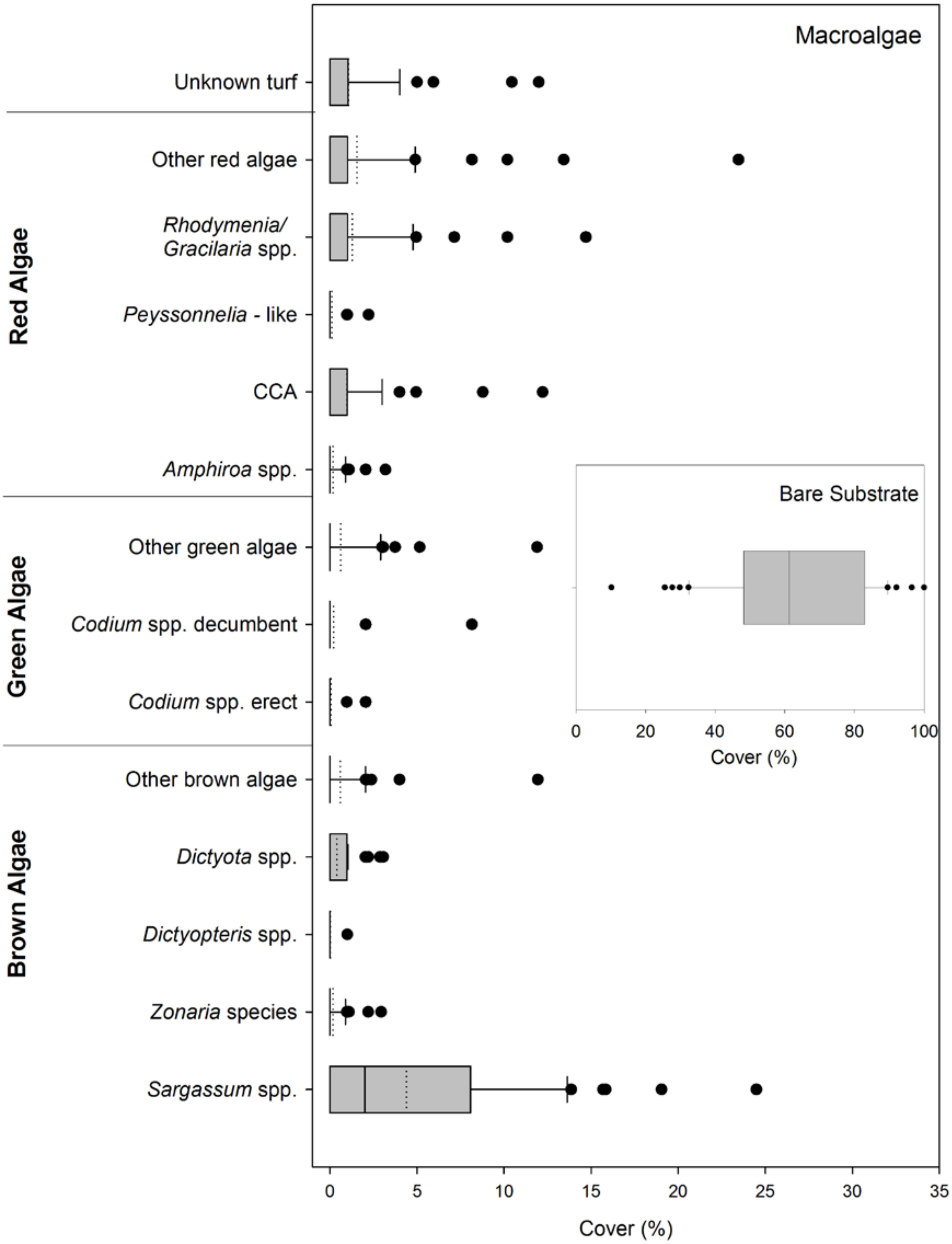

Figure 3-50. Percent cover of bare substrate, macroalgae, and invertebrate species and species groups for all May 2014 diver surveys combined. Mean cover shown by dashed line, individual outliers presented as circles.

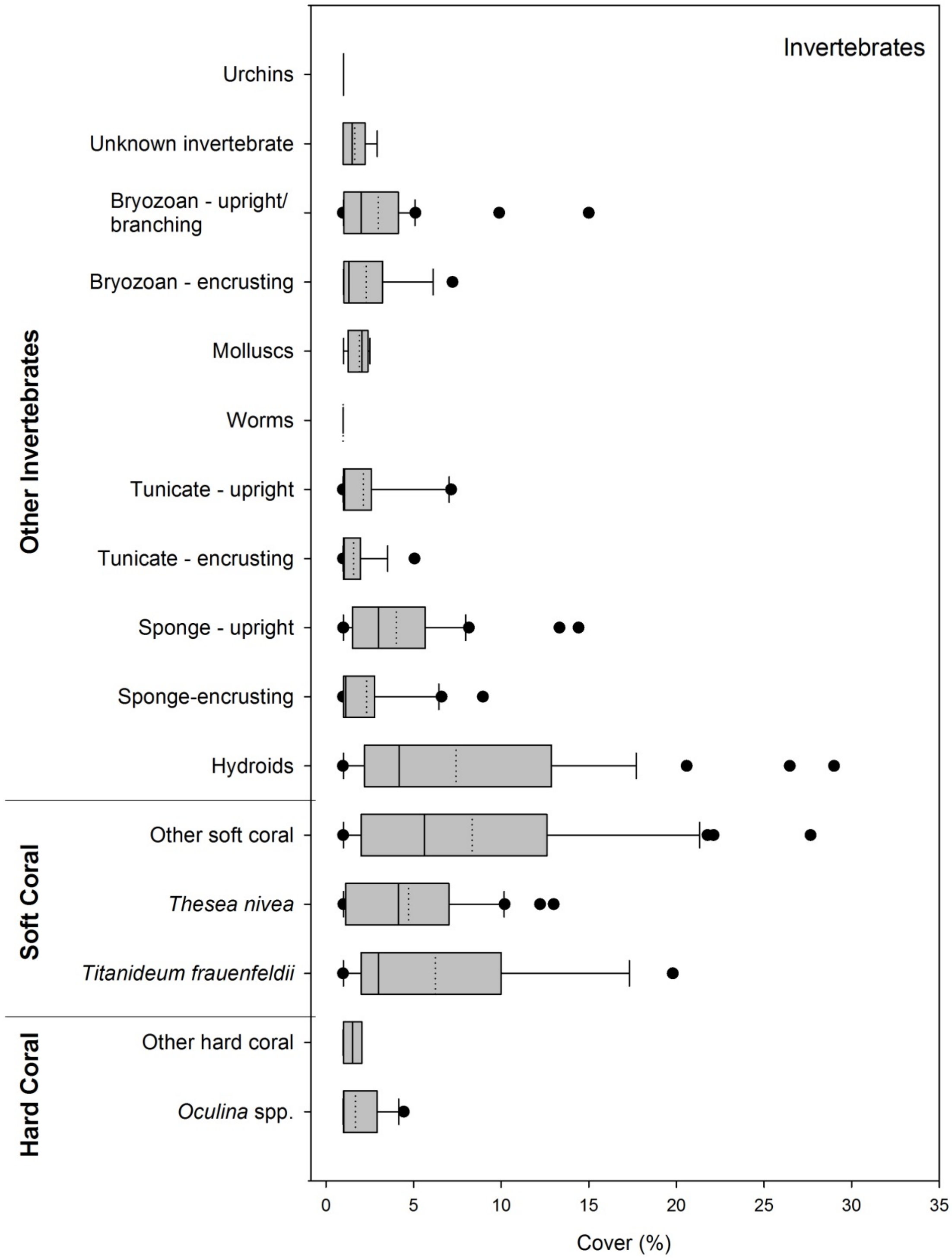

Figure 3-50. Continued.

The dominant species or species groups by cover were: other soft corals (excluding *Thesea* and *Titanideum*) (mean cover: 6.2%), hydroids (5.5%), *Sargassum* species (4.4%), and *Thesea nivea* (2.8%) (Figure 3-50). When examined by habitat type, only *Thesea nivea* (mean cover ledge: 4.8%, mixed HB/sand:1.7%) and *Sargassum* spp. cover (mean cover ledge: 7.4%, mixed HB/sand: 3.0%) were different between ledge and mixed HB/sand habitats, with both having higher cover in ledge habitats (*Thesea nivea* Z = 2.68, p = 0.007; *Sargassum* spp. Z = 2.33, p = 0.019). While overall cover for these species groups is low (<10%), some sites did have above average cover (maximum site cover: other soft coral 28%, hydroids 29%, *Sargassum* spp. 25%, and *Thesea nivea* 13%).

Cover of invertebrates, including soft corals, sponges, and hard coral, was related to amount of hardbottom as measured by divers. This predictor explained 36% of variance within invertebrate cover (Figure 3-51A). Cover of macroalgae was related to hardbottom cover, maximum slope, and multibeam derived rugosity (5-cell scale). Together, these predictors explained 24% of variance within macroalgal cover (Figure 3-51 B).

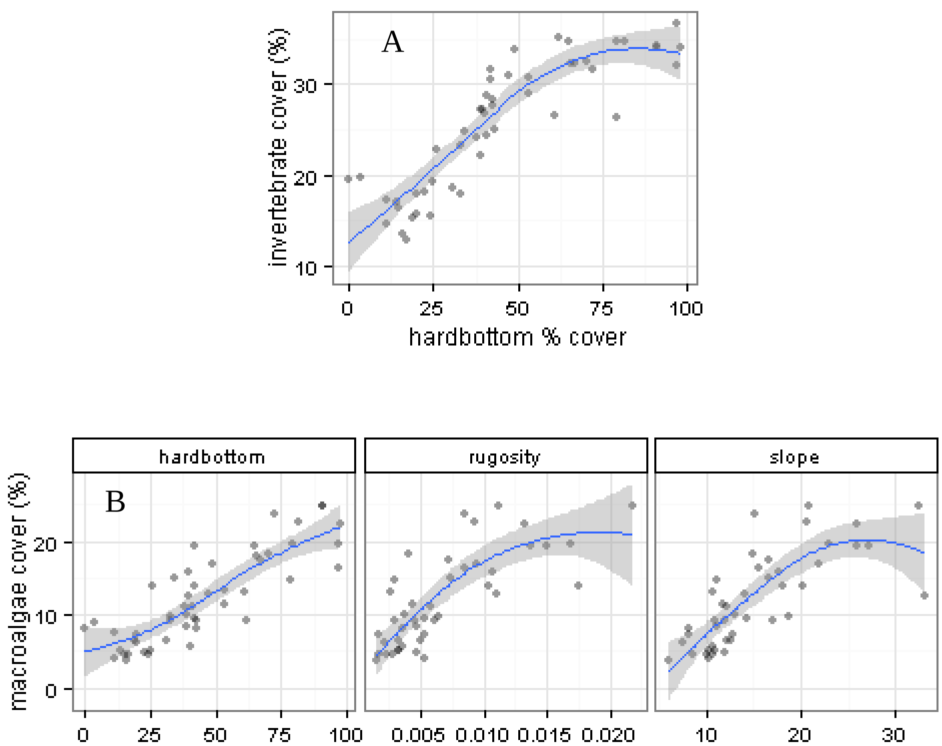

Figure 3-51. A. Partial dependence plot showing cover of invertebrates, including hard corals, soft corals, and sponges, as related to hardbottom cover (%). B. Partial dependence plots showing cover of macroalgae as related to hardbottom cover (%), multibeam derived rugosity (5 cell resolution), and slope (m). Line indicates smoothed fit, gray is confidence band.

3.4.1.3. Targeted benthic macro-invertebrate surveys

Benthic macro-invertebrate surveys were conducted at 13 sites quantifying density and structure (height in cm) of less seasonally ephemeral species in this environment. Surveyed species groups were: sponge, hard corals, and soft corals. Survey areas at these sites varied between from 10 – 27 m^2 due to time limitations at depth. Soft corals were significantly more abundant than sponge or hard corals (Figure 3-52) when all sites were combined ($\chi^2 = 19.95$, $p < 0.001$; soft coral mean #/m^2 (SE) 9.8 (2.8); sponge: 0.3 (0.1); hard coral: 0.5 (0.1)). Soft corals and hard corals were recorded in each habitat type, although sample size in artificial and pavement habitats was low for both groups. Sponges were only recorded in ledge and mixed HB/sand habitats (Figure 3-52). There were no significant differences in density between ledge and mixed HB/sand habitats for these three species groups. Sample sizes were too low to conduct further statistical analyses on other habitat types.

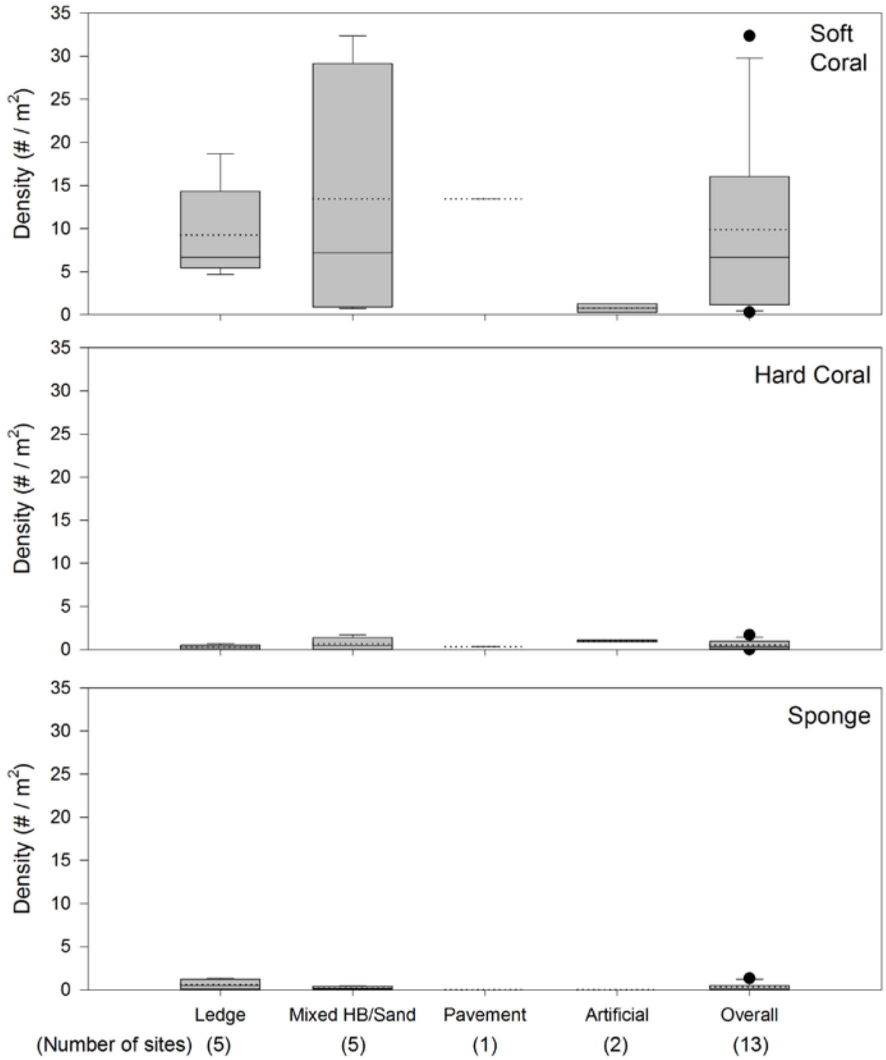

Figure 3-52. Soft coral, hard coral, and sponge densities by habitat type and all sites combined. Mean density shown by dashed line, individual outliers presented as circles. Number of sites by habitat type are in parentheses.

Eight unique soft coral species and an "other octocoral species" group were observed (Figure 3-54). Soft coral species richness was between 2 and 8 per site. *Thesea nivea* was the most frequently encountered (12 of 13 sites), followed by *Titanideum frauenfeldii* (10 sites). These two species not only had high incidences of encounter they were also found in high densities.

Titanideum frauenfeldii occurred at the highest density (overall mean (SE) 4.0 (1.5)) followed by *Thesea nivea* (2.7 (0.7)) and *Carioja riisei* (1.6 (0.7); Figure 3-53 and Figure 3-54). There were no significant density differences between ledge and mixed HB/sand habitats. *T. frauenfeldii* and *T. nivea* also contributed to site structure as both are upright octocoral species, unlike *C. riisei* which is considered a fouling organism with densely branching colonies. At some sites, octocoral density was recorded as 100 per size class (*Thesea nivea* (N sites =5), *Titanideum frauenfeldii* (5), *Carioja riisei* (4), *Leptogorgia hebes* (1), *Telesto sanguinea* (1)) and estimates may be underrepresented.

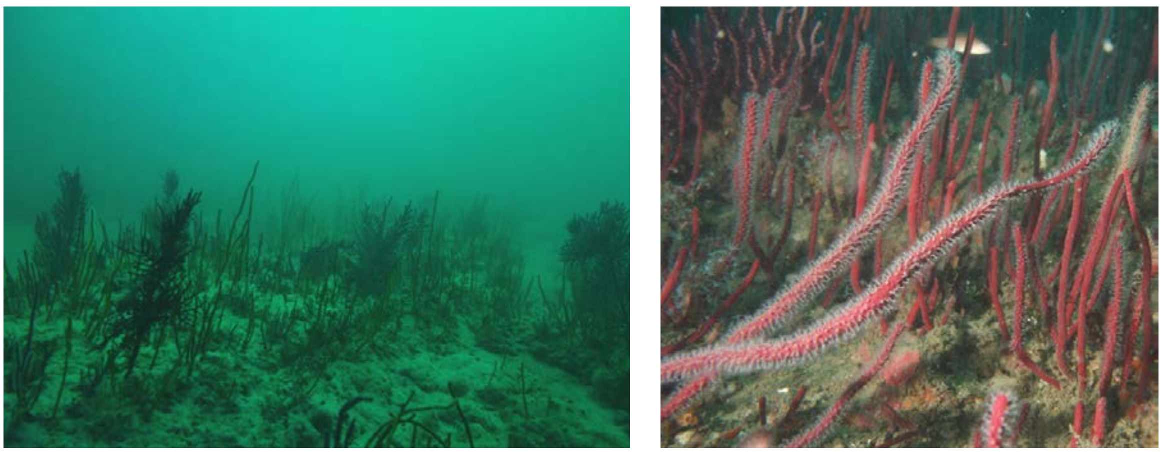

Figure 3-53. Examples of high densities of mixed soft coral species (left) and *Titanideum frauenfeldii* (right) at surveyed sites within the proposed wind energy area.

Hard coral species encountered included: cup corals (*Phyllangea* species), *Solenastrea hyades*, and *Oculina* species (Figure 3-54). Although densities of all hard coral species were low (max site density 1.6 scleractinia / m^2), *Oculina* was the most abundant species for both ledge and mixed HB/sand habitats as well as for all sites combined (overall mean: 0.5 (0.1)). All individuals were <10 cm in maximum height (Figure 3-54). Although taller *Oculina* colonies (10-20 cm) have been observed elsewhere off NC, they were not recorded here. Cup corals are generally small (<2 cm height) occurring in small groups (3 – 5 individuals) or solitary.

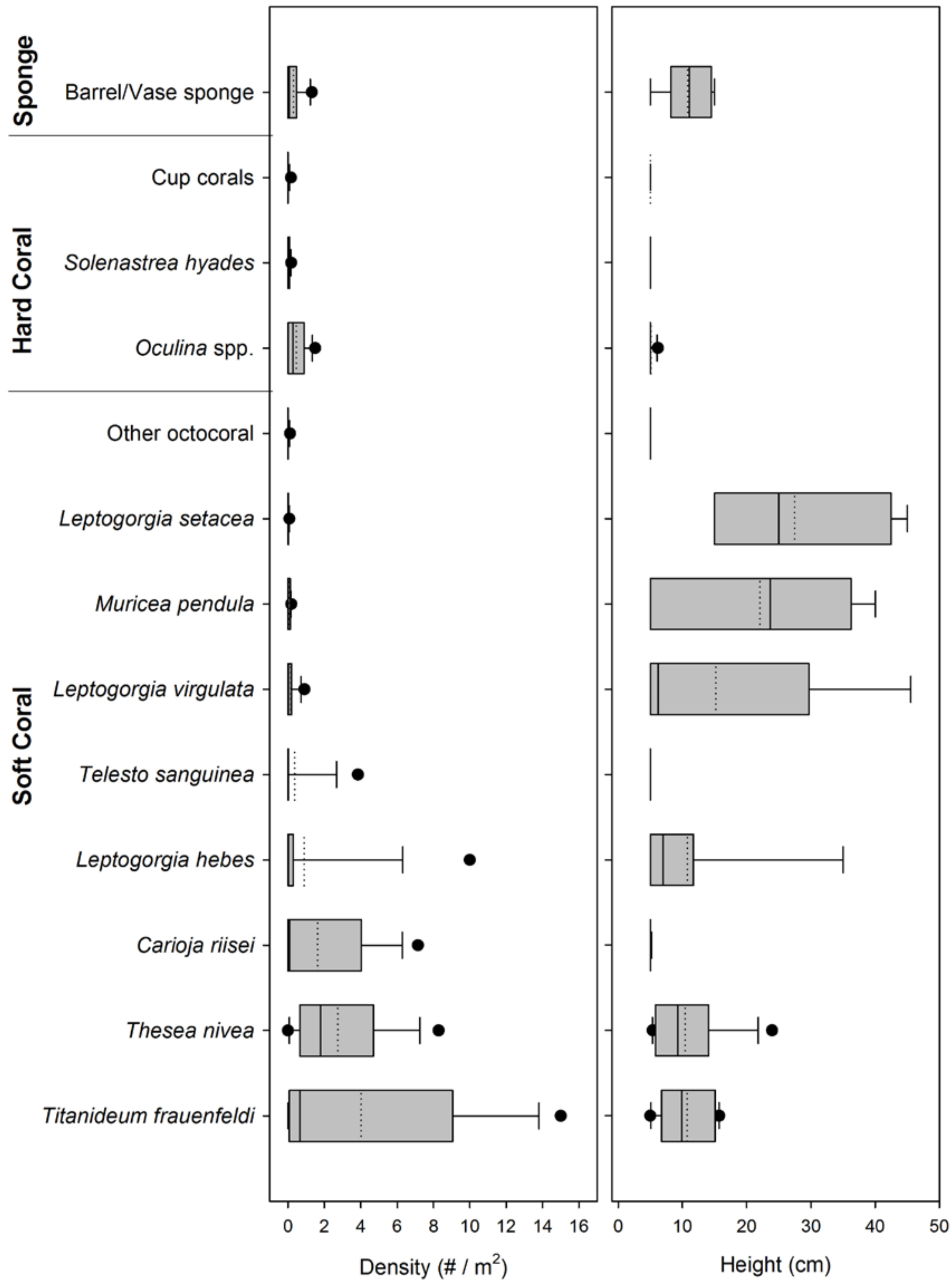

Figure 3-54. Soft coral, hard coral, and sponge densities (# / m^2) and height (cm) for all habitat types combined. Mean density and height shown by dashed line, individual outliers presented as circles. Total number of sites = 13.

The tallest organisms recorded during macro-invertebrate surveys were soft coral and sponges. When all sites and species were combined, hard coral height (mean height in cm (SE): 5.1 (0.4)) was significantly shorter than sponge (10.8 (3.6)) and soft coral (10.9 (4.1)) species or species groups (chi square 20.31, $p < 0.0001$). There was no significant difference between sponge and soft coral heights. There was also no difference in height between ledge and mixed HB/sand habitats for soft coral, hard coral and sponge. Due to small sample sizes differences in height between the other habitat types could not be evaluated.

While the majority of octocorals (84%; 2,319 of 2,748 individuals) were small (<15 cm) four octocoral species had some tall individuals (> 40 cm): *L. virgulata, T. frauenfeldii, L. setacea, M. pendula* (Figure 3-54 and Figure 3-55). These were found in all habitat types: mixed HB/sand (3 sites), ledge (3 sites), pavement (1), and artificial (1). At site 6605J-1, a mixed HB/sand site, a total of 4 40-50 cm and 9 50-60 cm individuals were recorded. All other sites had solitary large individuals. The tallest octocorals (50-60 cm) were all *L. virgulata* and occurred at a mixed HB/sand site (6605J-1) and an artificial site (6537k-1).

Figure 3-55. An example of the structure provided by soft corals in hardbottom habitats of the proposed wind energy area offshore Wilmington, NC.

3.4.1.4. Photo-quadrat Surveys

Benthic percent cover quantified by photo-quadrat analysis was dominated by bare substrate (mean cover (SE): 70.6% (2.4)) followed by invertebrate (21.9% (1.8)) and macroalgae cover (7.5% (1.3); N sites = 28) within each habitat and all sites combined (Figure 3-56A), consistent with results from the LPI surveys. There were no significant differences in bare substrate, macroalgae, or invertebrate cover between ledge and mixed HB/sand habitats. Sample sizes were too small to examine differences with pavement (n sites = 2): thus for the remainder of this section differences examined between habitat types will involve only ledge and mixed HB/sand sites. Benthic cover by abiotic type (rock, sand, rubble) and habitat type is provided in Appendix VI.

The invertebrate community was largely composed of a group of invertebrates (hydroids, other cnidarians, anemones, zoanthids, and worms) referred to as ‘other inverts’ (mean cover (SE):

16.8% (1.9)) followed by octocorals (5.1% (0.8)) and scleractinians (0.04% (0.02)). Other invert cover was greater in ledge (21.2% (6.5)) than in mixed HB/sand (14.5 (2.7)) habitats (Wilcoxon Z = 2.34, p = 0.019) There were no other significant differences in invertebrate cover by these three groups. Among individual invertebrate species, only *Telesto* species cover differed among habitat types (ledge: 1.6% (1.1); mixed HB/sand 3.2% (0.7); Wilcoxon Z= -2.16, p = 0.03). Percent cover for all invertebrate species by habitat type and all sites combined is listed in Appendix VI.

Rhodophyta cover was greatest among macroalgae species groups (mean cover (SE): 4.1% (1.0) followed by Phaeophyta (2.8% (0.5)) and Chlorophyta (0.4% (0.1)). Only Phaeophyta cover was greater in ledge habitats (4.5% (0.8)) than in mixed HB/sand (2.1% (0.5); Wilcoxon Z = 2.45, p = 0.014; Figure 3-56C). Other macroalgae cover, defined as turf algae that could not be identified to a specific class, was low in all habitat types (0.2% (0.07)). Dominant Rhodophyta were crustose coralline algae (CCA; 1.4% (0.3)) and unidentified red (1.4% (0.5)) followed by *Gracilaria / Rhodymenia* species (0.7% (0.3)). There were no significant differences in cover between ledge and mixed HB/sand habitats for these three groups. *Sargassum* spp. were the dominant Phaeophyta and overall algae species (2.6% (0.4)). All other Phaeophyta species exhibited low percent cover (<0.14% cover). Similarly, Chlorophyta cover was low in all habitats with the dominant species, *Cladophora prolifera*, at 0.13% (0.05). Percent cover for macroalgae species and species groups is provided in Appendix VI.

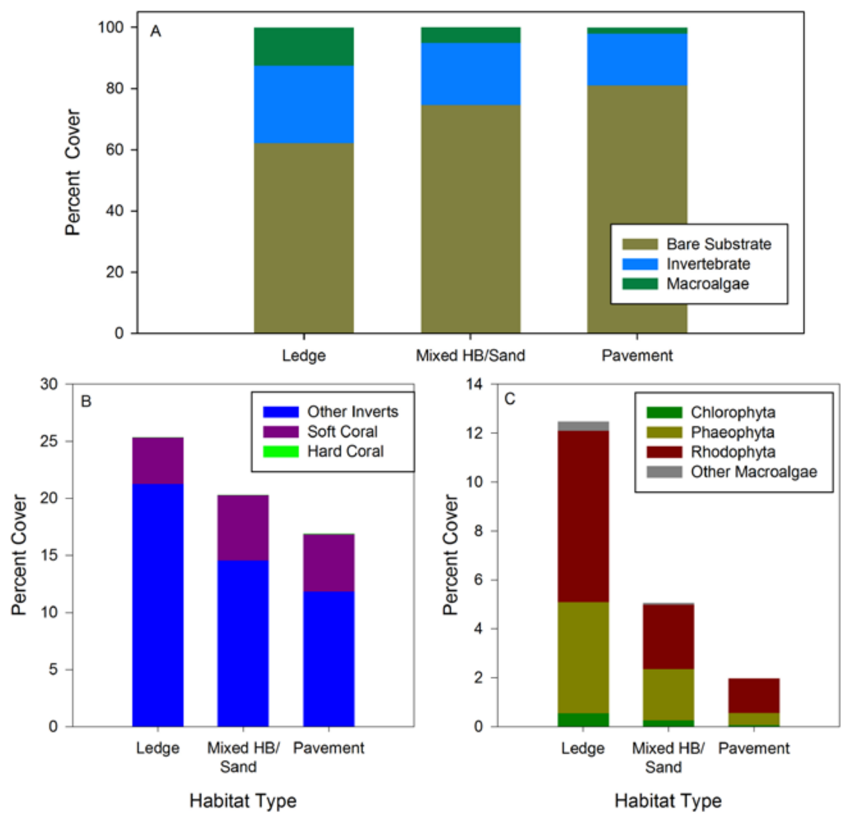

Figure 3-56. Percent cover for broad taxonomic groups (A), invertebrates only (B), and macroalgae only (C) by habitat type.

3.5. Fish Community Composition and Size

Over the course of nine days, 46,876 fish totaling 5,238.1 kg from 102 species or species groups and 41 families were observed at 52 sites in the Wilmington-East Call Area. Four bottom types were sampled: ledge, mixed HB/sand, pavement, and artificial (wreck). The highest species richness, density (# individual/100m^2), and biomass (kg/100m^2) for both conspicuous and cryptic communities over natural hardbottom were recorded from ledge habitat (Table 3-7). Across all bottom types, artificial sites had the highest mean richness, number of families, density and biomass; however, only two artificial sites (wrecks) were surveyed. Similarly, only three pavement sites were surveyed which is apparent in the very high standard error (SE) values. Because of this, neither bottom type was included in more extensive statistical analyses.

Table 3-7. Summary statistics (mean [SE]) for fish conspicuous and cryptic community metrics by bottom type (Ledge, Mixed HB/Sand (Mixed HB/Sand), Pavement, and Artificial for diver surveys conducted in May 2014.

Community	Bottom Type	Sites	Richness	Families	Density (#/100m^2)	Biomass (kg/ 100m^2)
Conspicuous	Ledge	18	16 (1.16)	9.67 (0.67)	178.05 (43.48)	33.03 (10.76)
	Mixed HB	29	11.93 (1.07)	7.69 (0.58)	151.02 (38.72)	11.85 (3.47)
	Pavement	3	8.34 (1.45)	5.67 (1.21)	66.13 (44.09)	13.90 (12.65)
	Artificial	2	17.5 (1.5)	10 (1)	660.12 (558.12)	41.03 (31.69)
Conspicuous Total		52	13.35 (0.79)	8.34 (0.43)	175.06 (33.37)	20.42 (4.52)
Cryptic	Ledge	15	9.00 (0.85)	6.26 (0.60)	204.62 (73.59)	3.06 (1.02)
	Mixed HB	27	5.93 (0.58)	4.03 (0.30)	95.76 (36.72)	2.21 (1.21)
	Pavement	3	6.67 (2.67)	4 (1.53)	48.66 (21.49)	0.86 (0.68)
	Artificial	2	7.5 (2.5)	6 (2)	175 (141)	2.67 (2.03)
Cryptic Total		47	7.06 (0.50)	4.83 (0.31)	130.87 (32.37.90)	2.42 (0.76)

3.5.1. Conspicuous Fish Community

Across all bottom types, 94 species from 38 families were documented during the 52 conspicuous surveys conducted in the call area (Appendix VIII). Divers encountered 73 species at mixed HB/sand sites, 66 at ledge, 28 at artificial sites, and 20 at pavement. Generally, higher density and biomass values were recorded for ledge and mixed HB/sand habitats, although in the sites with the ten highest values, all bottom types are represented (Figure 3-57 and Figure 3-58). In further examination, mean density, biomass, and family richness tended to be higher at ledge sites over mixed HB/sand, but biomass and family richness showed the only significant trends ($Z = 1.95$, $p = 0.05$; $Z = 2.12$, $p = 0.03$).

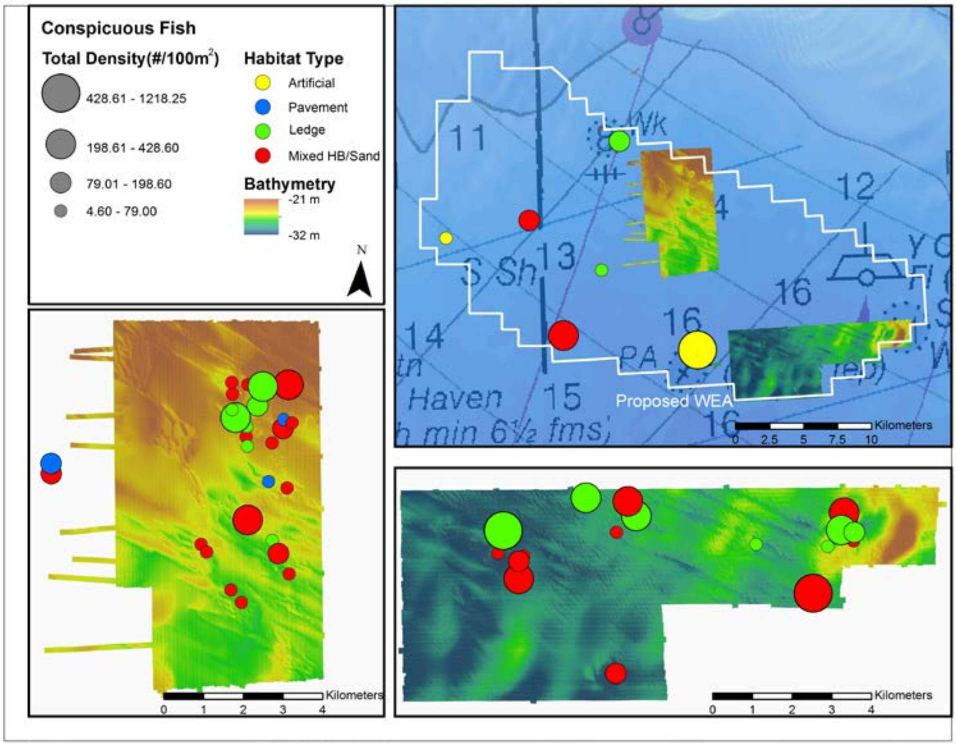

Figure 3-57. Overall conspicuous fish community density (#/100 m^2) for each site (N = 52).

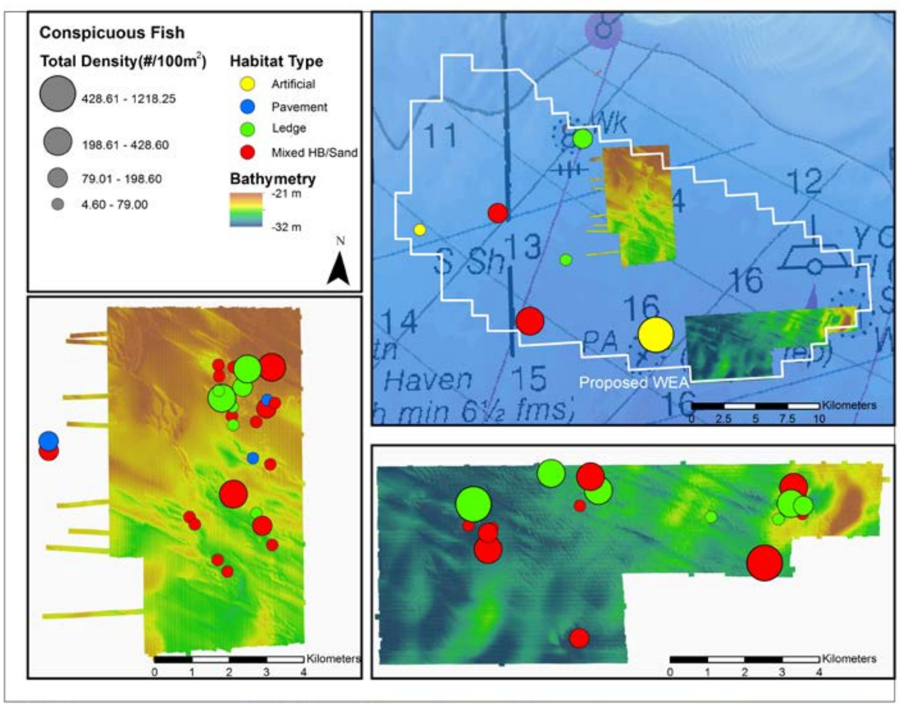

Figure 3-58. Overall biomass (kg/100m^2) for the conspicuous fish community by dive site (N = 52).

Species richness ranged from 4-29 species across all sites with the highest values recorded for ledges and the lowest values in mixed HB/sand (Figure 3-59). Among natural hardbottom habitats, species richness was significantly greater for ledge habitats than mixed HB/sand ($Z = 2.43$, $p = 0.014$).

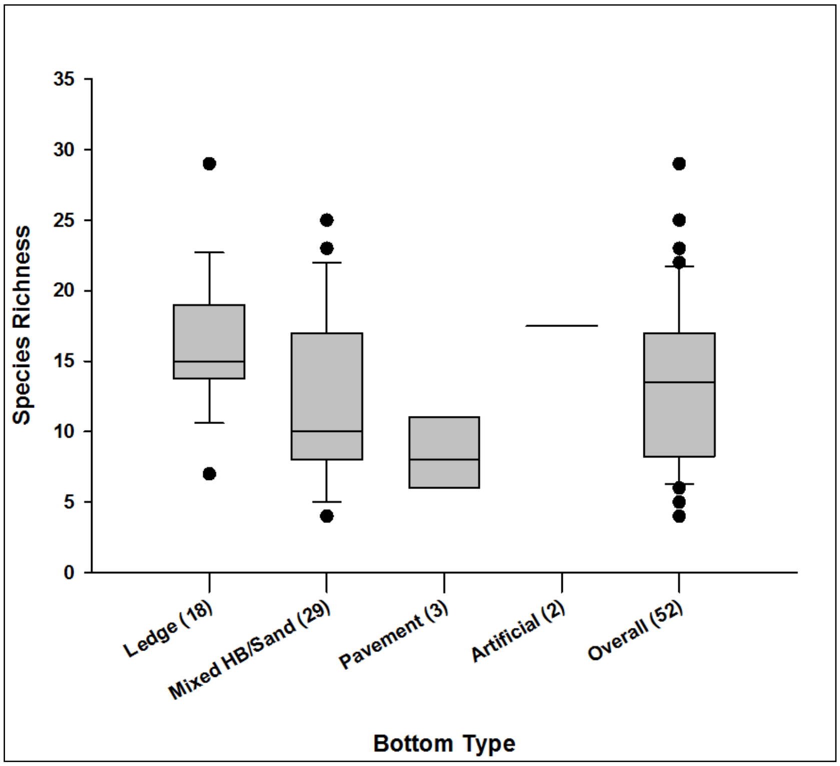

Figure 3-59. Species Richness for conspicuous surveys conducted at 52 sites by bottom type.

3.5.1.1. Density and Biomass

Overall density for the call area was 8,901.18 individuals /100 m^2 with a mean site density of 175.06 ± 33.37 individuals/100 m^2. The most abundant species in the call area was *Haemulon aurolineatum*, comprising 46% of total fish density (Table 3-8, Appendix IX). *Rhomboplites aurorubens* was the second most abundant species in conspicuous surveys comprising 10% of total fish density (Figure 3-60). The remaining species in the top five are from the sparid family: *Diplodus holbrookii*, *Stenotomus caprinus*, and *Stenotomus chrysops*.

Table 3-8. Overall percent density and biomass contribution by family and species for the study area. Species in bold indicate a member of the Snapper Grouper complex managed by the South Atlantic Fisheries Management Council (SAFMC).

Family	% Density	Species	% Density	Species	% Biomass
Haemulidae	47.76	***Haemulon aurolineatum***	46.29	***Seriola dumerili***	23.19
Sparidae	27.01	***Rhomboplites aurorubens***	10.35	*Carcharias taurus*	11.27
Lutjanidae	10.48	*Diplodus holbrookii*	9.85	***Mycteroperca microlepis***	9.47
Carangidae	5.52	***Stenotomus caprinus***	7.72	***Haemulon aurolineatum***	8.63
Serranidae	4.67	***Stenotomus chrysops***	7.21	***Stenotomus chrysops***	5.66
Family	**% Biomass**	***Centropristis striata***	3.24	*Diplodus holbrookii*	5.30
Carangidae	28.40	*Decapterus punctatus*	1.80	***Rhomboplites aurorubens***	4.37
Sparidae	16.15	***Haemulon plumierii***	1.43	***Centropristis striata***	3.80
Serranidae	15.38	*Lagodon rhomboides*	1.37	***Seriola zonata***	3.33
Odontaspididae	11.27	***Chaetodipterus faber***	1.23	*Carcharodon carcharias*	2.85
Haemulidae	10.34	*Pareques umbrosus*	1.20	***Stenotomus caprinus***	2.09

Call area biomass was 1,055.08 kg/100 m^2 with a mean site biomass of 20.42 ± 4.52 kg/100 m^2. Family percent contribution to biomass was dominated by large bodied carangids (jacks) for all of the bottom types excepting pavement habitats. *Seriola dumerili* in particular comprised a quarter of all fish biomass for the call area as well as the top species for biomass at ledge and mixed HB/sand sites (Figure 3-60). Serranids (sea bass and grouper) were also common across all habitat types, specifically *Mycteroperca microlepis* and *C. striata*. Due to the large abundance of *H. aurolineatum, D. holbrookii,* and *S. chrysops,* as all three species were top contributors of overall biomass for each habitat type.

Biomass at some sites was exceptional due to the sightings of large sharks: *C.taurus* (5 at 2.5 m TL), white shark (1 at 2.5 m TL), sandbar shark (2 at 2 m TL), and two Carcharhinus spp. (2 at 2 m TL). Almost all of the sharks were encountered at ledge sites. Carcharhinids (requiem sharks) show an uncharacteristically high representation in biomass of pavement, which is due to one 165 cm sandbar shark documented at one of the three pavement sites surveyed.

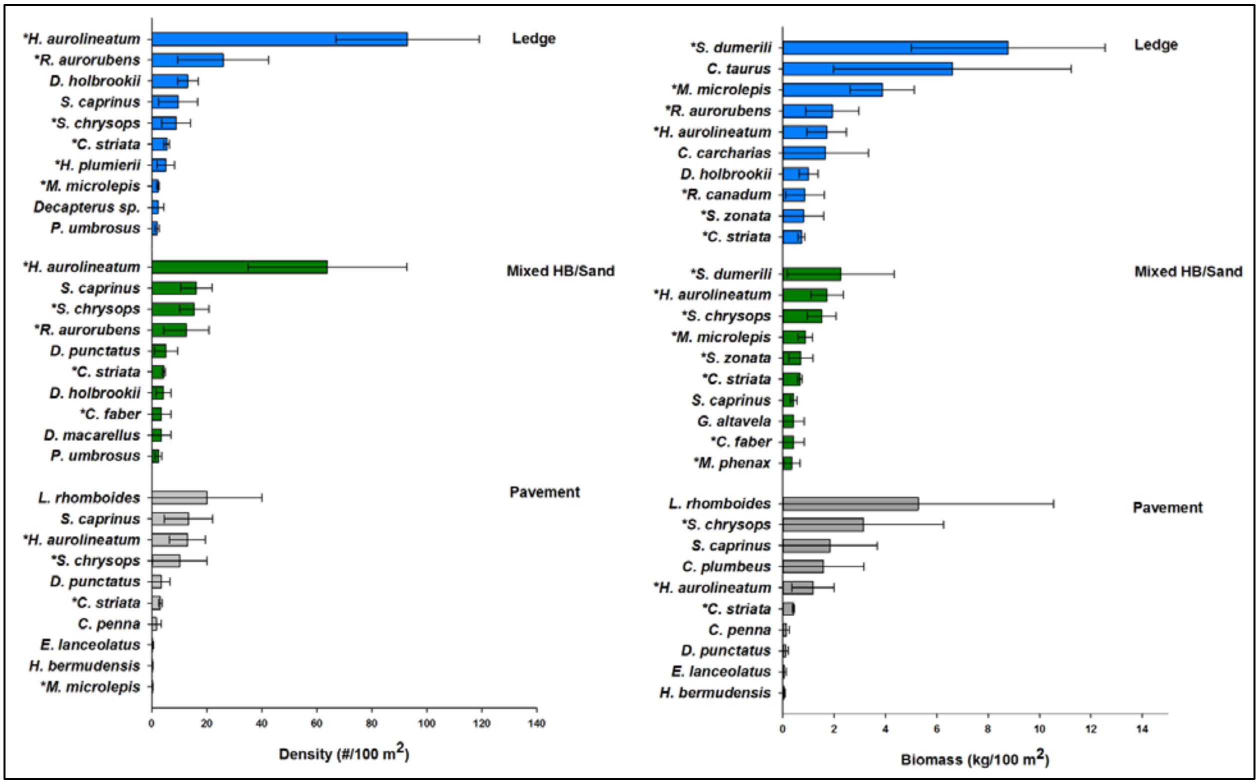

Figure 3-60. The top ten species of the conspicuous community's mean density (#/100 m^2) and mean biomass (kg/100 m^2) by natural hardbottom type: Ledge, Mixed HB/Sand, and Pavement. The asterisk (*) denotes a member of the Snapper Grouper Management Complex managed by the SAFMC.

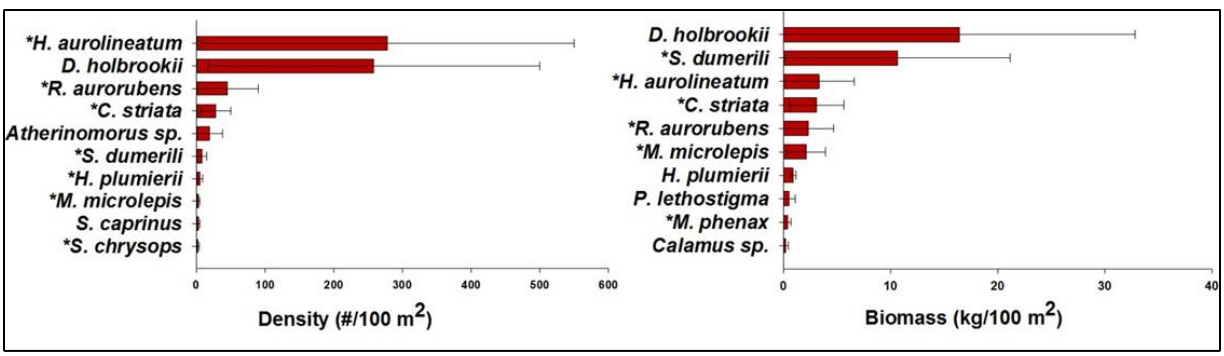

Figure 3-61. The top ten species by density and biomass for artificial sites (N = 2). The asterisk (*) denotes a member of the Snapper Grouper Management Complex managed by the SAFMC.

Species lists in order of contribution to abundance and biomass by habitat type suggest the ledge, mixed HB/sand, and artificial communities appear similar with pavement being more unique. Multivariate analyses were used to investigate fish community structure further. The nMDS and ANOSIM analyses found no significant differences between community composition based on density by habitat type (Figure 3-62; Global R = 0.071, p = 0.09). Community structure based on biomass results did indicate weak differences between habitat types may exist (Figure 3-62;

Global R = 0.127, p = 0.01). Further pairwise tests were not significant, possibly due to the low sample size of pavement habitat and the high variability within mixed HB/sand sites.

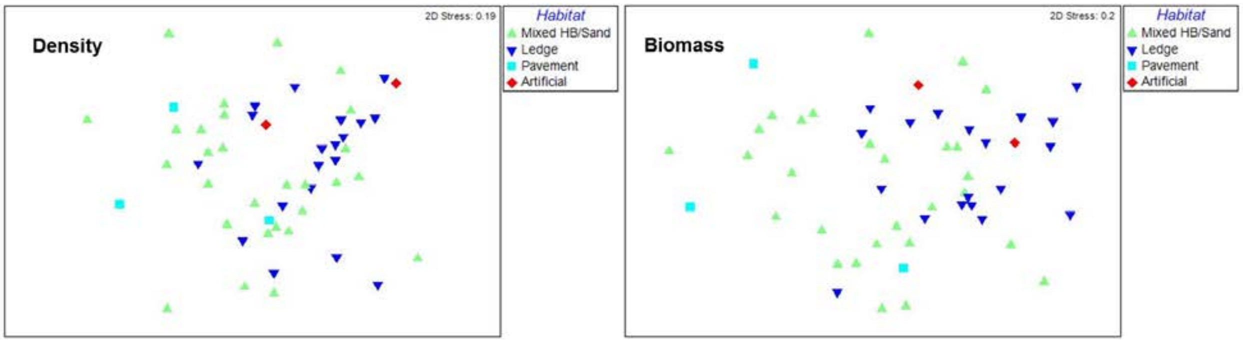

Figure 3-62. Non-metric multi-dimensional scaling plots of community composition based on density and biomass by habitat type. No significant differences in fish community density or biomass were found between habitat types.

Haemulidae (grunts) and sparidae (porgies) comprised over 70 % of total density for all bottom types (Appendix X). The top five families for total density were very similar across all bottom types. Pavement sites have a much higher percent total density of sparids than all other bottom types. Pavement has the lowest relief of all the bottom types and supports a possibly less diverse group of organisms, keeping in mind this is based on three surveys. Many of the sparids seen on these surveys were benthic carnivores which would thrive on the low relief habitat provided by pavement. Haemulids were found in greater numbers at the other habitat types, all of which provide greater variability in relief and support a greater diversity of invertebrates. The overall number of distinct families present was significantly higher at ledges than mixed HB/sand sites (Z = 2.16, p = 0.03).

3.5.1.2. Size Frequency

Mean fish densities were greatest in the smaller length categories (0-10 cm, 10-20 cm) and declined with increasing fish size. Mean density per site was 175.06 ± 33.37 individuals/100 m^2 across size classes and was comprised mostly of fish less than 20 cm TL (146.85 ± 35.37 individuals /100 m^2). Densities by size class were not significantly different by bottom type (Figure 3-63), however the 0-10 cm fish density tended to be higher for ledge sites and the 10-20 cm fish tended to be higher at mixed HB/sand sites. The mean density peaks in the 0-10 cm class was driven by *H. aurolineatum*, which comprised 60% of the individuals for that size class. *H. aurolineatum* was also responsible for 47% of the density peak within the 10-20 cm size class, particularly one large school (4000 individuals) documented at one mixed HB/sand site. *S. dumerili* figured prominently in total fish density for the larger size classes comprising 46% of the 50-100 cm size fish and 56% of the >100 cm size class. *M. microlepis* comprised 30% of the 50-100 cm size fish. Additional size frequency plots are provided in later sections for highlighted species.

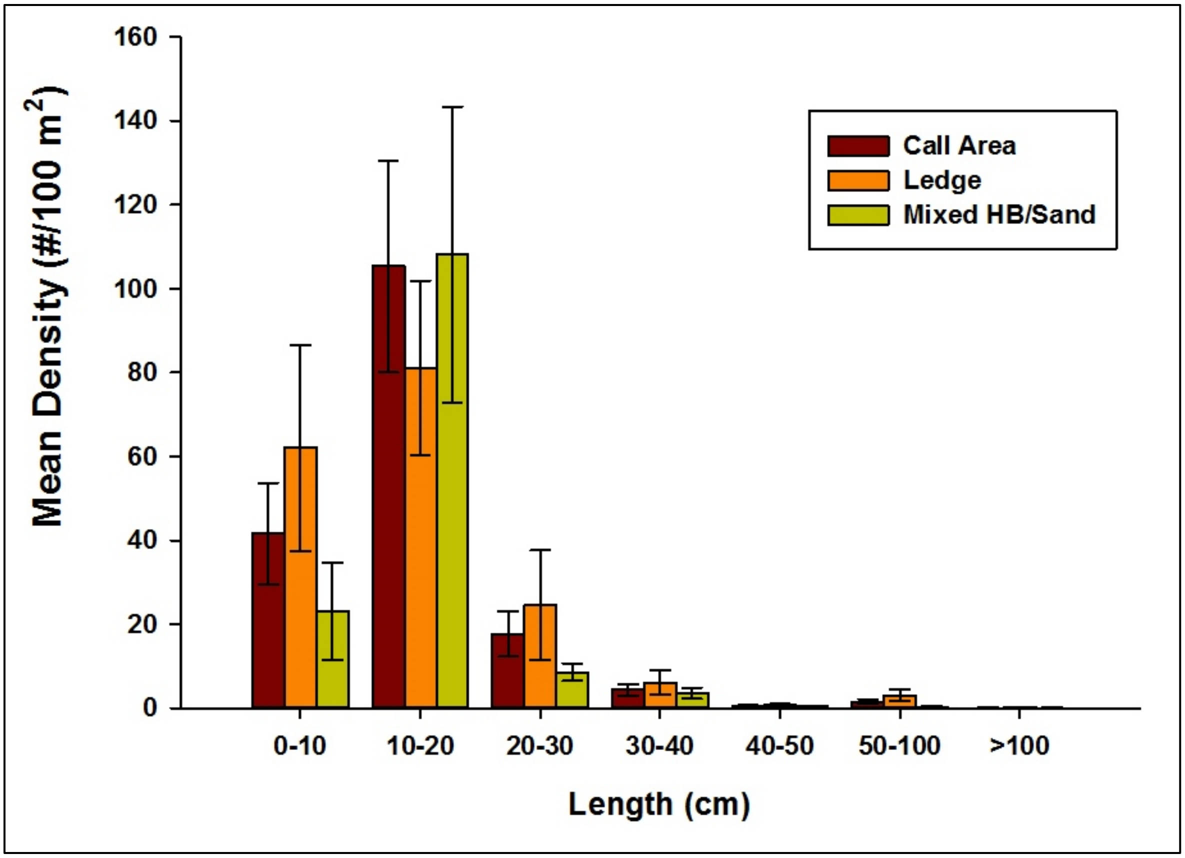

Figure 3-63. Mean fish density (#/100 m^2) by size class (cm TL) for the call area and by Ledge and Mixed HB/Sand.

3.5.1.3. Apex Predators and Large Fish

In the study area, 409 large fish (≥50 cm TL) were encountered at 31 out of 52 sites with individuals from families Carangidae (jacks), Dasyatidae (rays), Gymnuridae (butterfly rays), Lamnidae (mackerel sharks), Lutjanidae (snappers), Muraenidae (moray eels), Odontaspididae (sand sharks), Paralichthyididae (flounders), Rachycentridae (cobia), Serranidae (sea bass and grouper), Sparidae (porgies), and Sphyraenidae (barracudas). The majority of the large fish (87%) are apex predators (Table 3-9).

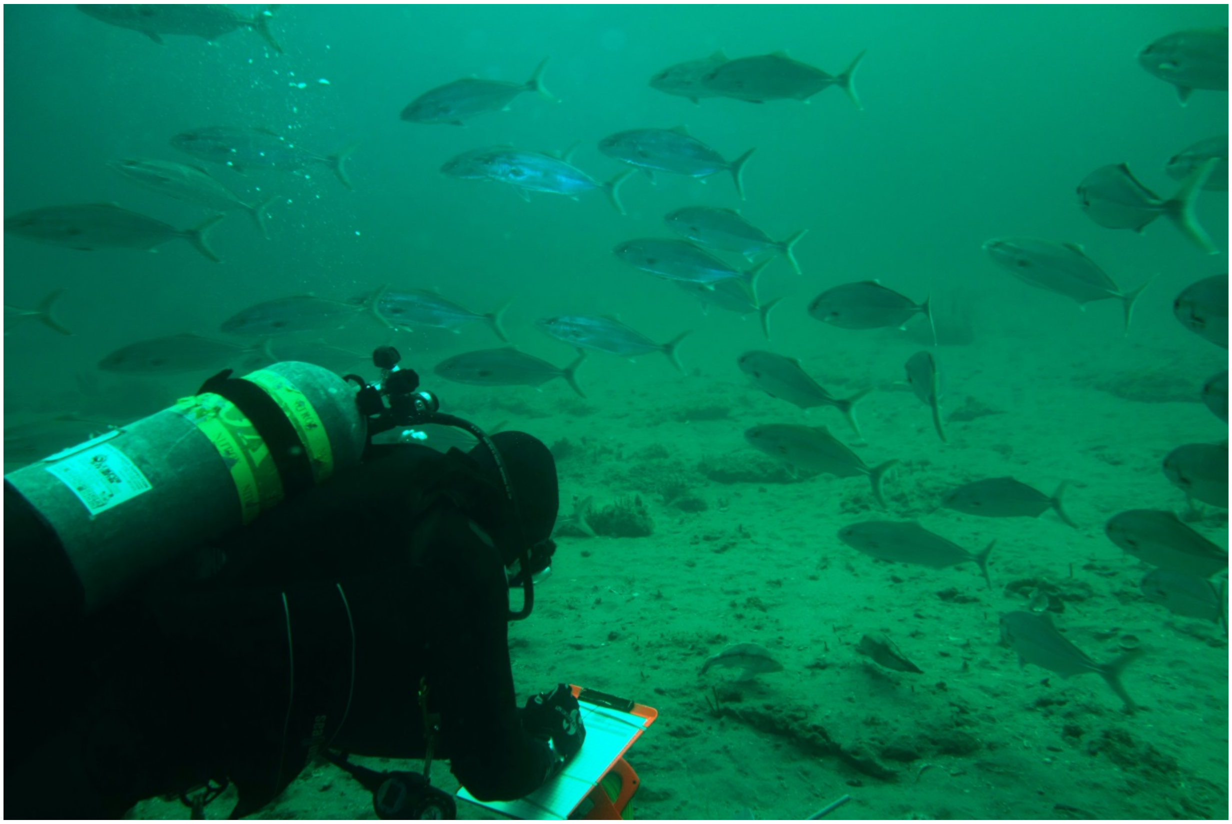

Figure 3-64. NOAA diver counts a school of *Seriola zonata*, a numerous species in the large fish size class.

Table 3-9. Species encountered in the Large Fish size category (≥ 50 cm TL) for the entire call area.

Large Fish Species	
Archosargus probatocephalus	*Muraena retifera*
Carcharhinus plumbeus	*Mycteroperca microlepis*
Carcharhinus species	*Mycteroperca phenax*
Carcharias taurus	*Paralichthys lethostigma*
Carcharodon carcharias	*Rachycentron canadum*
Dasyatis americana	*Rhizoprionodon terraenovae*
Gymnura altavela	*Seriola dumerili*
Lachnolaimus maximus	*Seriola rivoliana*
Lutjanus campechanus	*Seriola zonata*
Lutjanus synagris	*Sphyraena barracuda*

Mean site density for large fish was 1.68 ± 0.59 individuals/100 m^2 and was significantly greater at ledge sites than mixed HB/sand ($Z = 3.31$, $p = 0.0009$). Of the 31 sites at which large fish were encountered 16 were ledge habitats. The most abundant species encountered throughout the call area were *M. microlepis*, *S. zonata*, *M. phenax* and *L. campechanus* (Figure 3-65).

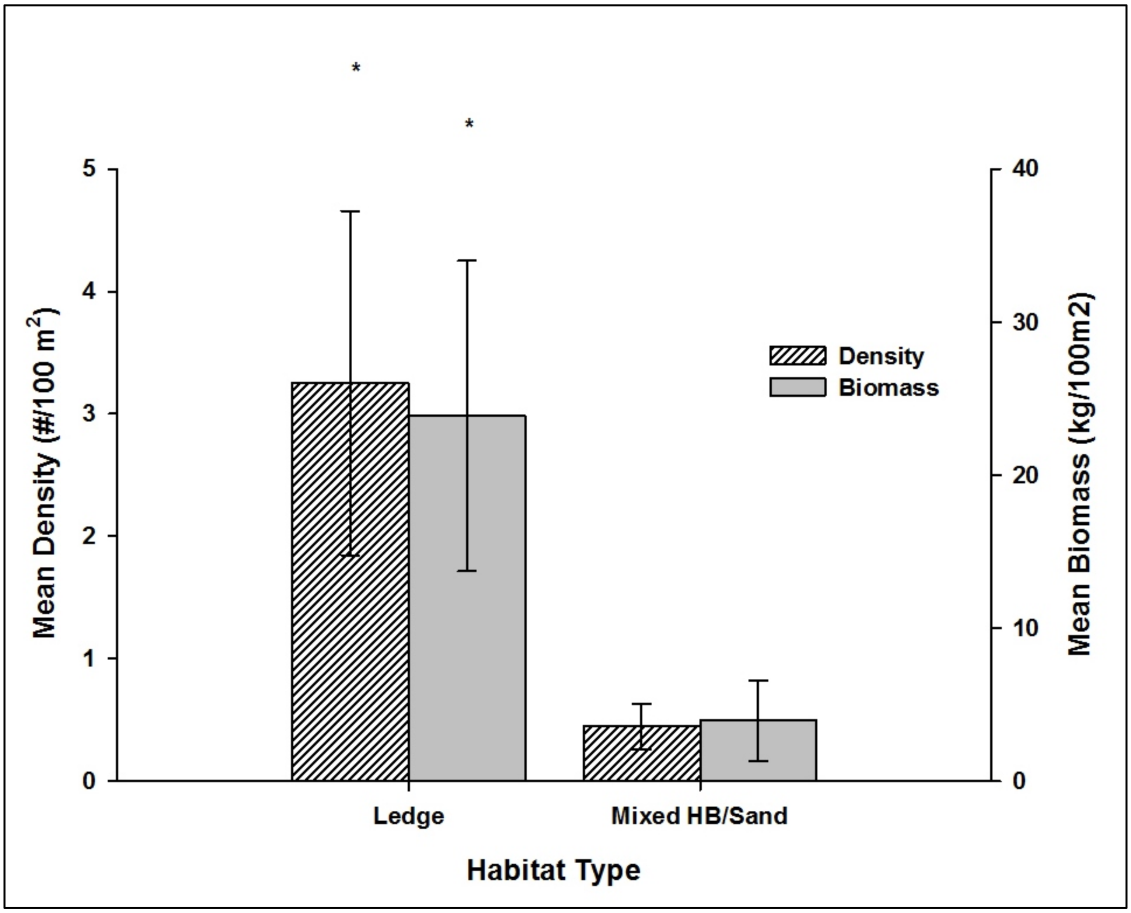

Figure 3-65. Mean density and biomass for Large Fish (≥ 50 cm TL) by Ledge and Mixed Hardbottom/Sand. * indicates significance probability where α < 0.05.

Overall biomass of large fish totaled 573.60 kg/100 m^2 which accounts for 54% of total biomass for the call area. Keeping with the relationship of large fish density and habitat, mean large fish biomass is greater for ledge habitats over mixed HB/sand ($Z = 3.18$, $p = 0.0015$). Apex predator biomass per site was 11.03 ± 3.98 kg/100 m^2, mostly attributed to *S. dumerili*, *C. taurus* and *M. microlepis*. Although more large fish were encountered in the Onslow Bay study, mean biomass per site for large fish was lower, 7.76 ± 2.42 kg/100m^2.

3.5.1.4. Snapper-Grouper Complex and Species of Interest

The hardbottom conspicuous community of offshore North Carolina is comprised of many species in the Snapper Grouper Management Complex (Table 3-10). Mean snapper-grouper (SG) density by site was responsible for 79% (138 ± 26.91 individuals/100 m^2) of total mean site density for the call area and 95% (1.60 ± 0.58 individuals/100 m^2) of the large fish density for each site. The remaining species are sharks and rays, which contributed a greater proportion of biomass. Mean SG biomass by site was 68% (14.01 ± 2.97 kg /100 m^2) of overall mean biomass for the sample area and only 63% (6.98 ± 2.47 kg individuals/100 m^2) of large fish biomass. The much larger bodied shark and ray species comprised the remaining biomass, but from only a few large individuals and are therefore over-represented in biomass estimates.

Overall density and biomass for the SG species were not significantly different by habitat type. When broken into size classes large fish (≥ 50 cm TL) density and biomass was greater for ledge sites than mixed HB/sand (Z = 3.16, p = 0.0015; Z = 3.06, p = 0.002). The species contributing to this difference were *M. microlepis, S. dumerili, M. phenax, and L. campechanus,* which occurred at ledge sites in twice the densities documented at mixed HB/sand sites.

Table 3-10. Snapper Grouper Management Complex members encountered in the call area by percent contribution to overall density and biomass. An asterisk (*) denotes a species that does not have specific management measures in place but are still considered Ecosystem Component Species.

Species	% Density	% Biomass	Species	% Density	% Biomass
Calamus bajonado	0.01	0.05	*Lutjanus synagris*	0	0.03
Calamus calamus	0.06	0.08	*Mycteroperca interstitialis*	0	0
Calamus leucosteus	0.03	0.03	*Mycteroperca microlepis*	0.84	9.47
Calamus species	0.46	1.07	*Mycteroperca phenax*	0.21	1.92
*Centropristis ocyurus**	0.23	0.16	*Pagrus pagrus*	0.06	0.07
Centropristis striata	3.24	3.80	*Rhomboplites aurorubens*	10.35	4.37
Chaetodipterus faber	1.23	1.26	*Seriola dumerili*	0.54	23.19
Haemulon album	0	0	*Seriola rivoliana*	0.09	0.77
Haemulon aurolineatum	46.29	8.63	*Seriola zonata*	0.75	3.33
Haemulon plumierii	1.43	1.68	*Sphyraena barracuda*	0.01	0.04
Lachnolaimus maximus	0.02	0.26	*Stenotomus caprinus**	7.72	2.09
Lutjanus campechanus	0.13	1.06	*Stenotomus chrysops*	7.21	5.66

Black sea bass (*Centropristis striata*)

A total of 1,443 (1,295 conspicuous, 148 cryptic) *C. striata* were encountered at 51 out of 52 sites. Mean site density was 5.55 ± 0.99 individuals/100 m^2 with the highest values seen at a ledge site (53.4/100 m^2) and an artificial site (49.67 individuals/100 m^2). No significant density differences between habitat types were detected. Mean site biomass was 0.77 ± 0.11 kg /100 m^2 with the highest values detected at an artificial site (5.65 kg/100 m^2) and a ledge site (3.16 kg/100 m^2). Most *C. striata* observed fell into the smallest size classes (0-10 cm and 10-20 cm, Figure 3-66) and the mean length per site was 20.8 ± 0.68 cm TL. Correlative analyses of density and biomass versus habitat variables (hardbottom height, benthic cover, rugosity) as co-variates detected no relationships.

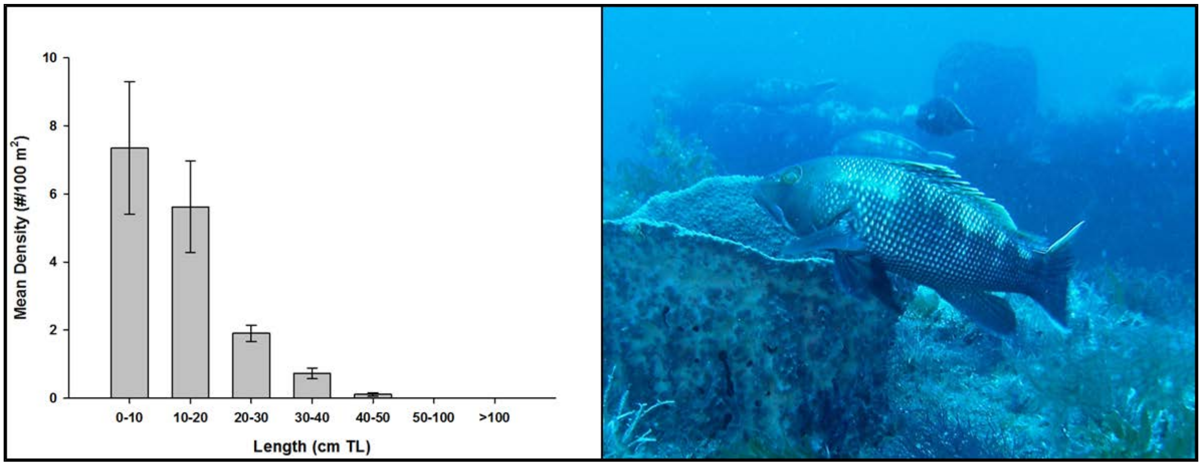

Figure 3-66. Length frequency (cm TL) by mean site density for *C. striata* detected in the call area (N = 51).

Gag grouper (*Mycteroperca microlepsis*)

We encountered 363 individuals at 37 out of 52 sites during conspicuous surveys. Mean site density was 1.44 ± 0.22 individuals/100 m^2 with the highest values seen at ledge sites (6.6 individuals/100 m^2). Almost all size classes of *M. microlepis* were encountered (Figure 3-67) but the mean length was 37.29 ± 1.54 cm TL. Mean site biomass was 1.92 ± 0.49 kg/100 m^2 with the highest values also found at ledge sites (17.65 kg/100 m^2). Neither density nor biomass was significantly different between ledge and mixed HB/sand habitat types.

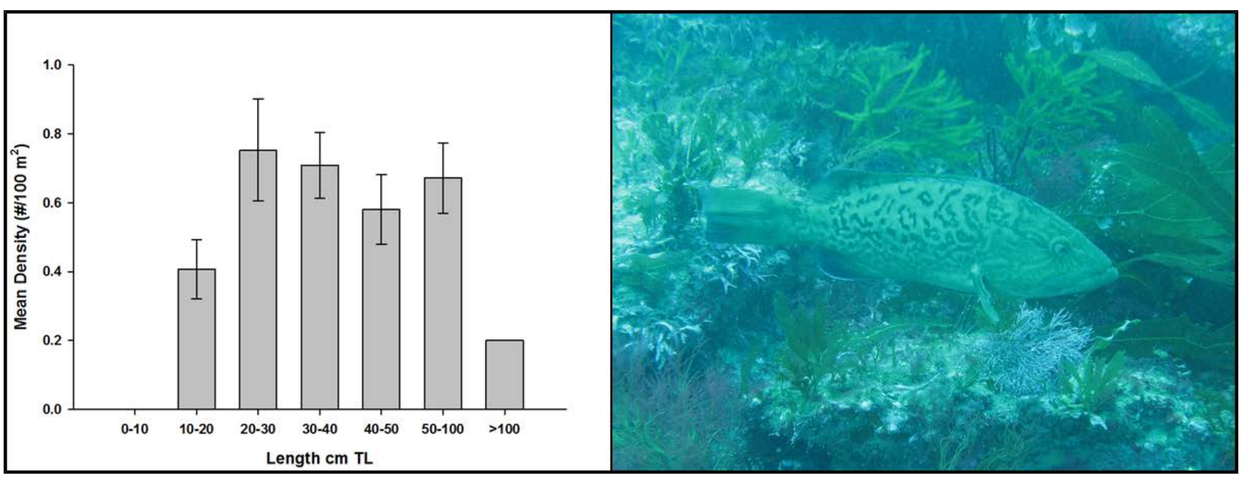

Figure 3-67. Length frequency (cm TL) by mean site density for *M. microlepis* (N = 37).

Vermilion snapper (*Rhomboplites aurorubens*)

R. aurorubens is one of the most frequently caught snapper throughout the South Atlantic coast. In the call area, *R. aurorubens* was encountered at less than one third of the sites sampled, 16 out of 52 sites, yet was the second most abundant species across all sites. At sites where it was documented, vermilion snapper had a mean site density of 17.72 ± 7.44 individuals/100 m^2 and a mean site biomass of 0.88 ± 0.38 kg/100 m^2. Fish encountered had a mean length of 19.87 ± 1.49 cm TL (Figure 3-68). This species was the seventh highest for biomass across all species and sites. The greatest density value of 280 /100 m^2 was documented at a ledge site with the second highest value of 220 /100 m^2 recorded at a mixed HB/sand site. The greatest values for biomass were recorded at two ledge sites: 12.74 kg/100 m^2.

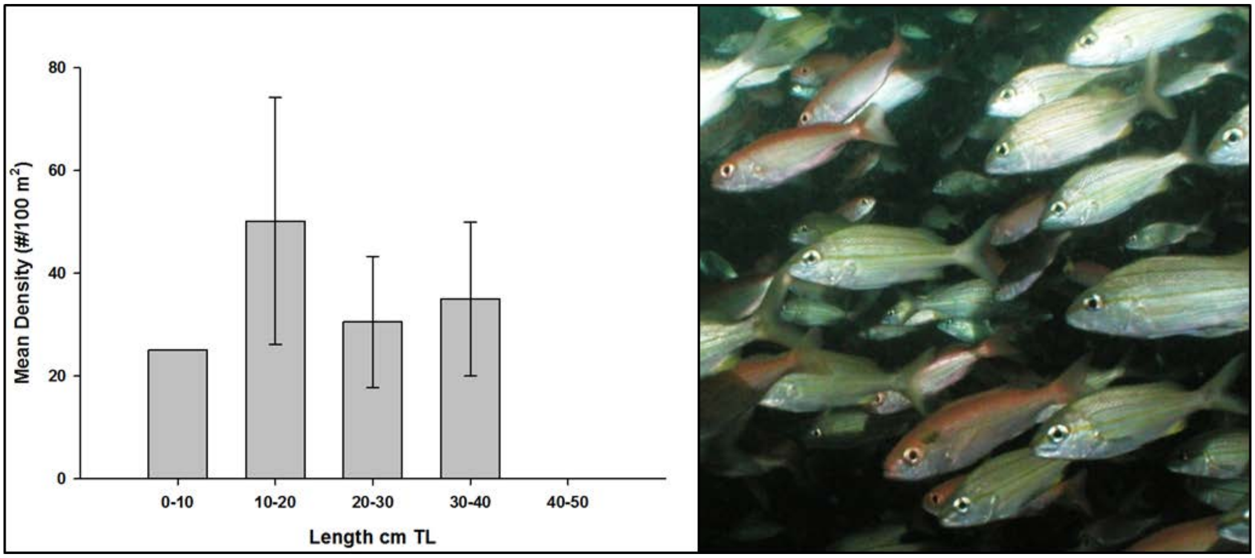

Figure 3-68. Length frequency (cm TL) by mean site density for *R. aurorubens* (N = 16). On the right, *R. aurorubens* (red fish with red eye orb) mixed with a school of *H. aurolineatum*.

Greater amberjack (*Seriola dumerili*)

S. dumerili is a popular fish for commercial and recreational fishers. *S. dumerili* were documented at 18 of 52 sites with a mean site density 0.93 ± 0.37 individuals/100 m^2 and highest values seen at an artificial site (15 /100 m^2) and a ledge site (10 /100 m^2). Mean length was 72.60 ± 7.79 cm TL (Figure 3-69). Mean site biomass was 4.70 ± 1.81 kg/100m^2 with the highest values found at a mixed HB/sand (60.41 /100 m^2) site and a ledge (49.53 /100m^2). *S. dumerili* were the most numerous Large Fish (≥ 50 cm TL) encountered comprising 47% of the density and 42% of the biomass of all Large Fish as well as 22% of total biomass for the call area.

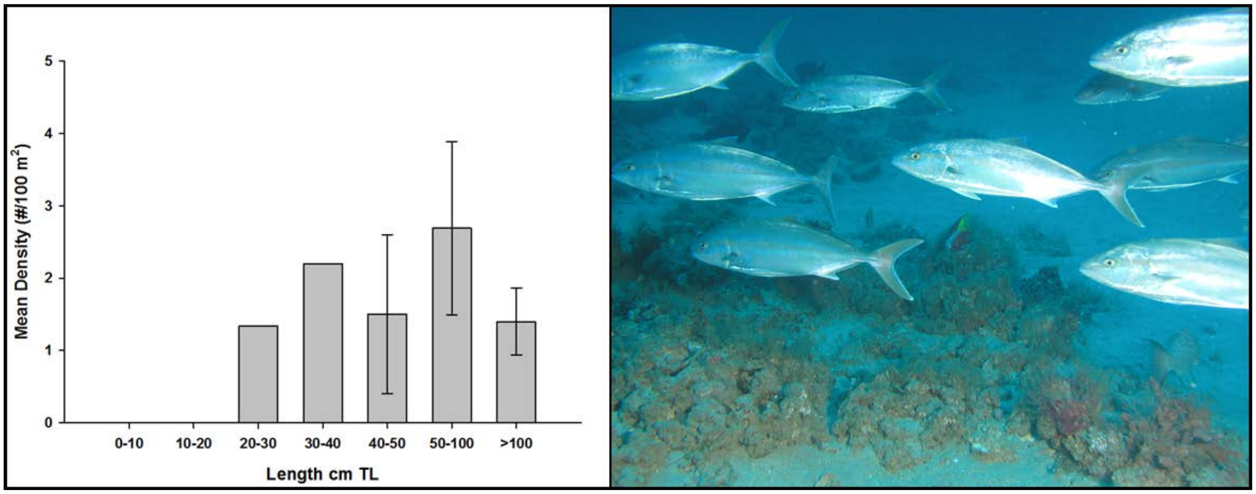

Figure 3-69. Length frequency (cm TL) by mean site density for *S. dumerili* (N = 18).

3.5.1.5. Trophic Guilds

The fish communities of ledge and MIXED HB/SAND, were dominated by invertivores (50% overall; Table 3-11) and benthic carnivores (31.62% overall) based on density. *H. aurolineatum* was responsible for the high percentage of invertivores for all habitat types, but *R. aurorubens* and *Stenotomus spp*. were responsible for the high percentage of benthic carnivores at ledge and mixed HB/sand sites. Artificial habitats were dominated by invertivores and omnivores (83.02% combined) while benthic carnivores were less abundant. *D. holbrookii* comprised much of the omnivore percentage for all habitat types. Pavement deviated from the other habitat types with respect to trophic guild: benthic carnivores (41.23%) were the most encountered trophic guild with omnivores and invertivores of lesser importance. For pavement sites, *Stenotomus spp.* (*S. chrysops* and *S. caprinus*) comprised the majority of invertivore percent by density. Only two herbivorous species were encountered, cocoa damselfish (*Stegastes variabilis*) and doctorfish (*Acanthurus chirurgus*), in very low numbers at one ledge and three mixed HB/sand habitats. Planktivores were not abundant across the call area and were only documented at a few sites overall.

Table 3-11. Percent density by trophic guild for overall density and by habitat type.

Trophic Guild	Species	% Total	% Ledge	% Mixed HB	% Pavement	% Artificial
Benthic Carnivore	33	31.62	31.76	39.89	41.23	12.72
Herbivore	2	0.03	0.02	0.05	0	0
Invertivore	28	50.81	57.59	46.90	23.19	43.79
Omnivore	6	11.29	7.45	4.32	30.24	39.13
Piscivore	16	1.67	1.83	1.59	0.10	1.52
Planktivore	9	4.58	1.34	7.23	5.24	2.84

Omnivore and piscivore densities were greater for ledge habitats compared to mixed HB/sand ($Z = 2.82$, $p = 0.0047$; $Z = 3.014$, $p = 0.0026$). The omnivore densities were comprised mostly of *L.*

rhomboides and *D. holbrookii* which were found in greater numbers at ledge sites. *M. microlepis*, *S. zonata* and *S. dumerili* were mostly responsible for the differences in piscivore density by habitat type.

While piscivores comprised a small percentage of the community based on number (1.67%,Table 3-11), they were first in total biomass (46%, Figure 3-70) due to the occurrence of *M. microlepis*, *S. zonata*, *S. dumerili* and some shark species. Benthic Carnivores comprised the second highest percent by biomass across all bottom types (31.7%) similar to the percentage based on density. Invertivores, which made up 50% of total density, only comprised 14.22% of biomass data. The smaller bodied *S. chrysops* and *S. caprinus* are most responsible for this disparity. At ledge sites, biomass of omnivores and piscivores was greater than at mixed HB/sand ($Z = 2.75$, $p = 0.0058$; $Z = 2.61$, $p = 0.009$). Piscivore biomass was dominated by *S. dumerili* and *C.taurus* for ledges while omnivore biomass was made up mostly of *D. holbrookii* and *L. rhomboides*.

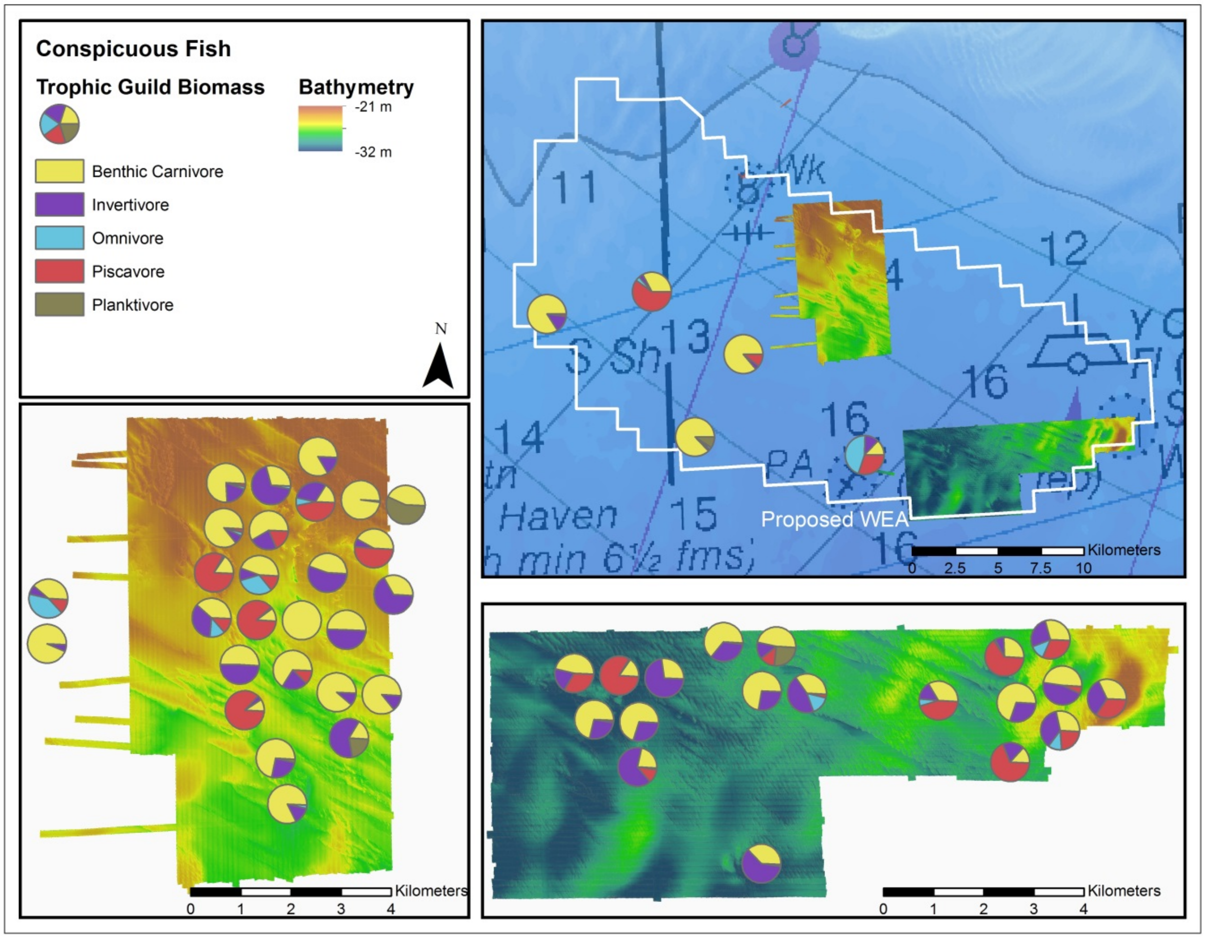

Figure 3-70. Trophic guilds by percent biomass per site for conspicuous surveys.

3.5.1.6. Habitat Relationships

Linking fish metrics to habitat characteristics is part of any ecological characterization. In this study, sample size limited the potential to investigate differences among habitat types surveyed; therefore, analyses were focused on ledge and mixed HB/sand communities. Overall density and biomass did not vary significantly between these two bottom types until the data were parsed into size classes (acoustic size bins and large fish) and even then only the large fish (> 50 cm TL) density and biomass were significantly different. Large fish density and biomass were significantly higher for ledge communities ($Z = 3.31$, $p = 0.0009$) over mixed HB/sand (Figure 3-71). Trophic guilds also differed significantly in density and biomass by habitat type: percent omnivores and piscivores by density and biomass both were greater at ledge sites than mixed HB/sand.

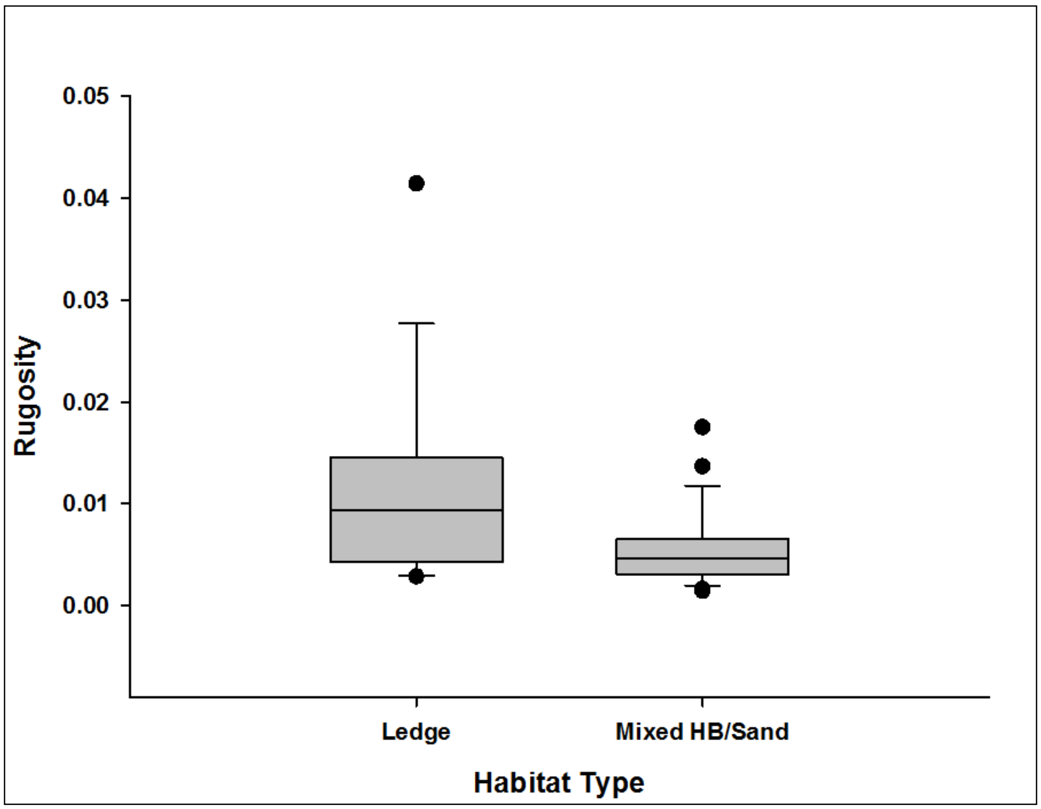

Figure 3-71. Multibeam-derived rugosity by Ledge (N = 16) and Mixed HB/Sand (N = 26).

To explore these differences further, correlative analyses were conducted with benthic parameters collected *in situ*, percent cover: hardbottom, softbottom, bare, macroalgae, invertebrate; hardbottom height (cm); and depth (m). Rugosity as derived from multibeam surfaces was also included in the analysis to explore relationships between density and habitat variability. Multi-beam derived rugosity was also found to be greater at ledge sites than mixed HB/sand sites (Figure 3-71). Ledge habitats are characterized by higher hardbottom height (cm), greater percent cover of macroalgae and invertebrates, and lower percent cover of bare substrate than mixed HB/sand.

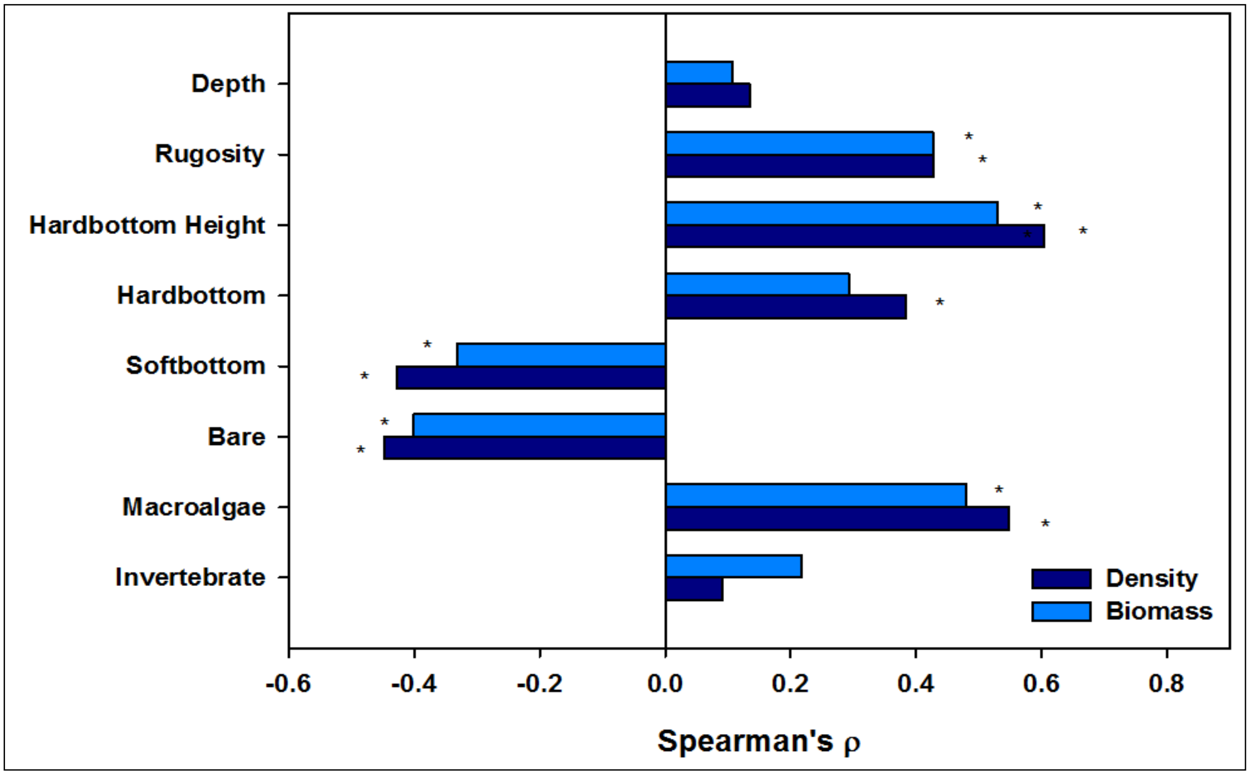

Figure 3-72. Large Fish (50 cm TL) mean site density and biomass Spearman rank correlations by depth (m), multi-beam derived rugosity, hardbottom height (cm), and percent cover: hardbottom, softbottom, macroalgae, and invertebrates. * indicates significance probability where α < 0.05.

When pooled across habitat types, Large Fish (≥ 50 cm TL) density and biomass were positively correlated with rugosity, hardbottom height, and percent cover of: macroalgae and hardbottom (Figure 3-72). Both density and biomass were negatively correlated with percent cover of softbottom and bare. These results suggest that the higher density and biomass associated with ledge habitats is tied to the greater rugosity and height of ledges as well as the higher percent cover of macroalgae characteristic of ledge habitats. These habitat variables that are correlated with large fish densities and biomass are the primary benthic characteristics of ledge habitats described in an earlier chapter.

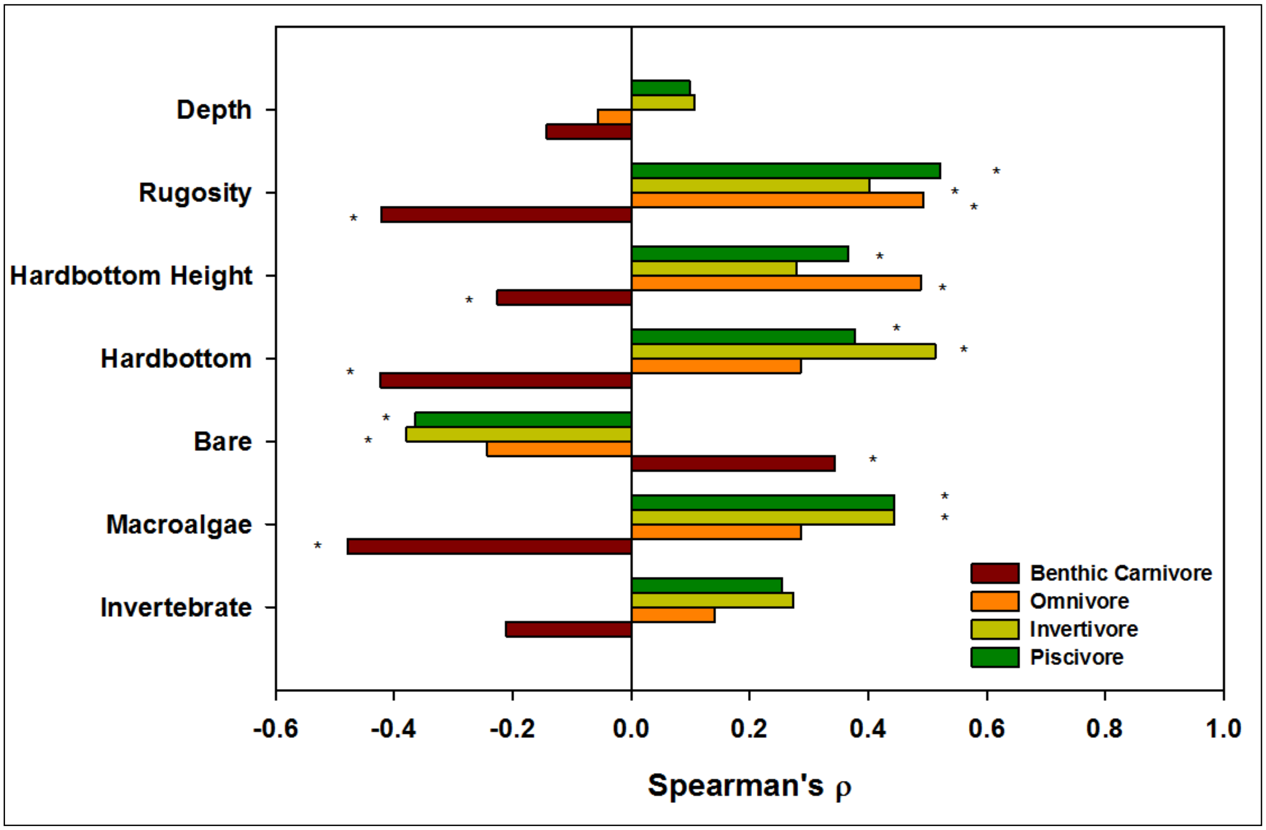

Figure 3-73. Spearman rho (ρ) correlations between fish density by trophic guild (benthic carnivore, omnivore, invertivore, piscivore) and benthic characteristics: depth (N = 50), rugosity (N = 44), hardbottom height (N = 43), and percent cover (hardbottom, softbottom, macroalgae, and invertebrate; N = 50). * indicates significance probability where α < 0.05.

Relationships between trophic guilds and habitat types were further examined using correlative analyses (Figure 3-73). Density and biomass data were analyzed with very similar results, consequently, we present the density results only. Omnivores and piscivores were positively correlated with rugosity, hardbottom height, and percent cover of macroalgae. Both guilds were negatively correlated with percent cover of softbottom and bare substrate. These correlations resemble the benthic characteristics of ledge habitats and are the influential variables supporting omnivore and piscivore density.

Multivariate analyses were used to investigate the contribution of benthic characteristics to fish community structure (based on density and biomass). Results from the BIOENV method of the BEST procedure indicate there are no significant relationships in our data between community composition and habitat variables: depth, rugosity (R = 0.117, p = 0.08), hardbottom height, biotic height, and benthic percent cover of hardbottom, softbottom, bare, macroalgae, and invertebrate (all R < 0.117 and p > 0.08).

3.5.1.7. Cryptic Fish Community

Across all bottom types, 48 species from 20 families were documented during the 47 cryptic surveys conducted in the call area (Appendix XI). Divers encountered 36 species at ledge, 35 species at mixed HB/sand, 15 species at pavement, and 15 species at artificial sites. Generally, higher density and biomass values were recorded for ledge and mixed HB/sand and habitats, with one artificial site in the top ten of both fish community metrics (Figure 3-74 and Figure 3-75). Mean density and biomass were significantly higher at ledge sites over mixed HB/sand ($Z = 3.03$, $p = 0.0024$; $Z = 2.312$, $p = 0.02$). This pattern was also true for small fish (≤ 10 cm TL) mean density but did not hold true for mean biomass of small fish ($Z = 2.59$, $p = 0.0094$; $Z = 1.89$, $p = 0.05$). Similar to the conspicuous fish community, species richness was also significantly greater for ledge habitats than mixed HB/sand ($Z = 3.07$, $p = 0.0048$).

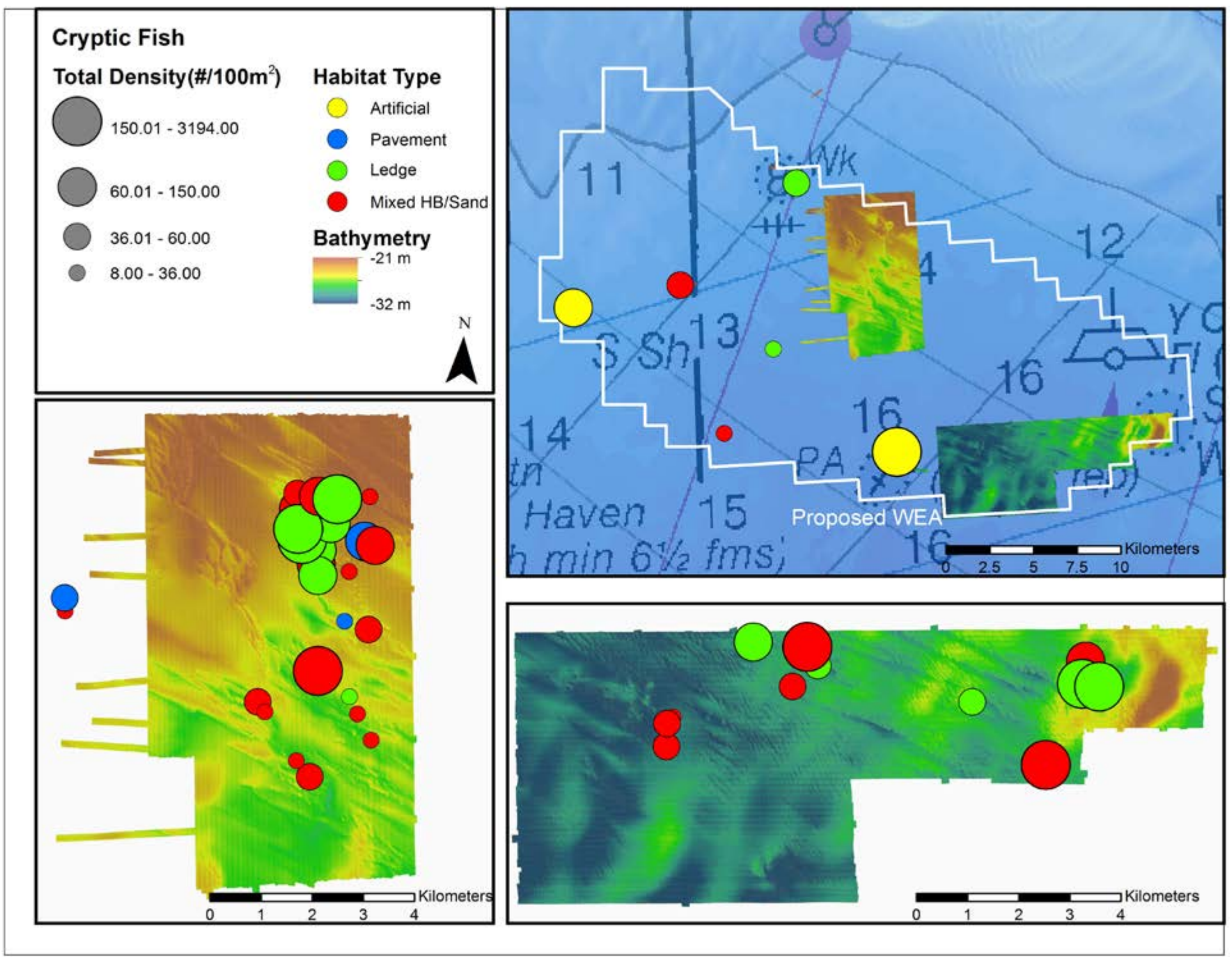

Figure 3-74. Total density (#/100 m²) for the cryptic fish community by site (N = 47) in the Wilmington-East Call Area.

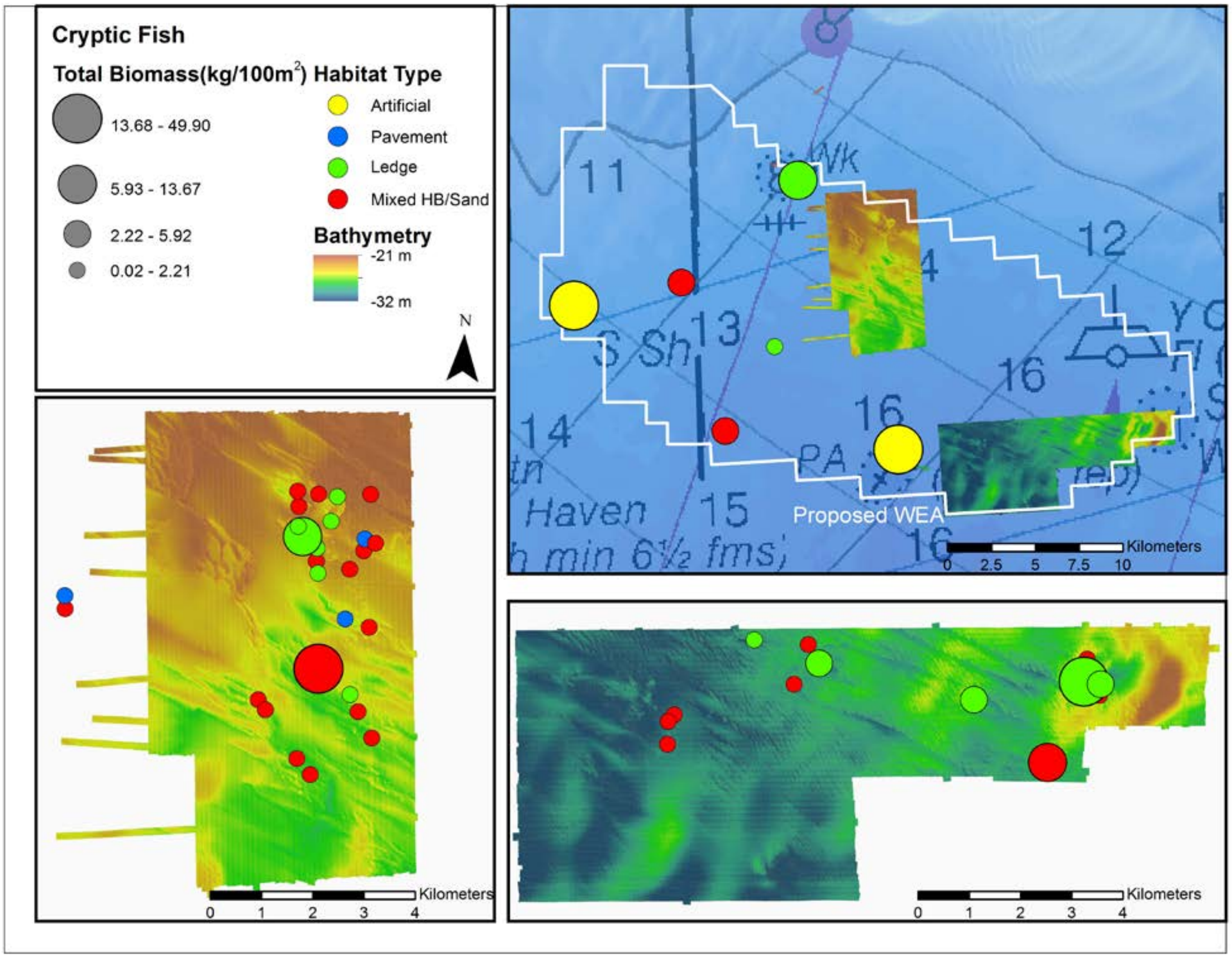

Figure 3-75. Overall biomass (kg/100 m^2) for the cryptic community by site (N = 47) inside the Wilmington East Call Area.

3.5.1.8. Density and Biomass

Overall density for the cryptic surveys was 6,151.11 individuals/100 m^2 with a mean site density of 130 ± 32.37 individuals/100 m^2. The most abundant species was *H. aurolineatrum*, comprising 19.9% of total fish density (Table 3-12, Figure 3-76). Members of Labridae, *Halichoeres bivittatus* (slippery dick) and *Pareques umbrosus* (cubbyu), were the second and third most abundant species in cryptic surveys together comprising 27.4% of total fish density (Appendix XII). Although *S. caprinus* and *S. chrysops* were the fourth and fifth most encountered species, the Sparidae family is the most abundant family seen during the cryptic surveys.

Table 3-12. Overall percent density and biomass contribution by family and species for the cryptic community. Species in bold indicate a member of the Snapper Grouper complex managed by the SAFMC.

Family	% Density	Species	% Density	Species	% Biomass
Sparidae	21.13	Haemulon aurolineatum	19.90	Pareques umbrosus	27.58
Haemulidae	20.24	Halichoeres bivittatus	16.04	Stenotomus chrysops	19.64
Labridae	18.69	Pareques umbrosus	11.44	Stenotomus caprinus	12.29
Serranidae	15.97	Stenotomus caprinus	10.08	Haemulon aurolineatum	10.33
Sciaenidae	11.57	Stenotomus chrysops	9.07	Halichoeres bivittatus	5.17
Family	**% Biomass**	Serranus subligarius	6.86	Centropristis striata	4.94
Sparidae	36.82	Centropristis striata	4.96	Diplodus holbrookii	4.45
Sciaenidae	27.58	Parablennius marmoreus	3.00	Centropristis ocyurus	4.05
Serranidae	11.19	Centropristis ocyurus	2.75	Halichoeres caudalis	2.71
Haemulidae	10.47	Halichoeres caudalis	2.58	Serranus subligarius	1.12
Labridae	7.90	Diplodus holbrookii	1.8	Urophycis earllii	1.11

Cryptic community biomass was 113.63 kg/100 m^2 with a mean site biomass of 2.41± 0.76 kg/100 m^2 (Appendix XII). In contrast with the conspicuous community, the majority of density and biomass for all bottom types are comprised of the same species and families (Table 3-12). The methods of this sampling approach restrict the survey to fish measuring ≤ 20 cm TL, which helps explain the species composition. Of particular note is the presence of *Urophyscis earllii* (Carolina hake) as this species favors crevices and overhangs and is often overlooked during conspicuous surveys. This species usually occurs at ledges at sizes that are outside the sampling domain of cryptic surveys, and thus larger individuals go unrepresented in the dataset.

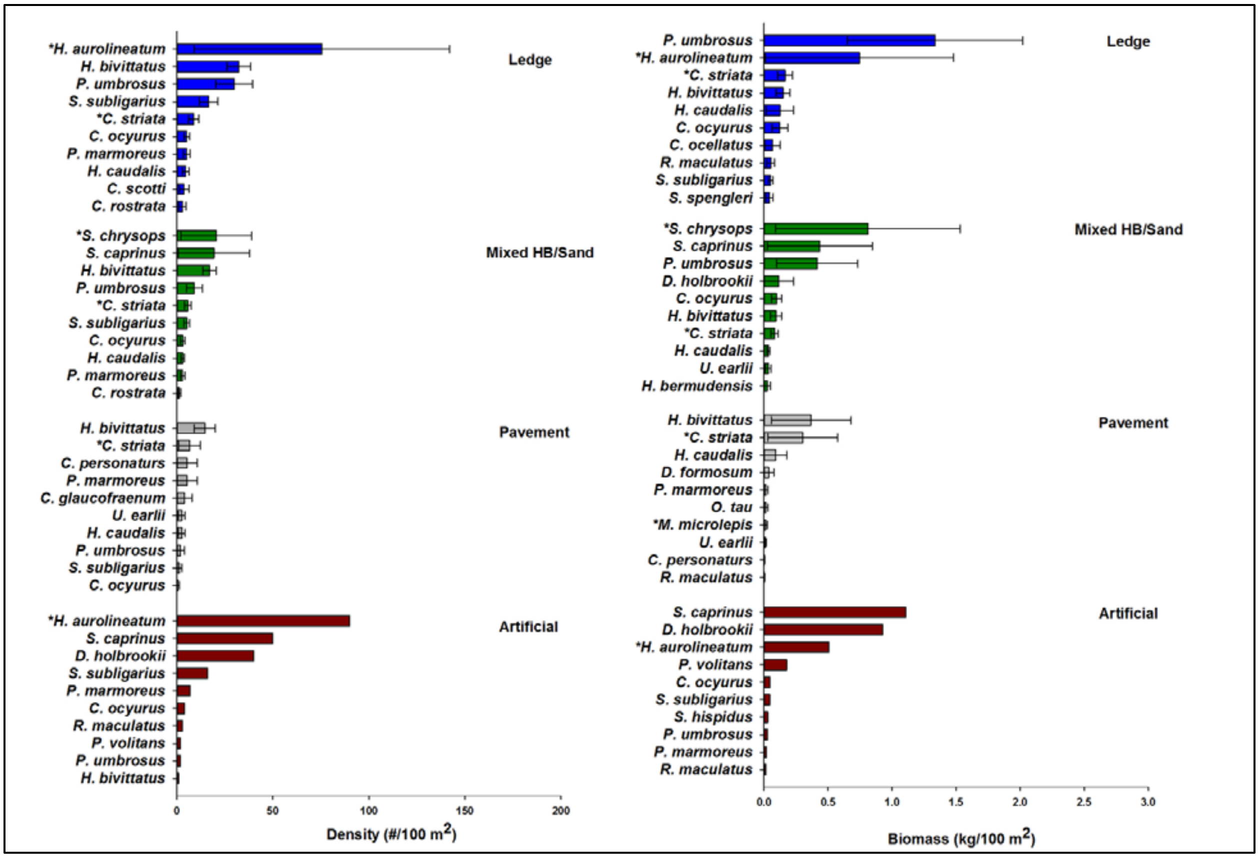

Figure 3-76. The top ten species by mean site density (#/100 m^2) and mean site biomass (kg/100 m^2) by habitat type: Ledge (N = 15), Mixed HB/Sand (N = 27), Pavement (N = 3), and Artificial (N = 1). We were only able to conduct a cryptic survey at one artificial site, therefor error bars are not present.

Species lists in order of contribution to abundance and biomass by habitat type suggest different community compositions among habitats. Multivariate analyses were used to investigate fish community structure further. The nMDS and ANOSIM analyses found no significant differences between community composition based on density or biomass by habitat type (Figure 41; Global R = 0.042, p = 0.26; Global R = 0.056, p = 0.20). The species list suggests dissimilar communities by habitat, but the large variability within habitat types hinders the interpretation.

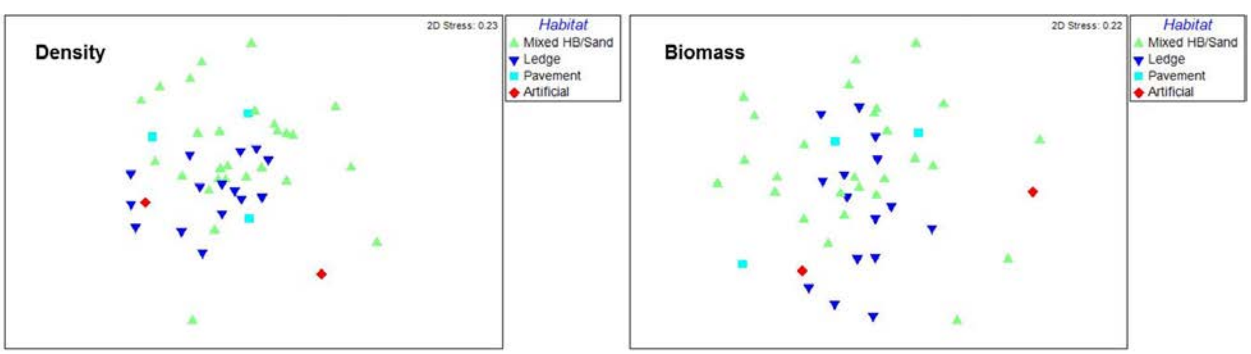

Figure 3-77. Non-metric multi-dimensional scaling plots of community composition based on density and biomass by habitat type.

3.5.1.9. Snapper Grouper Management Complex

Species of the Snapper Grouper Management Complex are prevalent in the hardbottom cryptic community of the call area (Table 3-13). Only eight out of the 48 species encountered on cryptic surveys are members of the SG, but they comprise 47% of overall density and 52% of overall biomass of the cryptic community. *H. aurolineatum* is the most numerous of the SG species and second highest percent biomass. There were no differences by habitat type for SG density and biomass in the cryptic surveys.

Table 3-13. Snapper Grouper Management Complex members encountered on cryptic surveys by percent contribution to overall density and biomass. An asterisk denotes a species that does not have specific management measures in place but are still considered Ecosystem Component Species.

Species	% Density	% Biomass
Calamus species	0.46	1.07
*Centropristis ocyurus**	0.23	0.16
Centropristis striata	3.24	3.80
Haemulon aurolineatum	46.29	8.63

Species	% Density	% Biomass
Haemulon plumierii	1.43	1.68
Mycteroperca microlepis	0.84	9.47
*Stenotomus caprinus**	7.72	2.09
Stenotomus chrysops	7.21	5.66

3.5.1.10. Trophic Guilds

The cryptic fish community was dominated by invertivore and benthic carnivore species (

Table 3-14). *H. aurolineatum*, *H. bivittatus* and *S. subligarius* are responsible for the high percent of invertivores across all bottom types. Ledge habitats were dominated by invertivores due to the high incidence of *H. aurolineatum*, with 92% of all individuals were encountered at ledge sites. Benthic carnivores were a third as prominent at ledge sites and mostly comprised of *P. umbrosus* and *C. striata*. The opposite pattern was seen at mixed HB/sand habitats with benthic carnivores dominating and invertivores a distant second. This difference in composition is due to the high incidence of *S. chrysops*, *S. caprinus* and *S. subligarius* and very low incidence of *H. aurolineatum.* There were no significant differences observed between the mean percent density of trophic guilds among habitat types. Species composition of the cryptic community was so similar based on density and biomass and we are only presenting the results of density data.

Table 3-14. Percent density of cryptic fish by trophic guild for all of the sites combined and by habitat type.

Trophic Guild	Species	% Total	% Ledge	% Mixed HB	% Pavement	% Wreck
Benthic Carnivore	16	41.44	24.55	62.81	30.14	36.57
Herbivore	2	0.42	0.46	0.46	0	0
Invertivore	16	47.68	65.80	28.19	39.73	36.00
Omnivore	7	5.16	3.24	4.18	19.18	23.43
Piscivore	2	0.10	0.20	0	0	0
Planktivore	6	5.19	5.76	4.36	10.96	4.00

3.5.1.11. Habitat Relationships

In further examination of cryptic fish communities and habitat metrics, mean density and biomass were significantly higher at ledge sites over mixed HB/sand ($Z = 3.03$, $p = 0.0024$; $Z = 2.312$, $p = 0.02$; Figure 3-78). This pattern was also evident for small fish (≤ 10 cm TL) mean density but was not apparent in mean biomass of small fish ($Z = 2.59$, $p = 0.0094$; $Z = 1.89$, $p = 0.05$). Similar to the conspicuous community, species richness was also significantly greater for ledge habitats than mixed HB/sand ($Z = 3.07$, $p = 0.0048$).

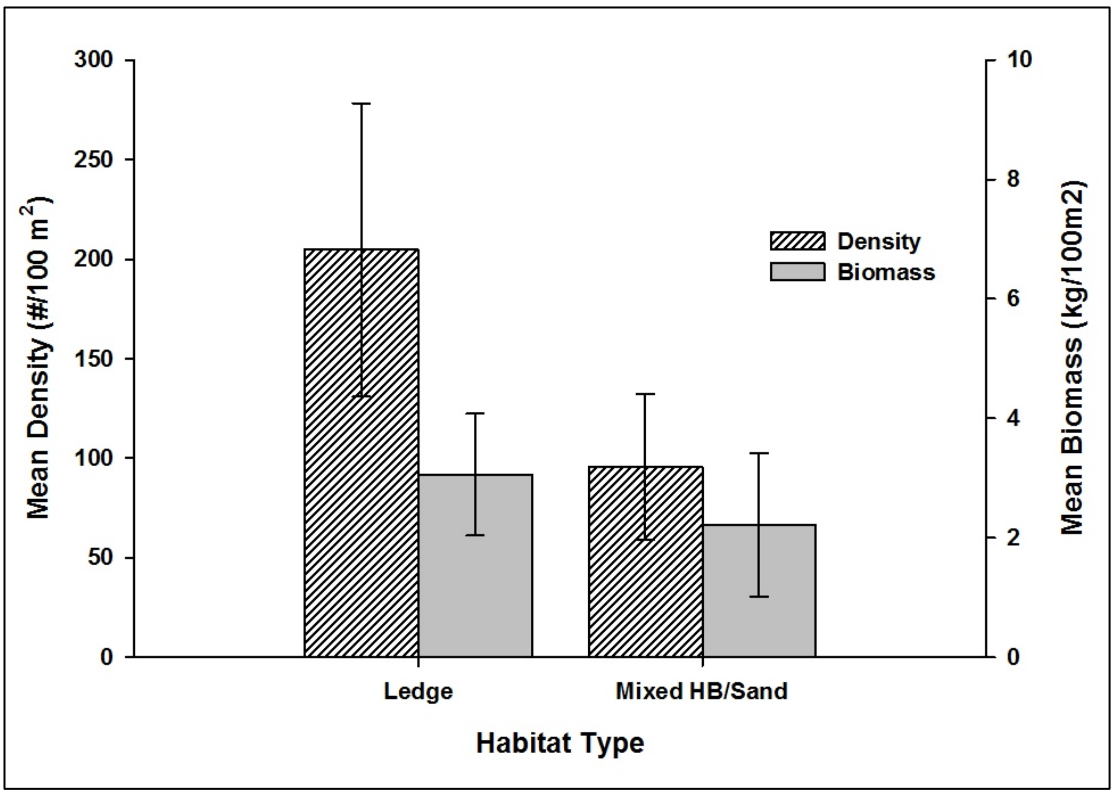

Figure 3-78. Mean site density and biomass for cryptic fish across size classes by Ledge and Mixed HB/Sand.

Correlative analysis was conducted with overall mean density and mean biomass and habitat characteristics collected in situ and from sonar (rugosity). Density was positively correlated with rugosity, hardbottom height, and percent cover of hardbottom and macroalgae (Figure 3-79). Density was negatively correlated with percent cover of softbottom. Biomass was also positively correlated with rugosity and hardbottom height but was not found to be associated with any benthic cover metrics. These results reflect the benthic characteristics described in the previous habitat chapters for ledge habitats: higher rugosity, hardbottom height, and percent cover of hardbottom and macroalgae, along with lower percent cover of softbottom and bare than mixed HB/sand.

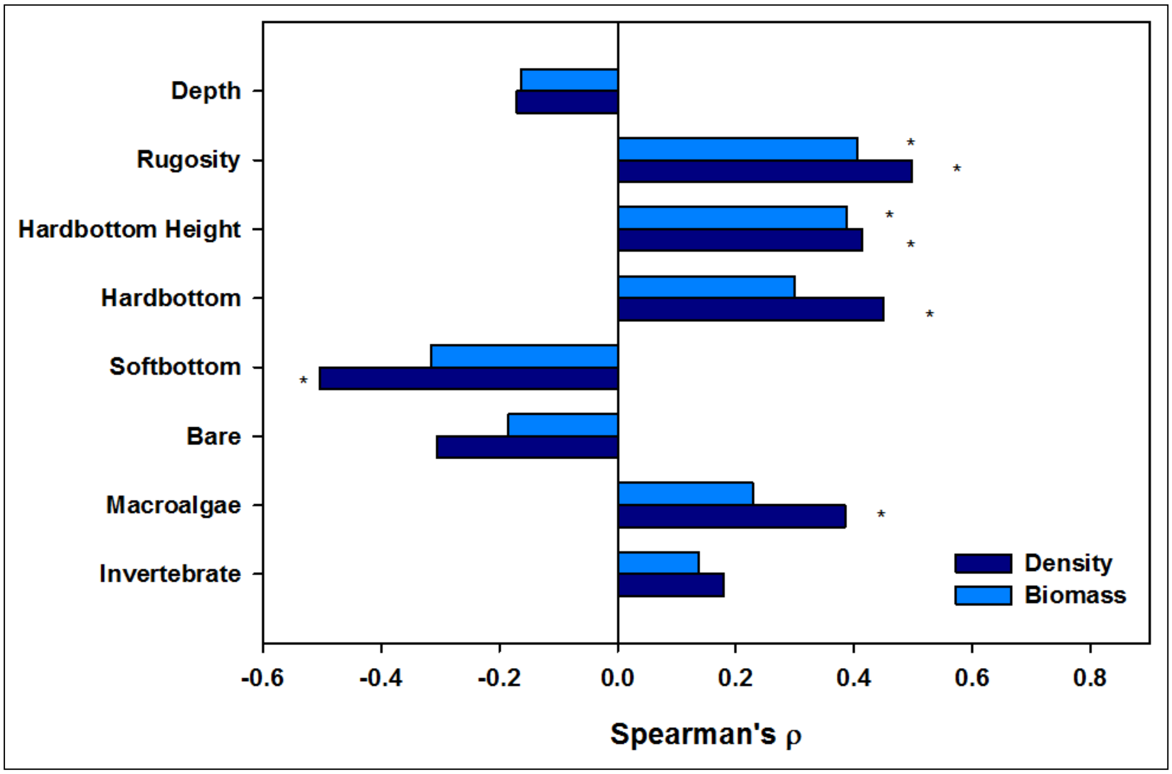

Figure 3-79. Cryptic fish community mean site density and biomass spearman rank correlations by depth (m), multi-beam derived rugosity, hardbottom height (cm), and percent cover: hardbottom, softbottom, bare, macroalgae, and invertebrates. Asterisks indicate a significant correlation.

Multivariate analyses were used to investigate the contribution of benthic characteristics to fish community structure (based on density and biomass). Results from the BIOENV method of the BEST procedure indicated there are no significant relationships in our data among community composition and habitat variables: depth, rugosity, hardbottom height, biotic height, and benthic percent cover of hardbottom, softbottom, bare, macroalgae, and invertebrate (all $R < 0.124$ and $p > 0.22$).

3.6. Seasonal Diver Assessments of Hardbottom and Artificial Habitats

3.6.1. Fish Community and Hardbottom Habitat

Over the 131 transects that were conducted across sixteen hardbottom reefs, we counted 268,460 total fish. These fish belong to 127 species and 46 families. The fish present on natural and artificial hardbottom reefs of Onslow Bay and Long Bay included tropical, subtropical, and warm-temperate reef fish, as well as coastal pelagic species. The fish represented functional groups of carnivores, piscivores, herbivores, omnivores, invertivores, and planktivores. Twenty-four species of fish in the snapper-grouper complex were recorded on the hardbottom sites.

Fish community composition on natural and artificial hardbottom reefs differed at the taxonomic levels of fish species, families, and trophic groups (Figure 3-80). Notably, 39% of the differences in community composition among trophic groups were driven by planktivores (Figure 3-80). The planktivores, fish that typically feed on plankton in the water column, were primarily associated with artificial reefs. Both invertivores and carnivores were also more prevalent on artificial than natural reefs, constituting 29% and 14% of the community differences by reef type, respectively. Interestingly, herbivores were slightly more common on natural than artificial reefs along with macroalgae, which also have higher percent cover on select natural reefs than artificial.

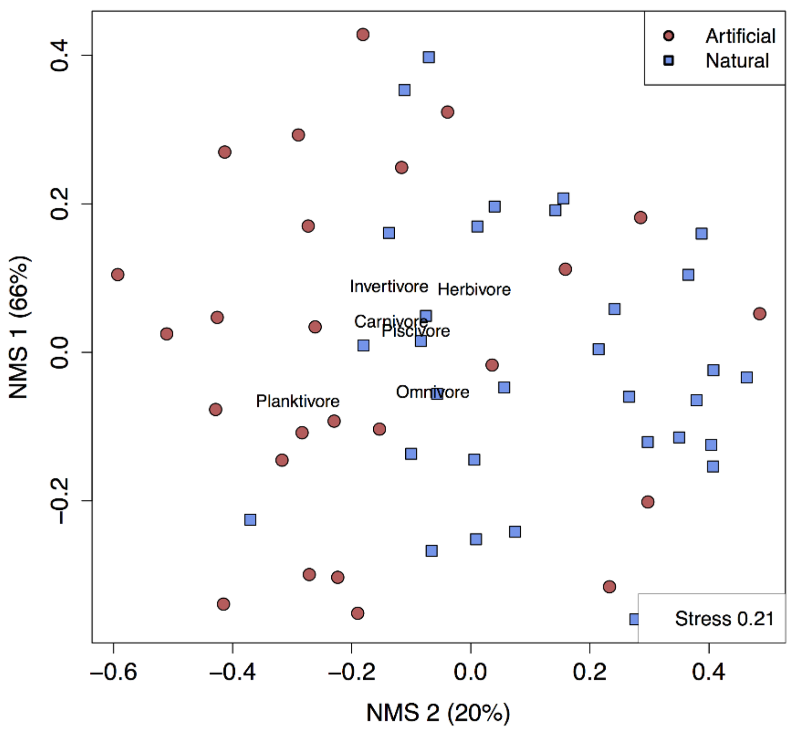

Figure 3-80. Non-metric multidimensional scaling (nMDS) ordination of fish community by trophic group for natural and artificial hardbottom. Points correspond to samples colored according to reef type. Artificial reefs are red circles. Natural reefs are blue squares. Black text corresponds to fish trophic groups.

There were seasonal changes in water temperature on the hardbottom reefs (Figure 3-81). The warmest water temperature during a survey dive was 28.0°C on June 25, 2014 at the shipwreck *City of Houston*. The minimum water temperature recorded during our surveys was 13.4°C on December 18, 2014 at the shipwreck *Raritan*. The average temperature across all sites was 24.2°C. The water temperature was similar in Wilmington-East and Onslow Bay. There was no difference in fish community composition among and between seasons of summer, fall, and spring (ANOSIM season, p= 0.26, R 0.014). However, there were differences in fish community composition with measured water temperature (PERMANOVA, p = 0.01; Figure 3-82), suggesting that season does influence the fish community. There was no overall difference in fish community composition for sites located within southwestern Onslow Bay versus those in study area (ANOSIM location, p = 0.14, R 0.02; Figure 3-82).

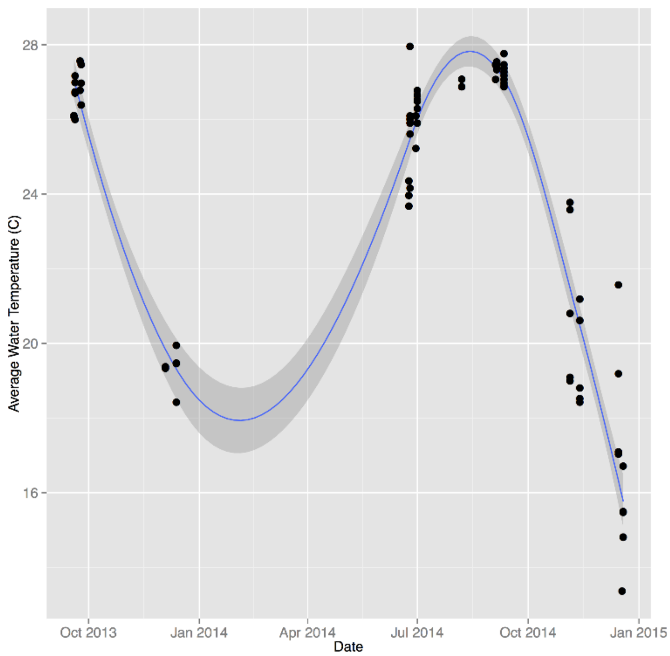

Figure 3-81. Changes in water temperature on hardbottom reefs across seasons. Blue line represents smoothed conditional mean. Black circles are temperature data from sampled reefs.

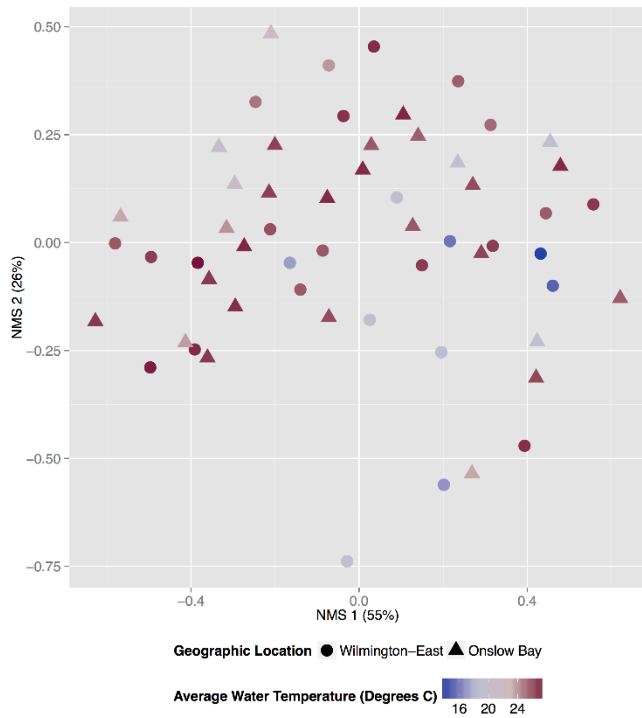

Figure 3-82. Non-metric multidimensional scaling (nMDS) ordination of snapper-grouper complex fish community on natural and artificial reefs. Points correspond to samples and are shaded corresponding to water temperature (°C) at each site. Samples that are circles occurred in the Wilmington-East Call Area, whereas triangles represent reefs in Onslow Bay.

3.6.2. Structural Complexity

The surveyed hardbottom reefs ranged from flat pavements to pronounced ledges and shipwrecks with diverse architecture, thereby varying by category in structural complexity (Figure 3-83). Specifically, natural hardbottom reefs included three general types of habitat: 1) flat pavements, 2) rubble fields, and 3) pronounced ledges, each with characteristic contours and spatial characterizations (Figure 3-84A-F). The flat pavements displayed relatively uniform contours (Figure 3-84A), having low variability in reef structure over the length of the transect along which fish were surveyed (Figure 3-84B). The contour of mixed hardbottom was bumpier than pavements (Figure 3-84C-B) and, therefore, had increased spatial variability (semivariance, Figure 3-84D). In contrast, the ledges contained either sharp or gradual drops and rises in reef height (Figure 3-84E). These ledges had the highest spatial variability compared to both rubble and pavement (Figure 3-84F). Overall, the pavements were the least complex type of natural, followed by rubble fields. Ledges were the most complex natural hardbottom. Similar to natural reefs, artificial hardbottom also represented architecturally diverse habitats. However, because the shipwrecks and artificial reefs have unique designs and physical characteristics (e.g., protrude into the water column) they were typically more complex in comparison to natural reefs (Figure 3-85). Within the artificial reefs, the structural complexity and spatial semivariance were dependent on the specific artificial reef type and history (Figure 3-84G-J). Typically, older shipwrecks had lower complexity (Figure 3-84G-H) than more recent wrecks (Figure 3-84I-J).

The complexity of both natural and artificial hardbottom reefs was calculated with a digital reef rugosity metric, such that low rugosity reflects low structural complexity and high rugosity coincides with high structural complexity. The distribution of digital reef rugosity for all reefs ranged from flat (0.087) to highly rugose (3.308), as displayed in kernel density estimations (Figure 3-84), yet the distribution of natural reefs was centered on flatter rugosity values than those of artificial, which had a larger range and was weighted towards the more complex part of the rugosity spectrum (Figure 3-85). The descriptive findings on structural complexity on natural and artificial reefs indicate that hardbottom of NC encompasses a wide variety of shapes and sizes, and thus a continuum of structural complexities.

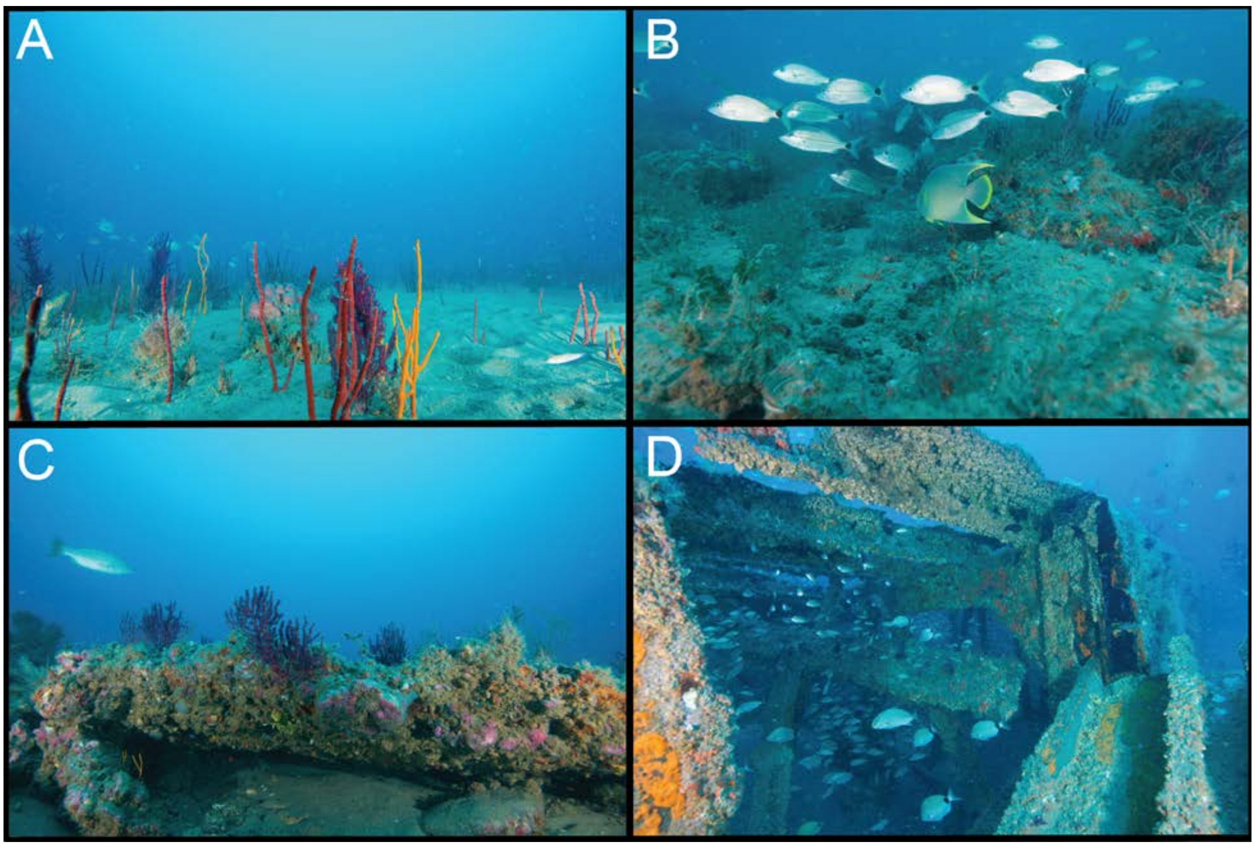

Figure 3-83. Hardbottom reef types based on structural complexity: A) Natural reef – flat pavement; B) Natural reef – rubble C) Natural reef – pronounced ledge; D) Artificial reef.

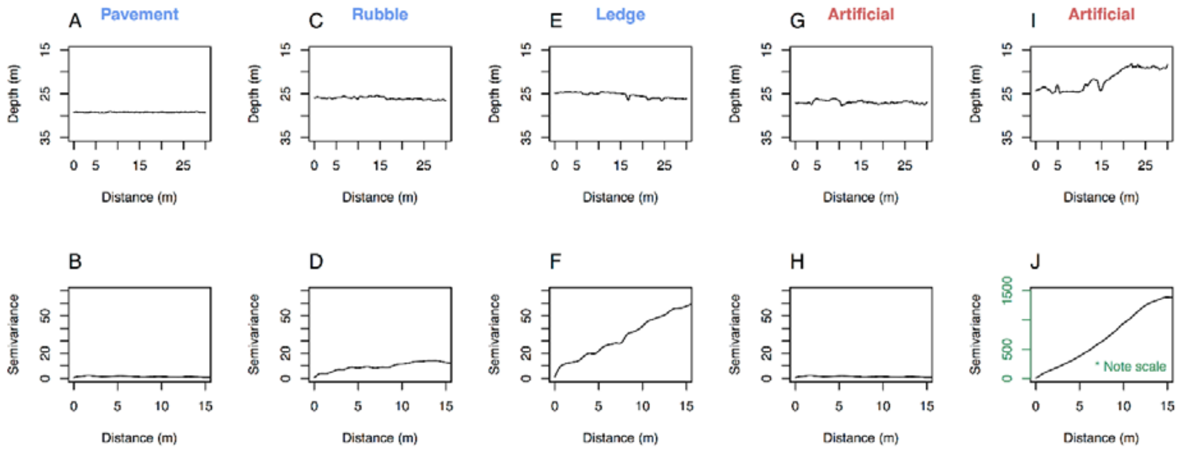

Figure 3-84. Structural complexity of natural and artificial hardbottom as contours (top row) and variograms (bottom row). A-B) Natural reef – flat pavement. C-D) Natural reef – rubble field. E-F) Natural reef – extensive ledge. G-H) Artificial reef (*City of Houston)* – low relief steamer, sank in 1878. I-J) Artificial reef (*Alexander Ramsey)* – high relief liberty ship, sank in 1974.

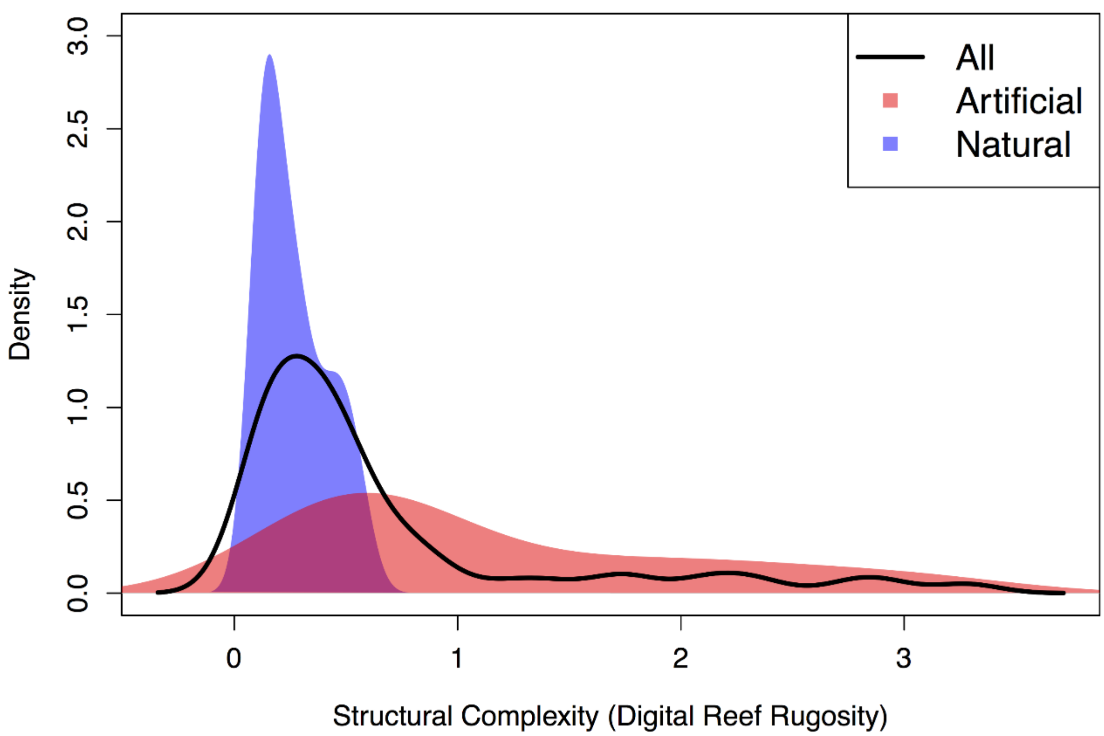

Figure 3-85. Gaussian kernel density of structural complexity calculated for digital reef rugosity. Black line is kernel density of all reefs, including both artificial and natural. Red polygon is artificial reefs. Blue polygon is natural reefs.

Fundamental fish community metrics on natural reefs were not influenced by structural complexity measured on the 16 sites. The lack of even a trend remained consistent at the species, family, and trophic group level (PERMANOVA). Likewise, analyzing only the snapper-grouper complex yielded the same results. The community composition of fish in the snapper-grouper complex bore a marginal increasing trend with structural complexity of natural reefs (PERMANOVA, p= 0.066; Figure 3-86). Despite expectations of a positive correlation between structural complexity and abundance of the snapper-grouper complex, there was no relationship (Figure 3-87A). Peaks in snapper-grouper abundance occurred on a natural reef of moderate complexity (23MLE); otherwise, snapper-grouper abundance appeared uniformly distributed across the range of complexity values (Figure 3-87A). Species richness and diversity of the snapper-grouper complex were similarly unaffected by structural complexity (Figure 3-87B-C). Likewise, there was no relationship between complexity and the evenness of the snapper-grouper complex (Figure 3-87D). These results suggest that reefs of a broad variety of complexity, rather than just the most complex habitats, are valuable for supporting not only the overall community of fish that use these reefs, but also the highly-valued snapper-grouper complex.

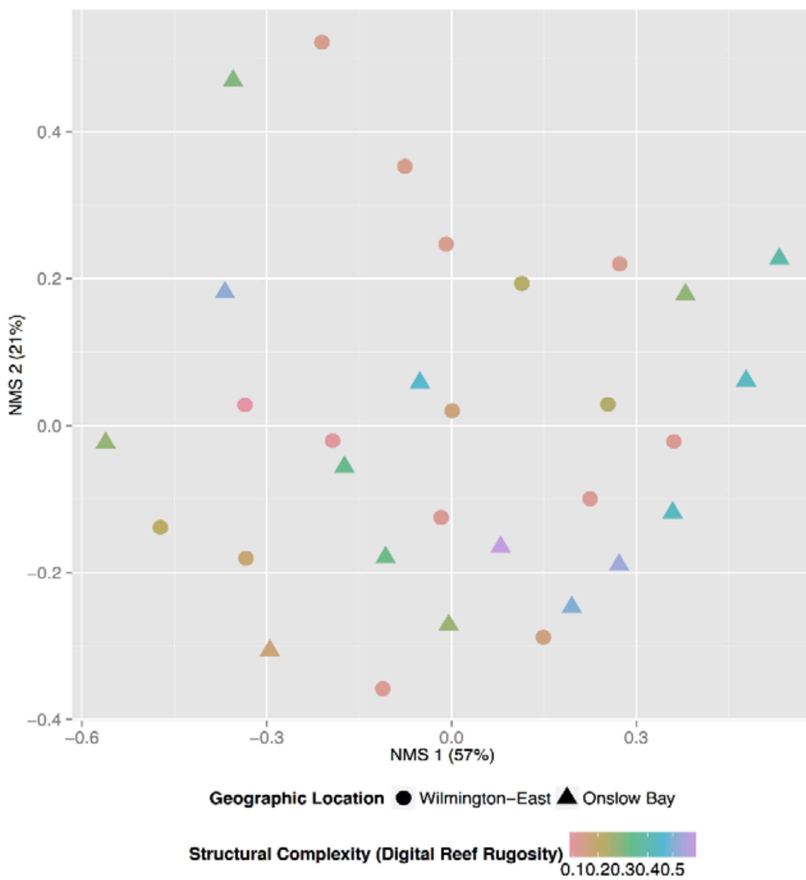

Figure 3-86. Non-metric multidimensional scaling (nMDS) ordination of fish community on natural reefs. Complexity is digital reef rugosity. Points correspond to samples and are shaded corresponding to structural complexity at each site. Samples that are circles occurred in the Wilmington-East Call Area while triangles represent reefs in Onslow Bay.

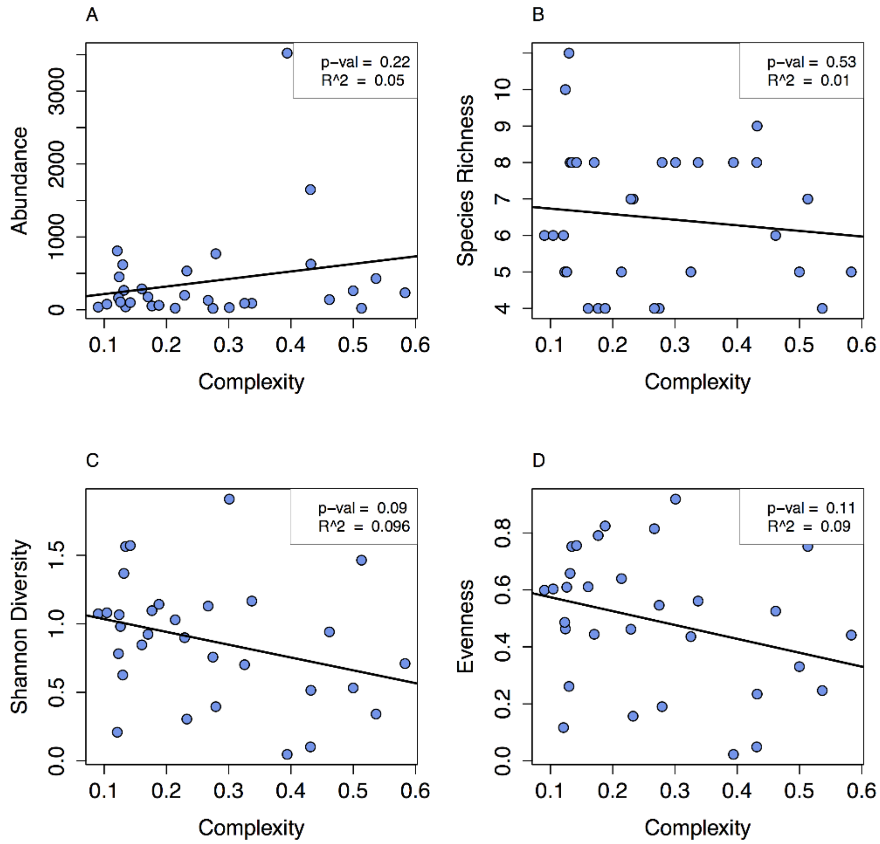

Figure 3-87. Effect of structural complexity of natural reefs on community metrics of fish in the snapper-grouper complex on A) abundance, B) species richness, C) Shannon-Wiener species diversity, and D) evenness. Black lines represent linear models.

Similarly to natural reefs, we did not find the expected positive relationship between artificial reef complexity and fundamental fish community metrics. Across species, family, and functional groups, there was no difference in community composition with structural complexity (PERMANOVA). The community composition within the snapper-grouper complex that is of high management concern, however, yielded marginal negative differences with structural complexity of artificial reefs (PERMANOVA, $p = 0.0499$). When we examined the effect of structural complexity on univariate fish metrics, structural complexity did not positively affect the abundance of fishes in the snapper-grouper complex (Figure 3-88A). There was, however, an unexpected significant inverse relationship between structural complexity and species richness on artificial reefs (Figure 3-88B). This negative trend is driven by the separation of several shipwrecks that occur in deeper water (*City of Houston*, Unknown Wreck 2; Figure 3-88B) and one artificial reef that occurs in shallow water (*Alexander Ramsey*; Figure 3-88B). The deeper shipwrecks have both temperate and tropical species (high species richness) whereas the shallow wreck frequently has only temperate fish species (low species richness). The structural complexity of the artificial reefs had no effect on species diversity and evenness within the snapper-grouper complex (Figure 3-88C-D). These results suggest that reef fish that use hardbottom habitat exhibit no overall preference for higher complexity habitat and that all types and levels of hardbottom habitat are, in fact, essential fish habitat for a broad suite of reef associated fishes.

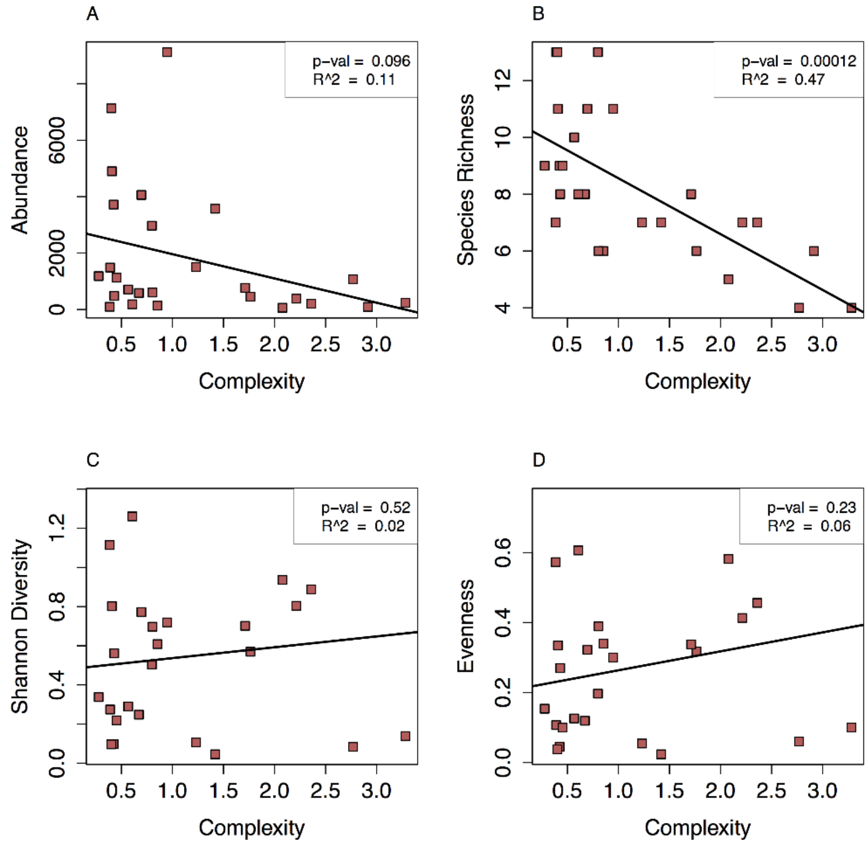

Figure 3-88. Effect of structural complexity of artificial reefs on community metrics of fish in the snapper-grouper complex on A) abundance, B) species richness, C) Shannon-Wiener species diversity, and D) evenness. Black lines represent linear models.

3.6.3. Sediment Cover

Sediment cover on hardbottom reefs can be described as either ephemeral (high standard deviation) or permanent (low standard deviation). When sediment was ephemeral, there was high variability in sediment depth across a reef, while when sediment was permanent, there was low variability in the depth of sediment cover on reefs. Sediment dynamics were only examined on natural reefs because surveys on artificial reefs were conducted on the man-made structure, which was usually devoid of sediment. The sediment dynamics on natural reefs did not have a direct effect on the fish community, as the community composition of fish present on sites with ephemeral sediment were similar to those with permanent cover (PERMANOVA, $p = 0.71$).

3.6.4. Benthic Community and Hardbottom Habitat

The benthic community differed by reef type and geographic location. Here we consider the benthic community formed by both macroalgae and benthic invertebrates at the phylum level. The community composition on natural and artificial hardbottom was distinct (ANOSIM, p =

0.001, R = 0.19). These differences are attributable to several specific phyla. For example, the natural reefs had more Phaeophyta (brown algae; SIMPER, 16% contribution) and exposed substrate (sediment, rubble, rock; SIMPER, 15% contribution) than the artificial reefs. Artificial reefs had more Cnidarians (hard coral, soft coral, anemones; SIMPER, 11% contribution), Hydrozoans and Bryozoans (SIMPER, 11% contribution), and Rhodophyta (red algae; SIMPER, 10% contribution) than natural reefs. Interestingly, in the area of well-known hardbottom habitat in southwestern Onlsow Bay, cover of Phaeophyta (brown algae; SIMPER 20% contribution) and Rhodophyta (red algae; SIMPER 9% contribution) were higher than in the study area. In contrast, there was higher cover of exposed substrate (sediment, rubble, rock; SIMPER 15% contribution), Cnidarians (hard coral, soft coral, anemones; SIMPER 11% contribution), and Hydrozoans and Bryozoans (SIMPER, 10% contribution) in the study area.

Because there were differences in the benthos on artificial and natural reefs, we examined natural reefs and artificial reefs separately. When considering solely the natural reefs, the benthic communities remained separate between the two geographic areas (Figure 3-89A; ANOSIM, p = 0.00, R = 0.65). However, among artificial reefs, the benthic communities were more uniform across the two geographic locations (Figure 3-89B; ANOSIM, p = 0.025, R = 0.146).

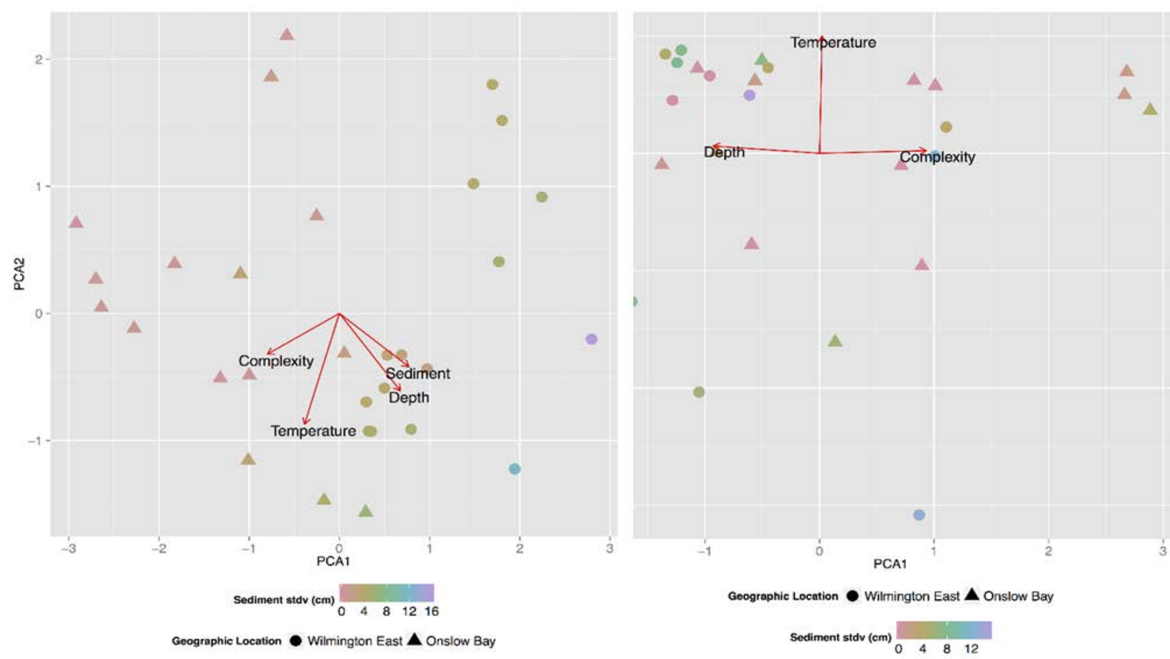

Figure 3-89. Principal components analysis (PCA) ordination of benthic community by phyla on natural reefs. Red arrows and corresponding black labels represent environmental vectors. Complexity is the structural complexity, calculated as digital reef rugosity. Temperature is the water temperature. Depth is the water depth at each reef. Sediment is the standard deviation of sediment cover. Points correspond to samples and are shaded corresponding to the standard deviation of sediment cover at each site. Samples that are circles occurred in the Wilmington-East Call Area while triangles represent reefs in Onslow Bay.

3.6.5. Structural Complexity and Sediment Cover

Both the structural complexity and sediment dynamics on temperate natural reefs affected the benthic community composition. Reefs with higher complexity had more permanent and less variable sediment cover (Figure 3-89), perhaps because sediment could not readily shift as a larger blanket over complex reef contours that obstruct movement. The reefs in the study area had less overall structural complexity and more ephemeral sediment cover than those in Onslow Bay (Figure 3-89). This suggests that the benthic community in the study area experiences more frequent burial and abrasion than sites further north in Onslow Bay. Additionally, deeper sites have a more ephemeral sedimentary landscape than shallower reefs. Together, the environmental variables of complexity, sediment, temperature, and depth on principal components 1 and 2 accounted for 81.3% of the variation among the benthic communities of natural reefs at the phyla level. Complexity, temperature, and depth accounted for 91.3% of the variation on artificial reefs. These findings indicate that the benthic invertebrate and macroalgal communities on natural sites are intimately linked to both the structural complexity of reefs and the degree to which sediment dynamics are either ephemeral or permanent.

On artificial reefs, where sediment dynamics were not investigated, structural complexity affected the macroalgae and benthic invertebrate community composition (PERMANOVA, $p = 0.007$).

3.6.6. Overall Biological Associations with Hardbottom Habitat

Structural complexity and sediment dynamics of hardbottom influenced the benthic community composition, which affected the fish community. The fish community, however, was affected by neither complexity nor sediment depth. According to CCA, across both artificial and natural reefs, invertivorous fish occurred with benthic invertebrates, including Porifera, Bryozoa, and Tunicata (Figure 3-90). Similarly, herbivorous fish co-occurred with Chlorophyta (green macroalgae) and Rhodophyta (red macroalgae) (Figure 3-90). Interestingly, among natural reefs, these trends are more pronounced (Figure 3-91). In the study area, where there was ephemeral sediment cover and low structural complexity, there was high cover of octocorals and raw substrate (sediment, rubble, hardbottom) (Figure 3-91). In contrast, reefs in Onslow Bay had more permanent sedimentary landscapes, as well as high structural complexity. These sites were characterized by high macroalgal (Chlorophyta, Rhydophyta, and Phaeophyta) and hard coral (scleractinian) cover (Figure 3-91). Piscivores and omnivores were distributed on the ordination near the Onslow Bay sites, whereas invertivores were largely clustered in the study area (Figure 3-91).

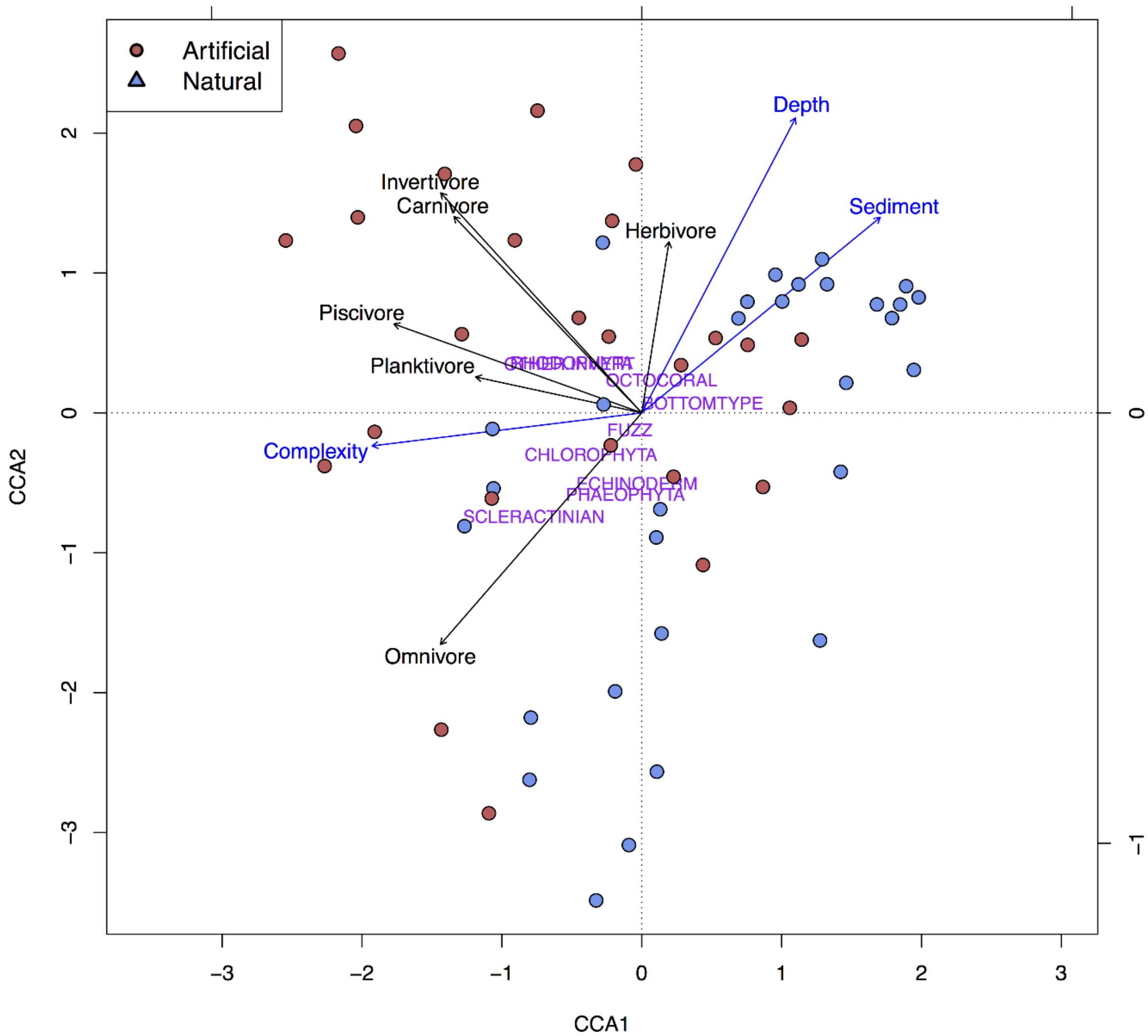

Figure 3-90. Canonical correspondence analysis (CCA) ordination of natural and artificial hardbottom reefs, fish functional group abundance, benthic cover, and environmental variables. Red circles represent artificial reefs. Blue circles are natural reefs. Purple text corresponds to cover of benthic invertebrates and macroalgae by major categories. Black vectors and labels are fish functional group abundances, scaled by magnitude. Blue vectors are environmental variables, complexity (digital reef rugosity), sediment (standard deviation of sediment cover), and depth (water depth), also scaled by magnitude.

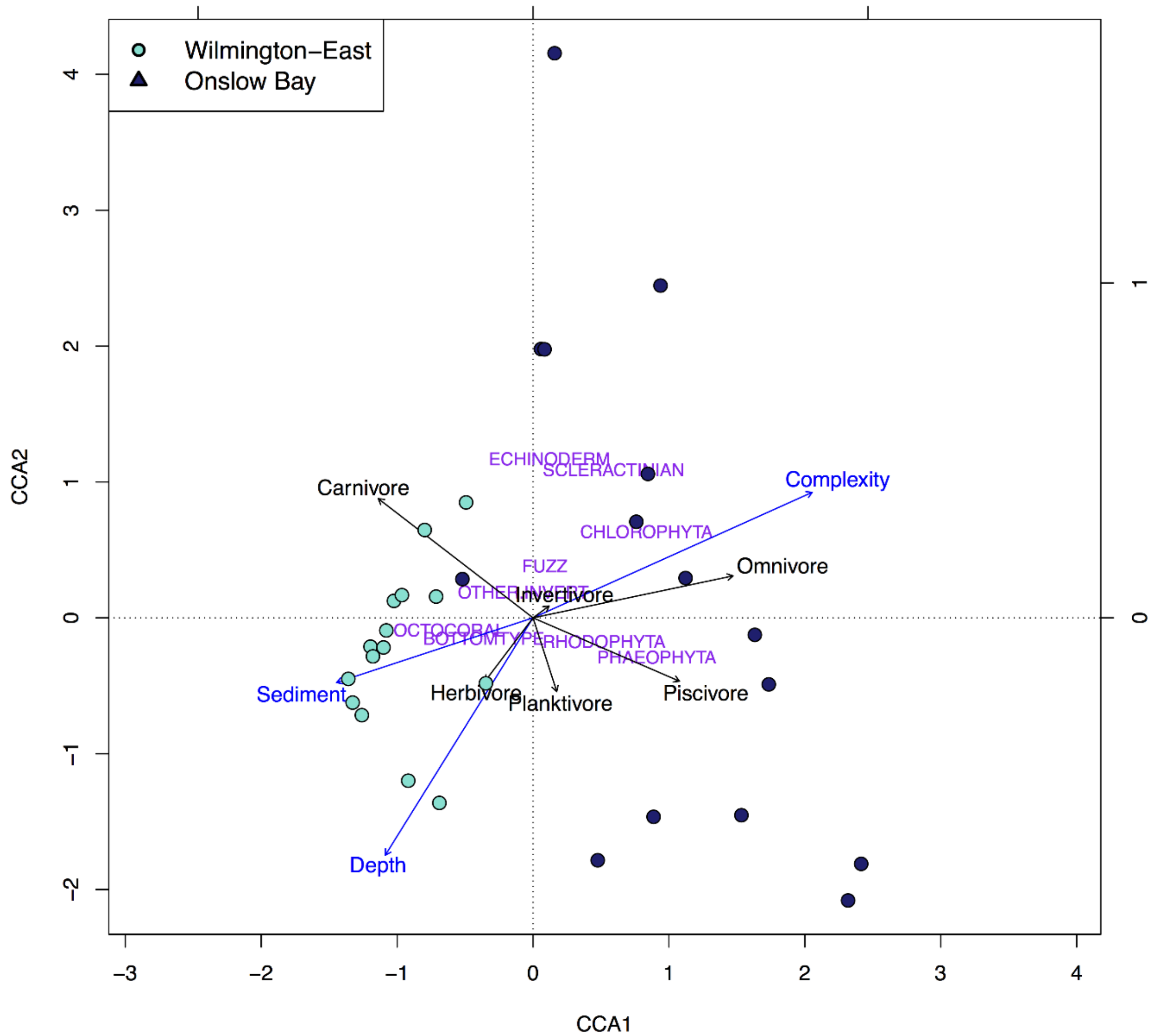

Figure 3-91. Canonical correspondence analysis (CCA) ordination of natural reefs, fish functional group abundance, benthic cover, and environmental variables. Reefs in Onslow Bay represented by navy circles while those in Wilmington-East are in turquoise circles. Purple text corresponds to cover of benthic invertebrates and macroalgae by major categories. Black vectors and labels are fish functional group abundances, scaled by magnitude. Blue vectors are environmental variables, complexity (digital reef rugosity), sediment (standard deviation of sediment cover), and depth (water depth), also scaled by magnitude.

4. Discussion

The southeast US Outer Continental Shelf (OCS) is characterized by a gradually sloping shelf with a mix of seafloor types including sand, pavement and rocky outcrops. A geological framework provides an understanding of the broad geomorphology and sedimentary dynamics; however, the distribution of seafloor types remain poorly described throughout the OCS, especially in terms of understanding the dynamics of sediment transport in the mid and outer shelf that influence the emergence of rocky reefs and pavement that support ecologically and economically important fisheries and other living marine resources. This project accomplished the primary objective of describing and delineating rocky outcrops within the original scope of the Wilmington-East Wind Energy Call Area and the subsequently designated Wilmington-East Wind Energy Area. The delineation of rocky outcrops and artificial hardbottom habitats guided an intensive diver visual assessment to characterize the benthic and fish communities as well as the seasonal changes in communities and influence of sand and sediment movement around hardbottom habitats.

4.1. Distribution of Natural and Artificial Hardbottom Habitats in the Wilmington-East Call Area

The large extent of the Wilmington-East Call Area (1,120 km^2) called for an adaptive survey design that took advantage of the efficiencies of modern hydrographic survey and mapping tools. Using SSS with wide detection range allowed us to conduct a broad survey of the large area and detect features indicative of emergent rock and hardbottom habitats. Coupling MBES with SSS during the survey provided additional interpretive power by revealing elevation and topography of the seafloor. The initial SSS survey was conducted in 19 days. By comparison, an MBES survey with greater than 100% coverage would have increased cost and effort by nearly three-fold.

The delineation of outcrops and rocky reefs showed a patchy distribution in the survey area and guided a focused hydrographic multibeam sonar survey of the seafloor, which confirmed the structure of the seafloor around the delineated outcrops. Patchy distribution of hardbottom conforms to the evolving geological framework for Long Bay, Cape Fear and adjacent regions (Riggs et al. 1998). Despite the genesis of sediment from emergent rock formations in Onslow Bay and southwestward and along-shelf movement of sediments, the region is generally sediment starved after entrapment by the Frying Pan Shoals to the northeast of the study area. Though areas of deep bedforms with recent sediment material may form shoals, exposed Miocene and Cretaceous layers, as well as incised paleoriver channels are exposed and form hard substrate. As with other cuspate embayments along the SE Atlantic OCS, the hardbottoms are not distributed uniformly throughout the inner and mid-shelf location of the study area, but are clustered in areas of uprising Cape Fear Arch (UNC-CH 2009). This is in contrast to the more continuous distribution of hardbottoms at the outer shelf of the OCS (Quattrini et al. 2004). The clusters of potential outcrops are located in the north central, the eastern region of the study area, and in the southern region of the area. The identification of localized outcrops from these surveys appears to support the low percent cover of rocky outcrops on the southeast OCS (Miller and Richards 1980, Parker et al. 1983).

The sidescan sonar (SSS) surveys provided initial detection and confirmation of five previously known shipwreck sites and identified two previously uncharted structures. There is a particularly high concentration of shipwrecks in NC coastal waters, which are commonly referred to as the ‘Graveyard of the Atlantic,’ because they form the resting grounds for thousands of shipwrecks from the past 500 years that were causalities of changing barrier island geomorphology, as well as war (Stick 1989). These shipwrecks are culturally significant, representing the rich commerce and wartime maritime history of the region.

The seafloor mapping effort conducted in this study updates the regional characterization of the seafloor habitats of the southeastern US produced by the Southeast Area Monitoring and Assessment Program (SEAMAP-SA 2001). The distribution of hardbottom habitats identified here also conforms spatially to the results from interviews with fishing and dive stakeholders that rely on hardbottom and wrecks (Voss et al. 2013). It is not surprising that the fishing and diving community that uses this region of Long Bay has thoroughly searched the region for fishing grounds. The distinct outcrops are distinctive features that can be identified with fish-finding sonars that are commonly used in commercial and recreational fisheries. Coupled with GPS technology, the fishing community is able to digitally log and return to these locations as well as share these locations with other fishers.

Following the extensive sidescan sonar mapping surveys conducted for this project, BOEM received input from stakeholders in the shipping and transport industry and reduced the study area to the Wilmington-East WEA (Figure 1-1). Coincidentally, the Wilmington-East WEA excludes a large cluster of rocky outcrops in the southern region of the original wind energy planning area.

4.2. Value of Hardbottom Habitats to Reef Fish Communities

The combination of diver and acoustic assessments of hardbottom habitat demonstrated how the value of natural and artificial temperate reefs as habitat for fish and the associated benthic community varies with structural complexity and sediment dynamics. Each survey approach employed in this component of the project provided a unique perspective into the complex process of assigning value to each habitat based on the interactions between physical features and biological function present at each location over space and time. Our findings reveal that NC hardbottom reefs include a wide variety of structural complexities, ranging from flat pavements to pronounced ledges, and differently structured shipwrecks. The results show that all types of hardbottom habitat, regardless of structural complexity, provide support for a diverse complement of benthic (macroalgae, sponge, soft coral, and hard coral) and fish species, including the highly valued snapper-grouper complex that use these reefs. While some measurements support previous studies in the region, which suggest a greater value of high relief habitats, such as ledges, based on relationships between fish and benthic communities, other observations from our research describe a temporally dynamic and spatially complex interaction between environmental, sedimentary, and biological processes across natural hardbottom and artificial reef habitats.

4.2.1. Fish and Benthic Communities Associated with Hardbottom Habitats

It has been widely accepted in ecology that greater structural complexity of habitat harbors more abundant, rich, and diverse communities of organisms. More recent research in terrestrial (e.g., Kovalenko et al. 2011), freshwater (Gorman and Karr 1978, Schneider and Winemiller 2008), and coral reef (e.g., McCormick 1994; Dustan et al. 2013) ecosystems has confirmed this pattern. Research in the southeast US Outer Continental Shelf over the past two decades continues to show that hardbottom habitats support larger and more diverse fish communities when compared to softbottom habitats (Parker et al. 1994, Quattrini et al. 2004, Kendall et al. 2009, and references therein). Results suggest that within the range of mid-shelf hardbottom habitats studied in the 2014 surveys, those with higher relief (including artificial reefs) have a fish community with greater species richness and a greater abundance of large fish than habitats with lower relief. This was particularly evident for the abundance of the large apex predator species. However, overall fish density and biomass did not vary with habitat type or relief. Higher species richness, abundance and biomass of reef associated fish species were also found on tall hardbottom ledges in the Grays Reef National Marine Sanctuary, 17 miles from the Georgia coast (Kendall et al. 2009).

The hardbottom habitats that we surveyed for this project were in a relatively narrow depth range from 24.7 to 32.0 m (mean=28.5 m). While there were noted observations of warmer-water and tropical species in the survey stations that were further offshore, statistical comparisons failed to find a difference in the community assemblage across depth gradients. Species encountered during the May 2014 survey were similar to those of an extensive study conducted over six years on hardbottom communities in Onslow Bay (Whitfield et al. 2014) as well as a study of similar mixed hardbottom habitats offshore of Georgia (Kendall et al. 2009). In agreement with our May 2014 surveys, Whitfield et al. (2014) also found *H. aurolineatrum* and *R. aurorubens* as the top encountered species and *D. holbrookii* as the fourth most sited. *Centropristis striata* was the seventh most abundant fish species in this study and ranked eighth in Whitfield’s study. Although species abundance was relatively similar between the two studies, one glaring difference is the abundance of *Pagrus pagrus*. It was the fifth most abundant species in the Onslow Bay study while only 25 individuals were recorded in our study. It should be noted that the Whitfield et al. (2014) work was a multi-year study that included much deeper sites (down to 44 m.) where red porgy are more abundant (Labropoulou et al., 1999). The differences in the species assemblages can be explained simply by depth. Whitfield et al. (2014) described three distinct assemblages of conspicuous fish on hardbottom reefs structured by depth and related to seasonal fluctuations in temperature: 5–14, 15–37 and 38–46 m. All of our stations were within the mid-depth assemblages.

Hardbottom habitats in the study area support a diverse community of soft corals, hard corals, sponge, bryozoans, and macroalgae species. Many of these species provide important structure and habitat for the fish community. The characteristics of the benthic community provided clues to the relationships between fish community metrics and ledge habitats. Our results suggest that along with higher habitat height and rugosity, ledges also tended to have greater percent cover of hardbottom and macroalgae, which all positively correlated with species richness, density and biomass of large fish and apex predators. Invertebrates, especially soft corals and sponges, are a dominant part of the persistent benthic community and provide much of the structural relief blanketing hardbottom habitats. Invertebrate variables were not significantly linked to the fish community metrics, but have been linked in previous studies to fish abundance (Kendall et al., 2008, 2009). In contrast to Kendall et al. (2009), the link between the fish and the benthic biological community was less pronounced than expected given the assumption that the benthic community provides prey resources and biogenic habitat refuge for a variety of fish. Macroalgae had the greatest height of biota, especially on the ledges, but because the sampling was conducted in May with cold bottom water temperatures, the macroalgae heights more likely approximated minimum macroalgae structure as it appeared macroalgae had not begun to grow substantially (presence of new growth and/or reproductive structures), typical of the summer bloom (C. Buckel, unpublished data). Previous studies have identified the strong influence of natural temperature fluctuations on marine communities offshore NC (Wenner et al. 1983, Peckol and Searles 1984, Sedberry and Van Dolah 1984, Schoebend and Sedberry 2009). The seasonal sampling described below provides additional interpretation of benthic biological habitats, and specifically macroalgae and other shorter-lived and largely annual biotic habitat cover.

The splitbeam echosounder (SBES) surveys provided an additional view of the distribution of fishes across the large mosaic of seafloor habitat types throughout the study area as well as a comparison between fish distributions during day and night. Despite the lack of species identification in the echosounder data, the distribution of large fish detected by the acoustics were positively correlated to the visual observations, though only when compared in narrow spatial context. Similar to the visual surveys, higher densities of large fish were found over seafloor with higher slope and change in slope in the multibeam bathymetry surfaces, an indicator of high-relief ledges. Previous spatial modeling of large-scale distribution maps using SBES in coral reefs found similar patterns of high densities of large fish related to high rugosity and other descriptors of high seafloor complexity (Costa et al. 2014). But in coral reefs, the relationship of seafloor complexity to abundance of "medium" sized fish was less pronounced, except for the highest densities of medium-size classes (Costa et al. 2014). Very large schools of single or mixed species were observed on several occasions during our study and in previous surveys of mid-shelf hardbottom ledges (Kendall et al. 2009). These schools were observed using the ledges, ledge undercuts and even the watercolumn above the ledges.

The lack of clear relationships between habitat metrics and fish communities could also be related to the arrangement of habitats adjacent to the stations studied and the restricted daytime diver observations. Many species of fish use the complex reefs as refuge during the day and migrate out to low-relief pavement or softbottom sand to forage in the evening. We conducted surveys over visual assessment stations during the day and noted restricted distributions around hardbottom habitat features. A significant proportion of fish detected were within 150 m, but studies of hardbottom communities have documented fish moving more than 75 m onto the adjacent softbottom habitats to feed on macroinvertebrates buried in the sediments (Ambrose and Anderson 1990, Posey and Ambrose 1994). The night SBES surveys show a broad dispersal of fish away from hardbottom habitats, extending hundreds of meters from the edge of ledge habitats. The direction and magnitude of movement is likely related to the arrangement of habitats (Grober-Dunsmore et al. 2007). Tagging telemetry studies on coral reef fish have documented nocturnal movement of fish over specific habitat types related to species foraging preference (Hitt et al. 2011). Unfortunately, we were not able to definitively assign habitat types to the adjacent flat seafloor (e.g., sand or pavement). Further research is needed to determine the magnitude of movement of fish from hardbottom habitats and across the mosaic of seafloor habitats.

The socioeconomic value and perceived importance of hardbottom habitats are largely realized through the presence of large, apex predators, of which many are in the snapper-grouper complex. The species of the snapper-grouper complex in the southeast US OCS, have been managed collectively since 1983 with the Fisheries Management Plan (FMP) for the Southeast region by the SAFMC. The FMP considered the snapper-grouper complex as a mixed-stock fishery for species that shared similar habitat requirements (e.g., hardbottom), life history characteristics, and are harvested by the same fishing practices in the region using a limited set of gears. Many of these large bodied species play an important ecological function in maintaining long-term ecosystem stability. Large predators can shape the number, distribution and behavior of their prey. System-wide removal of large fish is common offshore NC due to commercial and recreational fishing that targets these keys species that often occur over hardbottom habitat. Fished systems are often skewed to smaller bodied organisms and report few apex predators. In comparison, remote systems protected from fishing are dominated by apex predators and large bodied fishes.

Black seabass (*Centropristus straita*) were one of the most common species encountered from the snapper-grouper complex. Whitfield et al. (2014) found a similar mean length during their four year study in Onslow Bay but a much lower mean site density of 1.22 ± 0.24 /100 m^2. *C. striata* are thought to prefer 9 – 20 m. range which is in the shallowest range of depths surveyed by Whitfield et al. (2014). Within this depth range, *C. striata* abundance was significantly related to benthic cover and descriptors of ledge morphology in Gray's Reef National Marine Sanctuary (GRNMS, Kendall et al. 2008). Kendall et al. (2009) also noted a negative relationship in the abundance of *C. striata* when other larger grouper species were present. High variation in abundance across stations coupled with interactions between species and depth of our stations likely complicated any pattern of habitat preference that could be discerned from our study.

Gag grouper (*Myctoperca microlepis*) are very popular among commercial and recreational fisheries. *M. microlepis* was encountered in significantly higher numbers at ledges in our study. The Onslow Bay study had a lower mean site density (0.82 ± 0.13 /100 m^2; N = 33/44) but a greater mean length (48.29 ± 3.77 cm TL). Kendall et al. (2009) found similar mean site density (1/100 m^2) and biomass (2.58 ± 1.07 kg/100 m^2) of *M. microlepis* at 92 ledge sites located in GRNMS. It is interesting to note that our findings are similar to the GRNMS study (Kendall et al. 2009) although there is no commercial fishing or spearfishing allowed inside the sanctuary boundaries.

4.2.2. Seasonal Dynamics Across Biological Communities in Hardbottom Habitats

In contrast to the May 2014 observations that indicated higher relief hardbottom supports different fish communities and more large apex predators, the seasonal assessments and comparison of natural and artificial hardbottom reefs in Long Bay and Onslow Bay were more nuanced, emphasizing the complex seasonal dynamics and interactions among physical structure, benthic biological communities and reef fish assemblages. The May 2014 surveys conducted in the study area captured a snapshot of fish distribution while the seasonal sampling represents a more comprehensive view of the complex dynamics over seasons.

Each fundamental metric of the fish community that was studied seasonally proved independent of increasing structural complexity. It should be noted that the sampling universe for these data included 16 sites that were distributed between Long Bay and Onslow Bay, eight of which were natural hardbottom. Fish associated with hardbottom reefs of NC may utilize the larger seascape of hardbottom reefs than just specific reefs of greatest complexity, and possibly on a seasonal basis. The scale of our observations and complexity measurements was at a fine scale relative to the size of the benthic habitat features. The repeated sampling over the season elucidated patterns in the benthic community assemblage linked to growing seasons, especially for macroalgae. When the pavements that were sampled during the seasonal surveys are exposed, they support a diverse community of benthic invertebrates, including sponges, tunicates, bryozoans, octocorals, and to a lesser degree, macroalgae. Because of their low-relief, these pavements are subject to burial by encroaching sediment. The low percent cover of benthos during winter and early spring may cause fish to concentrate around ledge habitats for areas of refuge. During summer and fall macroalgae goes through an intense growth period during which a broad spectrum of hardbottom habitats support varying biomass of macroalgae. The benthic biological cover may serve to add structural complexity to an otherwise low complexity physical habitat. This suggests that during times of low macroalgal cover, physical habitat relief may be more important to the fish community and conversely, during times of high macroalgal cover, habitat complexity is less important. It is also possible that because the measurement of complexity did not include the physical height of the ledges being sampled, the complexity measurements were restricted to a finer scale of structure that does not correspond with the scale of fish metrics.

The benthic community, and to some extent the fish community, on natural hardbottom reefs may operate as a ‘bottom-up’ system, in the sense that physical habitat characteristics influence the benthic community composition on a seasonal basis. On hardbottom reefs, structural complexity influences the degree to which changes in sediment cover are ephemeral or permanent. For example, on flat reefs where there are no obstacles to prevent sediment movement, sediment can alternately bury or expose hardbottom habitat. When the pavements that were sampled during the seasonal surveys are exposed, they support a diverse community of benthic invertebrates, including sponges, tunicates, bryozoans, octocorals, and to a lesser degree, macroalgae. On complex reefs, however, the topographic variation presents an obstacle to sediment movement, such that the surfaces of complex habitats are covered by only sparse dustings of sediment (Renaud et al. 1996, Riggs et al. 1998). As such, both complexity and sediment influence the benthic invertebrate and macroalgal distribution. Sediment cover was more ephemeral in study area than in southwestern Onslow Bay and the benthic community composition differed between these two geographic locations. This suggests that the benthic communities in study area, where the sedimentary landscape is more ephemeral, are more capable of handling the higher frequencies of burial and abrasion by sediment than those in Onslow Bay. Interestingly, the phyla that occur most frequently in study area are emergent colonial organisms, such as octocorals, hydrozoans, and bryozoans, while macroalgae dominated in Onslow Bay, a location with less physical disturbance by sediment scour.

4.2.3. Value of Shipwrecks to Hardbottom Reef Fish Assemblages

Because the seasonal assessments of hardbottom habitat also targeted artificial reefs, our results have implications for how future introduction of novel artificial structures, such as offshore wind energy infrastructure, may influence biota. Notably, we found that location-specific (study area in Long Bay vs. Onslow Bay) patterns in benthic community composition are not replicated on artificial substrates. Frequently, man-made structures in the marine environment can form stepping stones and connectivity corridors for benthic organisms (Petersen and Maim 2006, Zintzen et al. 2006, Glasby et al. 2007, Dafforn et al. 2012). For example, artificial reefs have been hypothesized to be stepping stones for invertebrates, such as jellyfish, that may be space-limited in their benthic phases to settle (Duarte et al. 2012). We hypothesize that artificial reefs could facilitate the colonization of certain benthic invertebrates and macroalgae across the two geographic locations in our study. Furthermore, invasive species, such as tunicates (Stachowicz et al. 1999), are also known to use hard substrates as corridors to facilitate their spread (Tyrrell and Byers 2007, Dafforn et al. 2012). The similar benthic community composition on artificial reefs located in these two Bays of NC suggests that these man-made structures may facilitate colonization of benthic populations. This result is important for offshore wind energy development because installing turbines in the offshore environment may favor biotic homogenization (McKinney and Lockwood 1999, Olden et al. 2004) of the benthic community on offshore artificial structures. We do not have enough information to understand whether this would have positive or negative consequences for the habitat value of these reefs.

One of the major differences in fish community composition between artificial reefs and natural reefs was driven by comparatively higher abundance of planktivores. This trophic guild feed on plankton in the watercolumn and are distinguishable from abundant schools of demersal species that were observed over natural hardbottom ledges. In a previous study, planktivorous fish foraged in high abundance above an artificial reef when current velocity was low and upstream of the reef when current velocity was high (Lindquist and Pietrafesa 1989). Moreover, there was often a patch of visibly calmer water on the surface above shipwrecks and some artificial reefs, suggesting that man-made structures may modify flow conditions surrounding wrecks to create these glassy areas on the surface (A. Paxton, personal obsservation). Together, the two studies and our personal observations suggest that man-made structures may concentrate plankton above or surrounding artificial structures perhaps by creating localized eddies that aggregate plankton. Additional research is needed to determine the physical and ecological mechanisms underlying the overabundance of planktivores on artificial relative to natural reefs. However, if it can be shown that artificial structures aggregate plankton, thereby promoting increased use by an abundance of planktivorous fish, then these structures may contribute to fish production through physical-biological coupling and providing abundant prey for large apex predators.

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6. Appendices

Available as supplemental material at
http://www.boem.gov/Appendices-2016-003-NOAA-Tech-memo-NOS-NCCOS-196/

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

The Bureau of Ocean Energy Management (BOEM) works to manage the exploration and development of the nation's offshore resources in a way that appropriately balances economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.

www.boem.gov

U.S. Department of Commerce
Penny Pritzker, Secretary

National Oceanic and Atmospheric Administration
Dr. Kathleen Sullivan, Under Secretary for Oceans and Atmosphere

National Ocean Service
Dr. Russell Callender, Acting Director, Assistant Administrator for Ocean Service and Coastal Zone Management

The National Centers for Coastal Ocean Science
Mary Erickson, Director

The National Centers for Coastal Ocean Science provides research, scientific information and tools to help balance the nation's ecological, social and economic goals. Our partnerships with local and national coastal managers are essential in providing science and services to benefit communities around the nation.
coastalscience.noaa.gov