12-5-2017

Geological Framework of the Continental Shelf of South Carolina Winyah Bay: Paleodrainage, Transgressions and Essential Fish Habitat

Amanda Roach
Coastal Carolina University

Follow this and additional works at: https://digitalcommons.coastal.edu/etd
Part of the Climate Commons, and the Geology Commons

Recommended Citation
https://digitalcommons.coastal.edu/etd/43

This Thesis is brought to you for free and open access by the College of Graduate Studies and Research at CCU Digital Commons. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of CCU Digital Commons. For more information, please contact commons@coastal.edu.
Geological framework of the continental shelf of South Carolina Winyah Bay:
Paleodrainage, transgressions and Essential Fish Habitat

By

Amanda Roach

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Coastal and Marine Systems Science in the School of Coastal and Marine Systems Science Coastal Carolina University 2017

Dr. Paul Gayes
Major Professor

Dr. Till Hanebuth
Committee Member

Dr. Jenna Hill
Committee Member

Dr. Chris Taylor
Committee Member

Dr. Michael Roberts
Dean, College of Science

Dr. Paul Gayes
Director of SCMSS
Dedication

Thank you mom for always believing in my dreams.
Acknowledgements

First and foremost, I would like to thank my graduate advisor, Dr. Paul Gayes. Without his constant encouragement and support throughout this process, I would not have been able to see this effort through to completion. Dr. Gayes went above and beyond his duties as my advisor, navigating me through the many obstacles I encountered in my journey through graduate school. I would also like to thank my committee members, Dr. Hill, Dr. Hanebuth and Dr. Taylor, for both your wisdom and humor throughout this process. I am forever in debt to the technical expertise of Dr. Hill and Shinobu Okano, thank you for teaching me a fraction of your computer wizardry skills. Coastal Carolina University is blessed with a faculty that makes our graduate program feel like a family, a special thank you to Julie Quinn, Karen Fuss, Thomas Mullikin and all of the other faculty members. This process would also not have been possible without the friendships I formed at Coastal Carolina University. Thank you to my fellow graduate students, especially, Sam Ladewig, Matt Kestner, Katie Bozza-Smith, Jon Petrigac, Aundrea Dolan, Karsen Schottleutner, Alison Schillfarth and Brittany Stockmaster, for providing me with necessary breaks from data processing and for your constant support. Finally, a huge thank you to Ryan Beale for being proud of me, especially when I am my own worst critic and for making the trip down to Conway, SC from Buffalo, NY to watch my defense.
Abstract

A regional geophysical survey of the inner continental shelf off central South Carolina was completed on a cooperative cruise between NOAA and Coastal Carolina University in July 2015. An integrated mapping suite comprised of subbottom echosounder, side scan, multibeam and split beam sonars was used to define the regional geologic framework, including paleodrainage patterns across the shelf and to identify potential fish habitat locations that will provide additional inputs to a thematic habitat mapping routine developed by NOAA. Results from the thematic mapper characterization suggest that large-scale framework elements such as paleochannel networks may play a role in determining benthic habitat distribution. A large paleo-fluvial valley associated with the ancestral Santee and Pee Dee River system has been observed in the subbottom data and correlates with broad topographic lows identified by the thematic habitat mapping routine. The collective dataset provides opportunity to locally evaluate and provide a basis to refine the regional habitat mapping routine. Overall, the thematic mapper generally picked inshore complex features but did not pick up smaller detailed areas. This is where sub bottom data can be used to refine the habitat modeling scheme. Additional geophysical surveys are needed to connect the onshore and offshore framework and to further refine channel fill geometries, bottom habitat and Holocene reworking of the shelf system.
# Table of Contents

List of Figures..............................................................................................................................................viii

Introduction

1.1 *Physical description of region*..................................................................................................................1

1.2 *Geological framework and the shelf habitat*..............................................................................................4

1.3 *Habitat mapping*........................................................................................................................................5

1.4 *Statement of problem*................................................................................................................................10

1.5 *Hypothesis*................................................................................................................................................12

1.6 *Study*........................................................................................................................................................13

Methods

2.1 *Geophysical survey plan*..........................................................................................................................15

2.2 *Data flow acquisition, processing and interpretation*...............................................................................16

2.3 *Integrated products*..................................................................................................................................20

Results

3.1 *Regional grid*............................................................................................................................................21

3.2 *Higher resolution areas*...........................................................................................................................22

Discussion

4.1 *Regional grid*............................................................................................................................................23

4.2 *Thematic habitat mapper and the addition of higher resolution datasets*.............................................24

4.3 *Comparison of different datasets (Fishery, ARA and Sub-bottom)*.........................................................27

4.4 *Expectations on Habitat*..........................................................................................................................30

Conclusion..........................................................................................................................................................31

Figures...............................................................................................................................................................33
List of Figures

Figure 1: Pleistocene and Holocene beach barrier complexes formed landward of the present shoreline. Coastal plain (brown) and Piedmont (blue) rivers dissect these barrier systems (Baldwin et al., 2004).

Figure 2: First-order structural components underlying the U.S. Atlantic continental margin as indicated by structurally positive platforms and structurally negative embayments and basins. The organization of Cretaceous and Tertiary units has been regionally influenced by the Mid Carolina Platform High and its axis, as indicated by the thick arrow (Baldwin et al., 2006).

Figure 3: Paleochannel groups of the Pee Dee River system identified beneath the Long Bay inner shelf and Grand Strand regions of South Carolina using seismic-reflection profiles and borehole data. Onshore contours illustrate elevations at the base of Quaternary sediments and is depicted alongside offshore elevations of paleochannel unconformities (Baldwin et al., 2006).

Figure 4: Core table from borehole 6005 located 22 nautical miles off Georgetown, SC.

Figure 5: Pleistocene scarps of the South Carolina coastal plain marked by the inland limits of their respective formations (Doar and Kendall, 2014).

Figure 6: NOAA’s thematic habitat mapper predictions along the Eastern US Atlantic shelf, according to the likelihood of presence (red) or absence (blue) of hardbottom habitat.

Figure 7: Operating area for the Nancy Foster research cruise and Grayscale of NOAA’s predictive model for hardbottom habitat along the Atlantic shelf. Tracklines (red) for this study were designed to follow drainage patterns. Detailed study areas (green) illustrate areas for planned groundtruthing of the thematic mapper.

Figure 8: Coastal Carolina University’s work flow for Side-scan Sonar processing.

Figure 9: Coastal Carolina University’s work flow procedure for Chirp Subbottom processing.

Figure 10: Chirp profile and interpreted section from inshore shore parallel line 10 off Cape Romaine, SC.
**Figure 11:** Actual Chirp lines (red) from present 2015 *Nancy Foster* cruise dataset, including inshore detailed study area (yellow) and further offshore detailed study area (red). Chirp data included from previous *Nancy Foster* cruise datasets (blue) and grayscale of hardbottom predictions from NOAA’s thematic habitat mapper, from the highest probability of hardbottom occurrence (black) to lowest probability for hardbottom occurrence (white). Locations of modern (Holocene) sediment cover have been mapped across the study area, everywhere the marine unconformity is not at the surface.

**Figure 12:** Chirp profile from inshore shore parallel line 20 off Cape Romaine, SC showing connectivity patterns to Chirp profile line 10.

**Figure 13:** Paleochannel incising larger paleovalley from chirp profile from inshore shore parallel line 18 off Cape Romaine, SC.

**Figure 14:** Actual Chirp lines (green) from present 2015 *Nancy Foster* cruise dataset, including inshore detailed study area (yellow) and further offshore detailed study area (red). Chirp data included from previous *Nancy Foster* cruise datasets (blue) and grayscale of seven groups of Paleochannels previously mapped along Long Bay by Baldwin et al., 2006. Paleochannel locations and depths from present study highlight paleosystem mapped off Murrells Inlet. Grayscale hardbottom predictions from NOAA’s thematic habitat mapper, from the highest probability of hardbottom occurrence (black) to lowest probability for hardbottom occurrence (white).

**Figure 15:** Further inshore detailed study area Reson 7125 bathymetric data (A) highlighting comparisons to the high and highest predictive occurrences for hardbottom habitat (B) and fish distribution (C), counted as the number of fish per 100 meter interval along the transect.

**Figure 16:** Further inshore detailed study area Reson 7125 backscatter (A) with actual chirp lines (green) mapped, shown comparatively to depth of marked paleochannel location (B), depth to marine unconformity (C), shown as depth of modern (Holocene) sediment and mapped fish locations, in number of fish per 100 meter interval (D).

**Figure 17:** Further offshore detailed study area Bathymetric imagery (A) shown comparatively to the high and highest (red) predictions of hardbottom habitat (B) from NOAA’s thematic mapper predictions, groundtruthing data (C) from drop camera surveys and fish density data (D) counted as fish per 100 meter interval.

**Figure 18:** Further offshore detailed study area Backscatter data (A), shown with bathymetrically derived ARA data (B) showing roughness of the seafloor, fish density data (C) counted as fish per 100 meter interval and depth of modern sediment cover (D).
Figure 19: Sidescan sonar imagery draped over bathymetry (above) and chirp profile and interpretation (below) offshore of Murrells Inlet (Denny et al., 2007).

Figure 20: Further inshore detailed study area Backscatter data (A), shown comparatively to ARA (B) seafloor roughness, fish density data counted as the number of fish per 100 meter interval (C) and depth of modern sediment (D).

Figure 21: NOAA’s PCA analysis, breaking down the bathymetric data into red, green and blue bands based on rugosity, slope and curvature profile.

Figure 22: Seafloor characterization (A) of the further inshore detailed study area using polygon features. The number of fish per 100 meter interval (B) were counted according to distance to polygon features and seafloor characterization was compared to groundtruthing data (C) and predictions of the high and highest (red) predictions of hardbottom presence (C).

Figure 23: Fishery density data, categorized as number of fish per 100 meter interval, according to distance to polygon features used to classify seafloor habitats in the further inshore detailed study area.

Figure 24: Surficial geologic map of the inner shelf of Long Bay from Little River Inlet to Winyah Bay based on Baldwin and others (2004). (Denny et al. 2007)
1. Introduction

1.1 Physical description of region

This study seeks to improve habitat map prediction along the Southeastern Atlantic shelf, which has proven to be limiting based on spatial scale, map resolution and regional framework characteristics. The inner continental shelf of South Carolina is typically a sediment limited system (Gayes et al., 2002, 2003; Ojeda et al., 2004; Doar and Kendall, 2014). This region is largely defined by low relief, covered by a discontinuous veneer of sediment, which often allows for the outcropping of underlying Cretaceous/Tertiary strata and exposure of paleochannel fill (Wright et al., 1999; Ojeda et al., 2001; Baldwin et al., 2004, 2006). Previously, large amounts of sediment were delivered to the coast of South Carolina by the Pee Dee River system, mainly originating from the Piedmont and Appalachian Mountains (Hayes, 1994; Baldwin et al., 2004, 2006). As sea level fluctuated in the Pleistocene Epoch, beach barrier complexes formed landward of the present shoreline (Figure 1) (Colquhoun, 1965 and 1968; Colquhoun et al., 1972; Dubar et al., 1974; Baldwin et al., 2004, 2006). These barrier complexes strongly impacted subsequent depositional and drainage patterns over multiple regressions and transgressions, generally redirecting rivers in the northern coastal zone of the state parallel to the coastline before entering the sea south of their previous location (Baldwin et al., 2004, 2006).

Presently, the Waccamaw, Pee Dee and Black Rivers have been diverted to the south by the Myrtle Beach barrier complex, with a shared confluence at Winyah Bay (Figure 1) (Baldwin et al., 2004). As one of the larger tidal estuaries along the
southeastern Atlantic coastline, Winyah Bay receives discharge from a ~47,060 km² basin (Baldwin et al., 2006). While this system is the second largest source of fluvial sediment in the Georgia Bight, which extends from Cape Fear, NC to Cape Canaveral, FL, recent estimates have suggested that only ~20% of the fine-grained sediments supplied to Winyah Bay ever reach the open coast (Baldwin et al., 2006). The majority of these sediments become trapped by dams in the Pee Dee River or remain within the bay, including the main navigation channel to Georgetown Harbor, adjacent mud flats and marshes (Hayes, 1994; Patchineelam et al., 1999).

Several sources of local sediment to these sediment-starved coastal regions have been suggested, including the erosion of hardgrounds within Long Bay (Gayes et al., 2003; Ojeda et al., 2004). Offshore relic geological units have similarly been identified as a potential sediment source to an adjacent system nearby Onslow Bay (Riggs et al., 1996).

The location and trend of the Pee Dee River system, up to its present location at Winyah Bay, has been indirectly affected by structural influences associated with the Mid-Carolina Platform High (MCPH), also known as Cape Fear Arch (Figure 2) (Baldwin et al., 2006). The Mid-Carolina Platform High dominates the regional framework of the southeast U.S. Atlantic margin, comprised of a NW-SE trending Paleozoic crystalline basement high extending from Cape Lookout, North Carolina to Cape Romain, South Carolina (Mallinson et al., 2010; Van der Plassche et al., 2014). The underlying framework of variably erodible, tilted rocks produced by these regional structures afforded a southerly dipping gradient, which in turn exerted control of the system. Migration of the ancestral Pee Dee River system has resulted
in a shift in sediment supply from Pee Dee River derived sediments to the reworking of ancient deposits along the inner shelf and shoreline by erosion (Baldwin et al., 2006).

The location, elevation and trend of ancient channels can be inferred onshore by mapping unconformities at the base of Quaternary sediments and offshore by closely spaced seismic profiles. By spatially combining this data found beneath the lower coastal plain and adjacent inner shelf, seven distinct paleochannel groups of the Pee Dee River system were able to be reconstructed within the Long Bay and Grand Strand region of SC (Figure 3). Temporal development of these channels reveals a lateral, southwestward migration of the system between the late Pliocene and present. The chief driving mechanism for this migration is most likely barrier-island formation as a result of fluvial and shoreline processes interacting during sea-level high stands (Baldwin et al., 2006).

In the summer of 1976, the USGS drilled boreholes at 19 sites across the Atlantic continental shelf and slope, as part of the AMCOR program, to assess offshore resources. This included site 6005, located 22 nautical miles offshore from Georgetown, SC, which falls within this study area. This site was chosen at the minimum depth required for drilling, 18 meters (60 feet), in order to verify regional stratigraphy more extensively mapped onshore. At this site, 6 cores in total were recovered, for a total cumulative penetration of 48 meters (Figure 4). The lithology consisted of approximately 20 meters of Holocene/Pleistocene sand above dark gray calcareous clay and limestone. Tie lines across this published borehole were
selected to provide opportunity to establish validation of known stratigraphic contacts with reflectors mapped in this study.

1.2 Geological framework and the shelf habitat

The evolution of the continental shelf refers to broad-scale changes to the region and the influence this development has on processes over several temporal and spatial scales. Global climate change over tens to hundreds of thousands of years has driven sea level fluctuations, which in turn has impacted the geological framework (Barnhardt et al., 2007). Periods of lower sea level experienced deep fluvial incision of the exposed coastal plain and continental shelf and seaward shoreline deposition (Schwab et al., 2009; Mallinson et al., 2010). The inner shelf becomes submerged when sea level rises and erosion by currents and waves generally flattens the topography. Ancient shorelines are partially preserved as Pleistocene scarps, deposited during sea level high stands, moving lower in elevation towards the modern coast over time (Figure 5) (Doar and Kendall, 2014). This becomes important as the evolution of coastal regions is influenced by the antecedent geology of the inner-continental shelf. The availability of coastal sediment resources is heavily influenced by the erosion of the underlying framework and availability of transgressive sand deposits (Schwab et al., 2014).

In such sediment starved settings, older relict deposits and geologic units frequently exist at or near the sea floor (Baldwin et al., 2006). In the region, outcropping of competent older substrate is referred to as “hardbottom”. These indurated substrates can afford a stable foundation supporting attached invertebrates such as soft corals and sponges and are managed as “Essential Fish
Habitat” because of their importance in supporting concentrations of commercially and recreational fishery species (Diaz et al., 2004). On the mid to outer continental shelf of South Carolina, hardgrounds are typically patchy but with moderate to high relief. On the inner shelf, however, outcropping older substrates are typically patchy and eroded to relatively low relief by successive transgressions.

1.3 Habitat mapping

As the needs of resource managers expand, interests in understanding the complexity of the seafloor environment become more apparent. Developments in seabed-mapping techniques have allowed researchers to take a closer look at the state of living resources by generating benthic habitat maps (Diaz et al. 2004). However, translating bottom substrate characteristics into meaningful habitat maps has led to some confusion as to the definition of habitat (Diaz et al., 2004; Brown and Collier, 2008). Habitat is the place where a plant or animal is normally found. Seafloor mapping techniques generally define the environment in terms of physical properties of the substrate, which is then equated to habitat (Diaz et al., 2004; Brown and Collier, 2008). However, substrate only becomes habitat when combined with the preferences and tolerances of species (Diaz et al., 2004). Thus, the concept of benthic habitat mapping combines the physical properties and dynamics of the bottom with the biological characteristics of species (Diaz et al., 2004; Brown and Collier, 2008). This has led to the realization among geologists and biologists about the importance of collaboration in order to produce meaningful habitat research (Valentine et al., 2003).
Often times, marine conservation planners have used hardgrounds as proxy for habitat, as these areas support marine biodiversity (Dunn and Halpin, 2009). Hard bottom habitat constitutes a variety of structures, including “live coral, rock/coral rubble, exposed low-profile carbonate and phosphorite substrates, thinly covered pavement-like hard substrate with emergent growth, or artificial structures,” all of which support important recreational and commercial fisheries (Dunn and Halpin, 2009; SEAMAP-SA 2001). With the emergence of the Sustainable Fisheries Act of 1996, federal mandates to protect Essential Fish Habitat (EFH) become ever more apparent, and so was the need to be able to quantify EFH or hardgrounds (Rosenberg et al., 2000). In this sense, Essential Fish Habitat is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity” and policies surrounding EFH have directed the identification and protection of such habitat (Rosenberg et al., 2000; Diaz et al., 2004).

Policies surrounding the management strategy surrounding Essential Fish Habitat are broad in definition. Protecting these areas requires the development of a classification system based on a multitude of variables, including both the quantity and quality of aquatic habitat, with respect to various temporal and spatial scales (Diaz et al., 2004). This is no easy task and a universal set of guidelines for producing benthic habitat maps does not exist. While the advent of seafloor mapping technologies has increased the ability to quantify marine habitat based on bottom type and aereal extent, it is in the interpretation of these characteristics which corresponds to meaningful representations of habitat quality (Diaz et al., 2004). Habitat quality takes into consideration the biological tolerances and
preferences for species with respect to the physical structure and dimension of substrate which is used to quantify benthic habitat. Within this context of benthic habitat mapping is the importance of relief for classifying the quality of hardbottom habitat. The inner continental shelf of South Carolina is an expansive area of low relief, with a limited sediment budget, often allowing for the outcropping of hardbottom. The classic sense of classifying habitat puts more emphasis on high relief structures, which tend to be found further offshore. Thus, understanding the geological framework of the region is important for determining an appropriate strategy for capturing the range of habitats in the study area.

Prior to any study, the objectives and available resources need to be determined in order to choose a suitable scale. A wide variety of instrumentation exists to ensure complete coverage of the seafloor over a range of spatial scales and resolutions. The goal of any benthic habitat study should be to determine a suitable scale for sampling and use the collected data to produce maps that are meaningful to resource managers (Diaz et al., 2004). However, advances in seabed mapping techniques are relatively new and the budget, time and effort required to carry out such mapping efforts, at a resolution and spatial scale necessary for managing resources, is usually lacking.

The objective of each habitat mapping project will dictate the approaches and technologies employed to acquire information. Methods that have their roots in traditional seabed geologic mapping generally define benthic habitats in terms of bottom characteristics that are preferred substrate for plants and animals (Diaz et al., 2004). In this manner, modern acoustic survey techniques (bathymetry and
backscatter) characterizing the topography and sediment texture of the seafloor can form the backbone of a benthic habitat project when combined with biological interpretation (Diaz et al., 2004). Using geophysical techniques to map wide swaths of the seafloor allows for spatially continuous data, which is often combined with direct biological sampling to validate the acoustically derived seabed imagery (Valentine et al., 2003; Diaz et al., 2004). Determining the proper suite of technologies becomes important when considering the coverage and resolution necessary for the study. For example, while multibeam sonar surveys cover large areas of the seafloor relatively quickly, sidescan sonar surveys produce higher resolution seafloor images but lack elevation data in most cases (Valentine et al., 2003). Typical map products include topographic relief, seabed reflectivity (backscatter) and sediment types which can be further interpreted to characterize the sea floor based on the distribution of habitat types (Valentine et al., 2003).

While the advancement of seabed mapping technologies has greatly increased the spatial coverage and resolution of benthic habitat maps, this has resulted in interpretations of benthic habitat as inferred or modeled (Diaz et al., 2004). Mapping schemes generated to capture the spatial scale necessary for the objective of the study has led to fewer groundtruth points and in return less data is collected to directly link species tolerance and preferences to a particular bottom type. Fine-scale surveys linking biological distribution to physical seabed characteristics are well established but expanding this effort to broader spatial scales has proven to be difficult.
Bathymetric data has proven to be a useful tool to predict fish distributions, based on water depth and topography of preferred habitat (Costa et al., 2014). However, only a small percentage of coastal and continental shelf waters have been mapped. Conversely, direct methods for habitat mapping characterized through the deployment of diver and video observations, yield high confidence in the presence of habitat, these methods are poor at covering spatially distributed habitat, such as patchy but ecologically important habitat. Modeling predictions of the presence or absence of habitat could prove to be a useful tool for resource managers, in order to direct mapping efforts to critical habitat areas for large fish, as well as to eliminate large areas of the seafloor that do not need further mapping. NOAA has developed a predictive habitat model based on a coarse 90-meter pixel bathymetric dataset, from the National Geophysical Data Center Coastal Relief Model (Divins and Metzger 2003). The thematic habitat mapper predicts the likelihood of hardbottom occurrence in southeast U.S. Atlantic Ocean waters where limited to no fishery density data exists (Figure 6) (Dunn and Halpin 2009). Hardbottom in this case is used as a proxy for habitat, as it often supports marine biodiversity. Rugosity has been directly linked to reef fish diversity and predictor variables of rugosity (roughness of the seafloor), derived from bathymetric data, were used to generate a best regression model based on the ability to predict the presence or absence of hardbottom habitat. This model was found to have a predictive capability of 70%, as compared to random picks alone.
1.4 Statement of problem

Inherent in the definition of habitat is the idea of habitat quality with regard to substrate and biological cover of a particular location. In its simplest form, relief and/or abundance of invertebrate communities has often defined quality of habitat. Habitat models and classification schemes for mapping benthic habitat are often biased towards relief, as ledges and outcrops provide cover for species. Areas of low relief, expansive in aereal extent, are often not classified as high quality habitat but this may result in important resources being overlooked. High quality habitat may also be patchy and heterogeneous. Ecologically significant, expansive areas of coastal habitat are an important resource to study, as these areas are increasingly threatened by anthropogenic and natural global changes, including rising sea levels and temperatures, dredging, and overfishing (Seitz et al., 2013).

Collecting spatially rich datasets to assess fish abundance and diversity has been a challenge until the recent advent of split beam and other fishery sonars. Conventional fine scale fishery surveys (< 100m^2) typically employ SCUBA or drop cameras but these direct observations are limited by water depth, turbidity, time of day, transient nature of fish and do not cover a spatial scale necessary for marine management purposes (Costa et al., 2014). The demand for fishery data covering broader areas of the seafloor (10 s to 100 s km^2) has led to the more frequent use of splitbeam echosounders to map fish densities in real time. Fish are mapped according to size (large, medium, small) by a rapidly transmitted acoustic signal, which bounces off the swim bladder of fish in the water column. Although splitbeam echosounders are an improvement to in situ fish surveys, it still has a limited
footprint. While multibeam echosounders, often run simultaneously with fishery acoustics, have a typical swath of about $120^\circ$, splitbeam echosounders only cover only about a $7^\circ$ swath (Costa et al., 2014). There is also a temporal component to SBES which must be considered, as fish aggregations are transient and reside in different habitats depending on several environmental factors, including time of day.

A number of efforts to employ spatially rich data sets focus on widely available, consistent data types. Publically available bathymetric datasets cover broad areas of the Atlantic continental shelf but it is at a fairly coarse scale (90 m resolution) relative to the range of scales of habitat (e.g. individual outcrop or patches of outcrop). Ultimately, the resolution and coverage of the technologies employed will dictate habitat description. Broad scale surveys, ensuring complete coverage of the seafloor, such as sidescan sonar or multibeam, will provide information on substrate and sediment but the resolution of coverage will determine the detail of the bottom type. Coarse resolution datasets form the basis of important baseline maps to direct further study, such as the National Geophysical Data Center Coastal Relief Model, but are not at resolutions applicable to marine management. The addition of higher resolution datasets will add necessary detail about substrate and groundtruthing methods, such as camera drops and sediment grabs, will add biological detail, in addition to fishery acoustics.

Furthermore, the addition of a third dimension to mapping schemes can provide important detail for interpreting habitat. Chirp sub-bottom profilers map the shallow geologic framework and can detect sediment cover at $\sim0.5$ m vertical
resolution, which can improve the detection of low-relief hardbottom habitat being present or exclude broad areas of the seafloor as potential habitat. Understanding the geological framework of the region is essential for accurately characterizing the physical features of habitat, which can then be synthesized with additional datasets such as multibeam backscatter, bathymetry and fishery acoustics, to capture all of the physical and biological characteristics that make up benthic habitat. Since habitat are outcropping of geologic framework, integrated framework mapping can help narrow down areas where hardbottom habitat may be likely or unlikely to be present.

While higher resolution data types will provide greater detail to habitat maps, these tools are still limited by water depth. Shallow water, which tends to not have as high relief features, is not easily mappable and takes relatively more time than offshore sites. Data collected further offshore tends to yield quicker, higher resolution datasets. There is a need for increased benthic habitat mapping in areas along the inner shelf, as these areas are not as readily mapped as their offshore counterparts but are potential areas of extensive essential habitat.

1.5 Hypothesis

The use of coarse 90-meter resolution bathymetric data is likely to give a good regional scale projection of the probability of the presence or absence of hardbottom habitat but not on a detailed scale suitable for fisheries management and regulating sites for wind development, beach nourishment and dredge material disposal. By integrating higher resolution data sets with the basis of the thematic mapper, higher resolution habitat maps are projected to be generated displaying a
patchy distribution of habitat. While offshore habitats tend to be comprised of relatively high relief ledges and quality outcrop, inshore hard bottoms are most likely extensive in aerial extent but of much lower relief and different biological importance (Baldwin et al., 2006). NOAA’s thematic habitat mapper is biased towards rugosity, which is why the continental shelf edge produced high habitat likelihoods for habitat and coastal regions appear devoid of hardbottom (Figure 6). Furthermore, areas where hardbottom is present but low fish density exists may be due to a thin sand veneer on top of the hardbottom. This is where looking at the marine unconformity and sediment thickness above the unconformity (modern sediment cover) in the sub-bottom data becomes useful. Finally, a clear association is expected between the location and extent of essential fish habitat and interfluve areas where older materials supporting hard grounds may most likely be found. Paleochannels are less likely to provide habitat as this rocky material has been incised. Adding this dimension should help refine particularly where bathymetry is complicated by antecedent and modern processes.

1.6 Study

A cooperative project between NOAA National Marine Fisheries and Coastal Carolina University Center for Marine and Wetland Studies was developed to test the spatially broad but relatively low resolution regional thematic habitat mapper against a limited but higher resolution geophysical survey (Figure 7). This allowed for the incorporation of multiple sensors and techniques to assess the regional thematic mapper and improve the resolution of habitat maps. In addition to surficial characteristics provided by multibeam bathymetry (relief) and backscatter
(hardness), chirp sub-bottom profiling was included to provide incorporation of a third-dimension. The capability of chirp to contribute to refining habitat mapping was examined by identifying three components; clearly outcropping strata, areas where the surficial sediment veneer is below the resolution of the profiler and outcropping is possible but may not be of high relief and areas where near surface indurated strata are clearly incised and outcropping hardbottoms are highly unlikely but may exhibit relief in the form of sedimentary bedforms, sand waves or relict deltas.

This cooperative project also provided an opportunity to undertake a reconnaissance scale mapping of the paleodrainage system of the South Carolina shelf with direct applicability to habitat mapping. Lines were plotted to cross previous borings in the area to provide geophysical validation of sub-surface interpretations and stratigraphy. An effort was then made to match up offshore drainage identified in the sub-bottom data with onshore mapping that had been previously collected (Figure 3). There was also an opportunity to map paleochannels using sub-bottom data from three cruises previously completed by Coastal Carolina University and connect these drainage patterns to those mapped on this most recent effort. This allowed for an integrated paleodrainage map for the central South Carolina shelf and coastal plain.
2. Methods

2.1 Geophysical survey plan

The National Oceanic and Atmospheric Administration (NOAA) ship *Nancy Foster* was employed for 16 days at sea (July 8-24 2015), operating offshore of South Carolina, from Awendaw to North Myrtle Beach (Figure 7). A regional scale geophysical survey including side-scan, multibeam and chirp sonars was completed to define the geological framework of central South Carolina from the near shore to the edge of the continental shelf. A broad rectilinear grid of tracklines was designed to complete along shelf and cross shelf tracklines to frame the paleodrainage systems across the width of the shelf. Additionally, two detailed study areas were chosen to assess the accuracy of the Thematic Habitat Mapper.

Leg one of operations followed large-scale (~150m) alongshore tracklines off Winyah Bay. The survey plan during leg two navigated certain tracklines to ensure 110% bottom coverage in the detailed areas of study. In total, these geophysical surveys collected 2140 km multibeam, 505 km sidescan and 1140 km chirp. In tandem with geophysical data collection, the ship’s splitbeam echosounder collected fishery acoustics, 24 hours per day, except during small boat deployment and retrieval. Leg two of operations included drop camera surveys to groundtruth seafloor habitat types based on side scan and multibeam surveys, as well as to validate statistical predictions of hardbottom habitat locations. Additionally, chirp data from three previous *Nancy Foster* cruises was imported for interpretation.
2.2 Data flow acquisition, processing and interpretation

Multibeam

A suite of remote-sensing techniques were employed to map the primary components of the geological framework of the region, including seafloor topography and surficial and subsurface geology. Bathymetry was collected using two hull mounted multibeam systems, Reson 7125 or Kongsberg EM710, depending on water depth. A series of pulses are emitted from the transducer of the instrument, in a narrow band (swath) and the angle, travel time and intensity of acoustic return are measured and recorded. The angle and time of return are used to calculate water depth and generate highly resolvable images of seafloor bathymetry. The backscatter intensity of return is a measure of the hardness of the seafloor. Hardbottom will have a high intensity return signal, as most of the sound will reflect off the bottom surface and will not be absorbed by soft sediment.

Onshore study areas were mapped using the Reson 7125 dual frequency (200/400 kHz) multibeam system, producing a 128° swath. Areas further offshore were insonfied using the Kongsberg EM710 multibeam system, pinging at a ~100 kHz frequency, with a swath width of 140°. While the Reson multibeam system did yield high resolution data sets, this system was limited by water depth and did not produce as wide as a swath as the offshore system.

Multibeam bathymetric data was cleaned and initially processed on board the Nancy Foster using CARIS HIPS 9.0 hydrographic processing software. Depth corrections were made for latency, roll, pitch, sensor offsets, yaw, draft, tides and changing sound speed in the water column. Once the data was cleaned and outliers
in individual lines were removed, a bathymetric surface was generated using a
CUBE algorithm and soundings (xyz) from this surface were exported as xyz text
files. Multibeam data was initially processed to derive surfaces to identify the
locations for the upcoming day’s drop camera groundtruthing survey. After the
cruise, the bathymetric surface files were imported into Fledermaus Dmagic 7.4 to
create digital elevation model (DEM) grids for export into ArcGIS. Final surface
models, soundings and derived products are all relative to NAVD88 vertical datum.

Multibeam backscatter, a measure of the intensity of signal captured by the
instrument’s receiver, was processed post-survey using CARIS HIPS 9.0 and
Fledermaus Geocoder Tool (FMGT). In CARIS, the .HSX multibeam data was
exported to .GSF format using the export wizard. These .GSF files were then used in
FMGT to extract navigational information for each survey line. Reson 7125 HYPACK
.7k files were converted to .s7k format in FMGT by pairing .7k files with
corresponding .GSF files. Kongsberg EM710 .all files did not need to be paired with
navigational information in order to bring them into FMGT. These merged files and
.all files were then processed in FMGT using ARA and statistics to generate a
backscatter mosaic. These surfaces were exported as .asc files using FMCommand in
order to bring them into ArcGIS.

Sidescan

Coastal Carolina University’s Klein 3000 dual frequency (100/455 kHz) side
scan sonar was utilized as this system typically covers 190-200 meter swath widths
in shallow shelf settings, allowing for complete reflectivity coverage. This system
measures surficial geology by ensonifying the seafloor through a series of acoustic
pulses. The data collected by the side scan sonar was processed with Xsonar software developed by USGS Woods Hole Science Center. CCU’s standard workflow was followed for side scan sonar processing (Figure 8). The data was demultiplexed before merging navigation and sonar data. Overlapping swaths collected in the detailed study areas created a composite image. Mosaics were then output as geotiffs (25 cm pixel resolution) for import to ESRI ArcGIS.

Chirp systems image the subsurface by recording reflections produced by changes in acoustic impedance (density and seismic velocity) of different types of strata. Chirp data were acquired using CCU’s Edgetech sb512i Chirp sub-bottom profiler with Edgetech Discover acquisition software. The vertical resolution (40-50 centimeters) and sea floor penetration (10-50 m) of CCU’s Chirp sub-bottom profiler has consistently produced high quality images of the shallow sub-surface and surficial stratigraphy of this region. Chirp sub-bottom data was processed using Seismic Unix and SIOSEIS software packages. CCU’s workflow procedure was followed for Chirp processing (Figure 9). Sub-bottom data were trace balanced and heave corrected to reduce noise. Depth corrections were also made to the final processed data to account for tidal differences in water depth and fish depth in the water column. Tow-fish depth was approximated by correlating measurements of the seafloor depth collected in the sub-bottom data with those made by the georeferenced multibeam system. Chirp data was recorded in two-way travel time (TWT) and an average sound velocity in seawater of 1525 m/s was generally used to convert TWT to depth (e.g. Depth = (TWT * 1525 m/s)/2). Corrected sub-bottom
data was imported to The Kingdom Suite software for interpretation. Key surfaces mapped included the base of sediment and seafloor reflectors to create an isopach sediment thickness map, the trangressive and presumed modern marine unconformity and the base of incision of paleochannels and paleovalleys. These surfaces were then exported to ArcGIS.

Fishery Acoustics

Parallel to these efforts, NOAA collected fishery acoustics and drop camera surveys. The ship’s Simrad EK60 Splitbeam echosounder (38/120/200 kHz) was run alongside geophysical technologies to log fishery acoustics. The SBES works by transmitting rapid acoustic signals, which are reflected off the air bladders of fish in the water column. This tool is not able to discern individual species type but it does work off detecting different densities, allowing for fish to be categorized into large (>29 cm), medium (12-28 cm) and small (< 11 cm) fish. Splitbeam echosounder data was processed using Echoview software. Acoustic signals from the water-seafloor interface, air bubbles and faint echoes from non-fish targets and plankton were eliminated from the dataset. The splitbeam data is GIS referenced and each individual fish detection was assigned a GPS point, depth in water column and target strength. Target strength is used to determine fish length, to categorize the fish based on size. The density (total number) of fish, for each size class, were counted along the tracklines, in 100 meter intervals. This processing was completed by NOAA’s NOS Beaufort Laboratory, to which access has been granted to this dataset, which can be referenced in ArcGIS (Costa et al., 2013; Personal communication, Dr. Chris Taylor, Dr. Erik Ebert).
2.3 Integrated products

Angular Range Analysis (ARA) was run on raw bathymetric files using FM Geocoder (FMGT). Angular information was extracted from the multibeam backscatter data in order to estimate seafloor properties, including acoustic impedance, roughness and grain size. Principal Component Analysis (PCA) stacks multiple complex seafloor surfaces into a single image with multiple bands and breaks down the image into three principle components by removing redundant information and incorporating information that best characterizes the seafloor. PCA was run to segment bathymetric data into three principle components based on slope, rugosity and the curvature profile. In addition, the seafloor was mapped by digitizing polygons, with boundaries defined by changes in seabed roughness and/or slope as indicated by multibeam backscatter and bathymetry and geomorphic features derived from sub-bottom data. Appropriate nomenclature was adopted to characterize the seafloor based on terms used in NOAA NOS Beaufort Laboratory's parallel processing of this dataset; high relief ledges, low relief/mixed hardbottom and sand with no indication of biological/attached cover (Personal communication, Dr. Chris Taylor). Polygon features were categorized as smooth and rough edge sand ridge, complex seafloor (potential hardbottom), paleochannel and trough. Seafloor habitat features could then be related to the water column biomass of fishes. A statistical analysis of the distance to polygon classes, according to fishery density counts, was run in ArcGIS using feature class attribution.
3. Results

3.1 Regional grid

A representative Chirp line (NF1506_10) running parallel to the coast off Cape Romaine, SC, at about 15 meters water depth (TWT 0.02), was selected to illustrate some of the key reflectors that were identified and mapped throughout the study area (Figure 10). The marine erosional unconformity (green) is a primary reflector of interest to this study. This surface represents the transgression of coastal deposits with rising sea level forming a characteristically planar, flat-lying, regionally mappable reflector separating older antecedent deposits from post-transgression modern sedimentation. Where it is at the sea floor, older, often indurated deposits are directly exposed at the seafloor. In other areas, a thin veneer of modern sediment is observed separating older unconsolidated sediments such as might be expected within paleochannel fills or indurated Tertiary or Cretaceous deposits (Figure 10). Discernable thicknesses of modern sediment is most commonly found associated with paleochannels and locations of retreat of large tidal inlets and hold a lower likelihood of the presence of hard bottoms and essential fish habitat being present. Modern (Holocene) sediment is observed as a relatively transparent unit extending from the sea floor to the marine unconformity, characteristic of sediment cover throughout the study area (Figure 11). Where modern sediment exists, it is often only a thin veneer of sand (>0.5m), constantly being reworked by modern processes.

Well-defined paleochannels were identified by the geometry of the base of the channel and channel fills, which forms a characteristic channel and flood plain...
geometry. Channel fills are frequently observed to exhibit inclined progradational internal reflectors downlapping to either the base of the channel incision or locally smaller cuts and fills within the larger channel complex. Successive channel geometries are highlighted in line NF1506_10 and parallel adjacent line NF1506_20 (Figure 12), constraining the paleodrainage across the shelf in this region. Multiple incisions were also mapped in the sub-bottom dataset, as paleochannels incised larger paleovalleys during fluctuating sea levels (Figure 13). The two-dimensional geometry of this reflector typically forms a characteristic channel form with a main more deeply incised channel and where preserved broad shallow flood plains. A paleodrainage map of the inner continental shelf, integrating paleochannels mapped in the present study and paleochannels previously mapped along Long Bay by Baldwin et al (2004), reveals a large, SE trending, ancient fluvial system off Murrells Inlet (Figure 14).

3.2 Higher resolution areas

In addition to the regional study, an inshore and offshore detailed study area (Figure 7) were chosen to ensure complete bottom coverage in order to compare hardbottom predictions identified by the thematic habitat mapper to geophysical datasets and groundtruthing. Both detailed areas were chosen for further study as the habitat mapper had predicted these regions to possess extensive habitat. The further inshore detailed region has characteristic topographic highs (ridges) adjacent to steep sloping bathymetric lows (troughs) (Figure 15). The densest areas for fish (14-39 fish/100 M) aggregations occur along these ridges (figure 15), where slope is the greatest, generally where the thematic habitat mapper predicted the
highest probability of the presence of hardbottom habitat (figure 15). Additionally, two distinct paleochannel groups (figure 16) were mapped in this further inshore detailed area. The marine unconformity is coincident with the seafloor overtop these channels (figure 16) and high densities of fish (14-39 fish/100 M) flank the channel where hardbottom outcrops at the surface (figure 16).

The high and highest predictive occurrences for hardbottom habitat, according to NOAA’s habitat mapper, appear towards high relief offshore areas (figure 7). The detailed study area located further offshore (figure 17) was predicted to have extensive hardbottom habitat but groundtruthing data from drop camera surveys revealed only sand (figure 17). Chirp data was limited in this area but where it was present, revealed a layer of sand, 0.5 to 8 meters thick (figure 18). Additionally, this region had markedly low fish density (1-3 fish/100m) (figure 18).

4. Discussion

4.1 Regional grid

NOAA’s thematic habitat mapper predicts both the presence and absence of hardbottom habitat. Areas between hardbottom habitat (interfluves) represent the downcutting of ancient fluvial systems into Cretaceous and Tertiary shelf strata during sea level low stands (Baldwin et al., 2006). The channels are backfilled with Pleistocene sediment during subsequent transgressions (Baldwin et al., 2006) and this unconsolidated channel fill does not afford for the attachment of invertebrates. The large paleochannel group extending offshore of Murrells Inlet (figure 14) was mapped in the region between hardbottom areas (interfluves). Choosing tracklines to capture the paleodrainage of the study areas, based on regions between the high
and highest predictive occurrences of hardbottom, appears to be good way to direct the study. There are instances where the mapped location of a paleochannel is in a region predicted to have a high probability for the presence of hardbottom habitat and this may be due to the cementation of channel fill. Additionally, no paleochannels were mapped from the sub-bottom data on the outer continental shelf. This may due to an original shallow channel geometry possibly resulting from the hardness of the seafloor that was completely reworked during the transgression or the ability of the chirp to penetrate older, indurated layers.

Underlying channels and Cretaceous strata are buried by surficial sediment and truncated by this transgressive surface seen throughout the study area. A chirp seismic-reflection profile (Figure 19) off the coast of Murrells Inlet reveals >1m of relief and modern sand cover above the transgressive surface across the inlet shoal complex (Denny et al., 2007). Adjacent to this inlet shoal complex are smaller scale features (shore-oblique and low relief ridges) and exposure of underlying channel fill where there is little to no modern sediment cover. Similar profiles can be seen along lines further offshore of Winyah Bay on the 2015 Foster data set. A chirp profile and interpreted section (figure 11) from an inshore shore-parallel line off Winyah Bay reveals small scale ridge-like features, separated by areas of thin Holocene sediment cover. Underlying Pleistocene channel fill deposits are exposed at the surface in areas where modern sediment cover is not present.

4.2 Thematic habitat mapper and the addition of higher resolution datasets

NOAA’s thematic habitat mapper is based on 90-meter pixel resolution bathymetric data, a publically available dataset spanning the US Atlantic shelf. This
is a useful tool for predicting the probability of hardbottom habitat but applying this information for use in reconnaissance scale regional mapping efforts, such as the present study, has inherent challenges. Low-resolution bathymetry allows for broad scale coverage, such as the eastern US continental shelf, but a regional scale mapping requires higher resolution bathymetry in order to yield data applicable to the objectives of resource managers. Ninety-meter resolution bathymetry will pick up on high relief but low-relief areas, which may be equivalent in biological importance, will most likely not be identified by a model based on low-resolution bathymetry. The addition of higher resolution datasets, including, bathymetry, backscatter and chirp, should help refine habitat predictions yielded by the thematic habitat mapper. Chirp sub-bottom data becomes useful in interpreting habitat, as this directs the possibility of hardbottom habitat occurrence. In areas where there is clearly more than 1 meter of sediment, hardgrounds outcropping at the seafloor are unlikely. Whereas, areas of thin to no sediment cover suggest the likelihood of hardground outcrops. Multibeam bathymetry data displays the topography of the seafloor, revealing important outcrops and ledges for fishery habitat. Sidescan backscatter reveals areas of high and low backscatter, supporting interpretation of either very coarse sediment (hardgrounds) or continuous sediment cover at the seafloor.

Two detailed study areas were chosen (Figure 8) to ensure complete bottom coverage in order to compare hardbottom predictions identified by the mapper to higher resolution datasets and groundtruthing. Both areas were chosen for further study as the habitat mapper had predicted these regions to possess extensive
habitat. Surprisingly, however, the offshore study area was found to be devoid of hardbottom in groundtruthing efforts (Figure 17). The thematic mapper bases the likelihood of hardbottom occurrence on a multitude of parameters, each weighted differently on the model. A possible ranking of parameters may account for the difference between predicted and observed habitat. The model appears to be heavily biased towards rugosity and distance to shelf break, as the high and highest predictive occurrences for hardbottom in this study area all appear towards the higher relief offshore areas. Additionally, predictive models only provide static information, whereas seafloor features in this study area reflect a dynamic and evolving system, such as the repeated reworking of exposed hardbottom and seasonal shifting of sediment supply between onshore and offshore. This temporal component to the model may account for differences between observed and predicted hardbottom occurrences in the offshore detailed study area and may indicate there will be hardbottom at this site in the future. The further offshore detailed area had a veneer of sand pervasive across the area (figure 18), with progradational thinning out in some regions to 0.5 meters thick, indicating a shift in sediment supply. This highlights issues of presently productive hardbottom and “habitat potential” awaiting biological response to potentially favorable physical settings.

The second detailed study site, located further inshore, contained a more varied topography, affording a more detailed dataset for comparison against habitat predictions. Generally, the high and highest predictions of hardbottom occurrence from the thematic mapper in this detailed area consistently line up with regions of
the seafloor possessing the greatest slope, based on higher resolution Reson 7125 bathymetric data (Figure 15). This is to be expected as NOAA’s habitat model is biased towards rugosity and slope, rather than the low relief hardbottom.

4.3 Comparison of different datasets (Fishery, ARA and Sub-bottom)

Backscatter is related to seafloor roughness and sediment grain size. The roughest areas of the seafloor in this detailed offshore area, as characterized by FM geocoder, line up with regions displaying the highest backscatter (Figure 18). Areas of the seafloor that are somewhat hard to distinguish according to backscatter alone are well characterized according to seafloor roughness. Regions of both high seafloor roughness and backscatter reveal mappable areas where it is predicted the highest density of fish is expected. This is suspected as roughness of the seafloor should correspond to more complexity, relief, turbulence and nutrient mixing, areas where fish tend to be located. When comparing the ARA surface to fishery sonar data, higher densities of fish tend to aggregate around rougher areas of the seafloor (Figure 18).

In this detailed offshore area, subtle variations in topography, i.e. small ridges, correspond to rougher areas (figure 18). When comparing these trends to sub-bottom data, the underlying geological framework reveals more about these variations in bathymetry and seafloor roughness. Beneath the roughest areas of the seafloor in this region, the marine unconformity is pronounced and appears to be a hard surface with homogenous sediment overlay. While beneath areas of low seafloor roughness, the marine unconformity seems to disappear and sediments are distinctly layered. Sub-bottom data from this inshore detailed box suggest the
marine unconformity is at the surface in areas where the seafloor roughness is lower (figure 18). Seafloor roughness corresponds to coarser grain size, leading one to suspect that the area of low seafloor roughness where it appears that older shelf strata outcrops at the surface, may actually be covered by a thin veneer of fine sediment that is indiscernible in the sub-bottom data. Furthermore, modern sediment cover above the marine unconformity could possibly be medium to coarse sand.

In the inshore detailed area, the roughest areas of the seafloor line up with the shallowest regions, according to the bathymetric data (figure 20). The topographic highs in the bathymetric surface appear to be small ridges as the slope is greatest along the edges of these ridges (figure 20). When comparing the fishery density data to variations in slope, a clear relationship emerges. The densest aggregations of fish appear along the edges of these ridges where the slope is the greatest (figure 16). When comparing fishery density to the roughest areas of the seafloor, where it is expected the highest density of fish will be, the relationship is not as well-defined (Figure 20). This is illustrated where a large area of relatively rough seafloor within the inshore box, where one would predict to find high densities of fish is devoid of fish. It is along the edges and topographic lows surrounding this ridge where the fish aggregate (figure 16). Fishery density in this inshore box is more predictable comparatively to the offshore box as the rougher and more variable topography provides habitat for fish.

The high backscatter along ridges in the detailed inshore box (figure 16) is caused by coarser grain sizes but the hardbottom habitat in between ridges is
characterized by a high degree of variability and microrelief (figure 21).

Microtopography in the bathymetric lows between ridges appears as small ripples, which is picked up in the PCA analysis (figure 21). The presence ($\geq 1/100$m) of fish appears to be linked to not only relief and slope but also to microrelief picked up from high resolution bathymetry. This microtopography may explain the presence of fish in areas with more than 0.5 meter of sediment cover. The interaction of bottom currents with sediment may form these small ripple features and provide refuge for benthic organisms.

Also mapped in this inshore box from sub-bottom data are two distinct paleochannel groups (figure 16). The larger of the channel group appears in an area of the seafloor with a relatively extensive flat surface and modern sediment cover greater than 100cm (figure 16). The marine unconformity appears as a hard surface in the sub-bottom data everywhere in this region except overtop the paleochannel group (figure 16). This may suggest the outcropping of paleochannel fill at the surface but the marine unconformity may just not appear as a hard visible surface in the sub bottom data. The smaller paleochannel group in this inshore box appears in a smaller topographically flat expanse of seafloor with modern sediment cover greater than 100 cm (figure 16). The marine unconformity is not present over this paleochannel but it is also suspected that this hard surface is just not discernible over this region in the sub-bottom data. What is seen surrounding both paleochannel groups are high and low relief hardbottom areas where the highest densities of fish were seen from fishery acoustic data (figure 16).
4.4 Expectations on Habitat

Areas of the seafloor not incised during sea level low stands, where older materials supporting hardbottom are located, are more likely to support essential fish habitat. Hardbottom in this sense is a proxy for essential fish habitat, as mapping out individual fish aggregations would be impossible, but it is the presence of fish species which marine resource managers are ultimately after. The large paleochannel group mapped off Murrells Inlet generally follows this pattern (Figure 14). However, the scope of this study does not afford the line spacing or time necessary for concurrent fishery sonar data, ground truthing or complete seafloor coverage to assess the resources around this channel group. The more detailed inshore study area afforded such coverage and high densities of fish flank both sides of the paleochannel groups (Figure 16).

While hardbottom habitat does provide an accurate assessment for the location and extent of fish aggregations, this does not take into account fish located at other seafloor features (figure 22). Small densities of fish were pinged on top of both paleochannel groups mapped in the inshore detailed area (Figure 16) (Figure 23). While the density of fish is relatively small compared to complex seafloor features and bathymetric lows (troughs), there are still fish counts located on top of the channel which could be important to the management of resources (Figure 16) (figure 22). This could simply be due to the transient nature of fish aggregations or may point to the possibility of essential fish habitat where paleochannels have cemented. This is where looking at the sub bottom data becomes useful, as the hardness of the underlying surface can be evaluated.
Detailed survey areas have the distinct advantage of spatially continuous data. Considering geophysical datasets for regional scale habitat mapping becomes more challenging but there is potential for backscatter and bathymetric data to be used as a proxy for benthic habitat. Habitat in this sense is using physical descriptors, such as substrate and seafloor morphology, to describe areas where benthic organisms reside. There are inherent problems to mapping habitats as distinct boundaries between different environments do not exist nor can a combination of physical, biological and chemical conditions be directly linked to living assemblages.

Overall, the thematic mapper generally picked inshore complex features but did not pick up smaller detailed areas (Figure 2). Low relief features need refinement, as drawing polygons may not be accurate and PCA is smoothing off the edges of features. This is where sub bottom data can be used to refine the habitat modeling scheme. While derivatives on bathymetric data and fishery density data suggest the occurrence of hardbottom habitat, these are just predictions. Sub bottom is the final story as to the presence or absence of hard bottom habitat.

5. Conclusion

Establishing a baseline predictive habitat map is important for directing further study, as the finer scale, higher resolution datasets necessary for effective marine management are expensive and time consuming. There are inherent challenges when applying NOAA’s thematic habitat mapper from a wide scale 90-meter resolution bathymetric dataset to a regional scale mapping effort. However, this provides an important baseline for researches to direct the appropriate
coverage and resolution of study necessary for mapping objectives. Ruling out areas of the seafloor to be mapped, where there is less potential for benthic habitat, such as paleochannel networks, allows for a directed mapping effort of ecologically significant habitat. To further advance efforts, more integrated studies should include currents and water mass characteristics, in addition to fishery and geophysical data. Additionally, the relative importance of extensive low relief areas further inshore should be accounted for before beginning a reconnaissance scale mapping effort. This present study chose site specific areas, with high probability for hardbottom habitat, but one region was mainly sediment. This was based on bathymetric data biased towards distance to the shelf and rugosity, which is an important recognition, as ecologically important habitat is not solely confined to high relief structures found further offshore. The value of broadly expansive low relief inshore habitats versus smaller isolated relief would be best addressed by ecological and geophysical integration on broad scales. Reliable bathymetric data supports important spatial information to improve habitat conservation and energy development by providing the identification of benthic habitats, efficient corridors for transmission lines and appropriate sites for wind turbine platforms. The regional information compiled in this study is anticipated to provide an effective baseline for resource managers but not at the scale necessary to select specific sites for wind development sites. Mapping additional seafloor features, including sediment distribution, provides vital information for many offshore activities and bottom sediments are an important part of benthic habitat for groundfish, clams, corals and in the distribution of organic matter (NYDOS 2013). Further studies to
compound upon the information compiled in this study include coring, to add a temporal component, and measuring channel geometries to more accurately map the paleodrainage network.
Figure 1: Pleistocene and Holocene beach barrier complexes formed landward of the present shoreline. Coastal plain (brown) and Piedmont (blue) rivers dissect these barrier systems (Baldwin et al., 2004).
Figure 2: First-order structural components underlying the U.S. Atlantic continental margin as indicated by structurally positive platforms and structurally negative embayments and basins. The organization of Cretaceous and Tertiary units has been regionally influenced by the Mid Carolina Platform High and its axis, as indicated by the thick arrow (Baldwin et al., 2006).
Figure 3: Paleochannel groups of the Pee Dee River system identified beneath the Long Bay inner shelf and Grand Strand regions of South Carolina using seismic-reflection profiles and borehole data. Onshore contours illustrate elevations at the base of Quaternary sediments and is depicted alongside offshore elevations of paleochannel unconformities (Baldwin et al., 2006).
Figure 4: Core table from borehole 6005 located 22 nautical miles off Georgetown, SC.

<table>
<thead>
<tr>
<th>CORE</th>
<th>STRING DEPTH</th>
<th>PENETRATION</th>
<th>NO. OF RECOVERY</th>
<th>LITHOLOGY -- AGE</th>
<th>SALINITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Feet Top</td>
<td>Feet RMB Bottom</td>
<td>Cumulative Feet</td>
<td>Meters</td>
<td>%</td>
</tr>
<tr>
<td>1</td>
<td>93</td>
<td>124</td>
<td>31</td>
<td>31</td>
<td>9.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>124</td>
<td>157</td>
<td>33</td>
<td>64</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>157</td>
<td>186</td>
<td>29</td>
<td>93</td>
<td>28.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>186</td>
<td>218</td>
<td>32</td>
<td>125</td>
<td>38.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>218</td>
<td>249</td>
<td>31</td>
<td>156</td>
<td>47.6</td>
</tr>
<tr>
<td>6</td>
<td>218</td>
<td>249</td>
<td>31</td>
<td>156</td>
<td>47.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5: Pleistocene scarps of the South Carolina coastal plain marked by the inland limits of their respective formations (Doar and Kendall, 2014).
Figure 6: NOAA’s thematic habitat mapper predictions along the Eastern US Atlantic shelf, according to the likelihood of presence (red) or absence (blue) of hardbottom habitat.
Figure 7: Operating area for the Nancy Foster research cruise and Grayscale of NOAA’s predictive model for hardbottom habitat along the Atlantic shelf. Tracklines (red) for this study were designed to follow drainage patterns. Detailed study areas (green) illustrate areas for planned groundtruthing of the thematic mapper.
Figure 8: Coastal Carolina University's work flow for Side-scan Sonar processing.
Figure 9: Coastal Carolina University's work flow procedure for Chirp Subbottom processing.
Figure 10: Chirp profile and interpreted section from inshore shore parallel line 10 off Cape Romaine, SC.
Figure 11: Actual Chirp lines (red) from present 2015 Nancy Foster cruise dataset, including inshore detailed study area (yellow) and further offshore detailed study area (red). Chirp data included from previous Nancy Foster cruise datasets (blue) and grayscale of hardbottom predictions from NOAA’s thematic habitat mapper, from the highest probability of hardbottom occurrence (black) to lowest probability for hardbottom occurrence (white). Locations of modern (Holocene) sediment cover have been mapped across the study area, everywhere the marine unconformity is not at the surface.
Figure 12: Chirp profile from inshore shore parallel line 20 off Cape Romaine, SC showing connectivity patterns to Chirp profile line 10.
Figure 13: Paleochannel incising larger paleovalley from chirp profile from inshore shore parallel line 18 off Cape Romaine, SC.
Figure 14: Actual Chirp lines (green) from present 2015 *Nancy Foster* cruise dataset, including inshore detailed study area (yellow) and further offshore detailed study area (red). Chirp data included from previous *Nancy Foster* cruise datasets (blue) and grayscale of seven groups of Paleochannels previously mapped along Long Bay by Baldwin et al., 2006. Paleochannel locations and depths from present study highlight paleosystem mapped off Murrells Inlet. Grayscale hardbottom predictions from NOAA’s thematic habitat mapper, from the highest probability of hardbottom occurrence (black) to lowest probability for hardbottom occurrence (white).
Figure 15: Further inshore detailed study area Reson 7125 bathymetric data (A) highlighting comparisons to the high and highest predictive occurrences for hardbottom habitat (B) and fish distribution (C), counted as the number of fish per 100 meter interval along the transect.
Figure 16: Further inshore detailed study area Reson 7125 backscatter (A) with actual chirp lines (green) mapped, shown comparatively to depth of marked paleochannel location (B), depth to marine unconformity (C), shown as depth of modern (Holocene) sediment and mapped fish locations, in number of fish per 100 meter interval (D).
Figure 17: Further offshore detailed study area Bathymetric imagery (A) shown comparatively to the high and highest (red) predictions of hardbottom habitat (B) from NOAA’s thematic mapper predictions, groundtruthing data (C) from drop camera surveys and fish density data (D) counted as fish per 100 meter interval.
Figure 18: Further offshore detailed study area Backscatter data (A), shown with bathymetrically derived ARA data (B) showing roughness of the seafloor, fish density data (C) counted as fish per 100 meter interval and depth of modern sediment cover (D).
Figure 19: Sidescan sonar imagery draped over bathymetry (above) and chirp profile and interpretation (below) offshore of Murrells Inlet (Denny et al., 2007).
Figure 20: Further inshore detailed study area Backscatter data (A), shown comparatively to ARA (B) seafloor roughness, fish density data counted as the number of fish per 100 meter interval (C) and depth of modern sediment (D).
Figure 21: NOAA’s PCA analysis, breaking down the bathymetric data into red, green and blue bands based on rugosity, slope and curvature profile.
Figure 22: Seafloor characterization (A) of the further inshore detailed study area using polygon features. The number of fish per 100 meter interval (B) were counted according to distance to polygon features and seafloor characterization was compared to groundtruthing data (C) and predictions of the high and highest (red) predictions of hardbottom presence (C).
<table>
<thead>
<tr>
<th>Seafloor feature</th>
<th>0.9-3</th>
<th>3-6.6</th>
<th>6.6-13.5</th>
<th>13.5-39</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth sand ridge</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rough edge sand ridge</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Complex</td>
<td>493</td>
<td>200</td>
<td>61</td>
<td>10</td>
</tr>
<tr>
<td>Paleochannel</td>
<td>34</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Troughs</td>
<td>38</td>
<td>27</td>
<td>37</td>
<td>14</td>
</tr>
</tbody>
</table>

Figure 23: Fishery density data, categorized as number of fish per 100 meter interval, according to distance to polygon features used to classify seafloor habitats in the further inshore detailed study area.
Figure 24: Surficial geologic map of the inner shelf of Long Bay from Little River Inlet to Winyah Bay based on Baldwin and others (2004). (Denny et al. 2007)
Works Cited


Ojeda, G.Y., Gayes, P.T., Sapp, A.L., Jutte, P.C., and Van Dolah, R.F., 2001, Habitat mapping and sea bottom change detection on the shoreface and inner shelf adjacent to the Grand Strand Beach Nourishment Project: Final report prepared by the South Carolina Marine Resources Research Institute, South Carolina Marine Resources Division, Charleston, South Carolina, for the U.S. Army Corps of Engineers, Charleston District. 49 pp.


