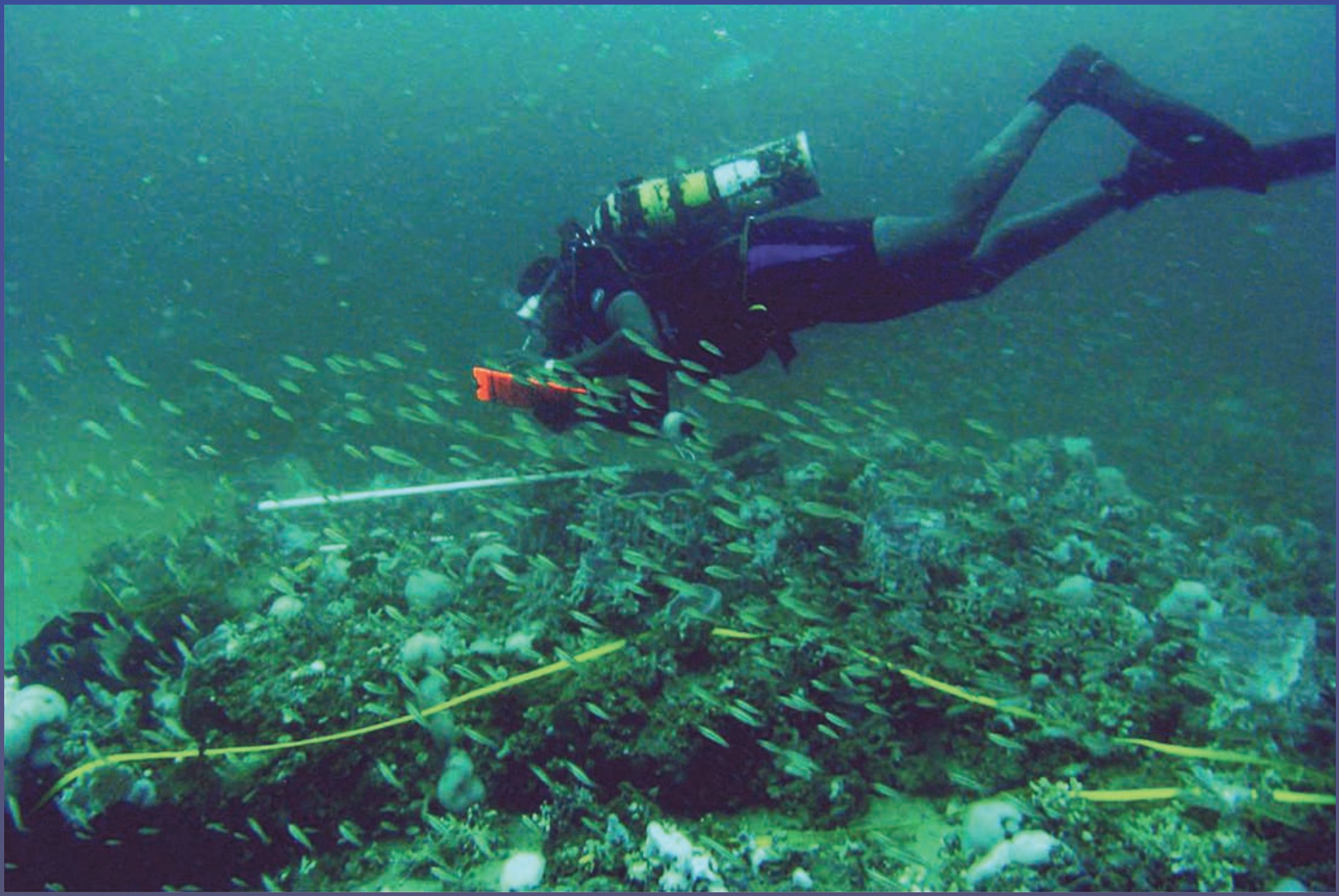
Characterization of the Benthos, Marine Debris and Bottom Fish at Gray's Reef National Marine Sanctuary

by Matthew S. Kendall, Laurie J. Bauer and Christopher F.G. Jeffrey
In partnership with Gray's Reef National Marine Sanctuary



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ABOUT THIS DOCUMENT

This ecological characterization represents the continuation of an ongoing partnership between the National Marine Sanctuary Program (NMSP) and the National Centers for Coastal Ocean Science (NCCOS), Center for Coastal Monitoring and Assessment (CCMA). The purpose of this collaboration is to apply a biogeographical approach to the management of marine resources within the National Marine Sanctuaries. This particular work, conducted in consultation with Gray's Reef National Marine Sanctuary (GRNMS) and scientists conducting research within the South Atlantic Bight region, builds on and advances biogeographic techniques developed by CCMA's Biogeography Team for other National Marine Sanctuaries including Channel Islands, Cordell Bank, Gulf of Farallones, Monterey Bay, and Stellwagen Bank. At the onset of the project, CCMA, GRNMS, and NMSP staff identified a set of targeted research topics to fill existing gaps in baseline data, and enhance the understanding of key ecological patterns and processes to support the Sanctuary.

The characterization consists of two complementary components: a text report that includes a suite of quantitative spatial and statistical analyses that characterize physical and biological features of GRNMS; and the raw database of all spatial data analyzed to conduct the characterization. The report provides essential information on the distribution of modeled and observed species and features needed to support the development of monitoring and scientific studies, the development of educational material, and support of other spatially-explicit management decisions. The results of this ecological characterization are available via website. For more information on this effort please visit the NCCOS Biogeography Team webpage dedicated to this project at http://ccma.nos.noaa.gov/ecosystems/sanctuaries/grays_nms.html or direct questions and comments to:

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EXECUTIVE SUMMARY

Baseline characterization of resources is an essential part of marine protected area (MPA) management and is critical to inform adaptive management. Gray's Reef National Marine Sanctuary (GRNMS) currently lacks adequate characterization of several key resources as identified in the 2006 Final Management Plan. The objectives of this characterization were to fulfill this need by characterizing the bottom fish, benthic features, marine debris, and the relationships among them for the different bottom types within the sanctuary: ledges, sparse live bottom, rippled sand, and flat sand. Particular attention was given to characterizing the different ledge types, their fish communities, and the marine debris associated with them given the importance of this bottom type to the sanctuary.


Image 1a. Fish schooling around densely colonized live bottom in GRNMS.

The characterization has been divided into four sections. Section 1 provides a brief overview of the project, its relevance to sanctuary needs, methods of site selection, and general field procedures. Section 2 provides the survey methods, results, discussion, and recommendations for monitoring specific to the benthic characterization. Section 3 describes the characterization of marine debris. Section 4 is specific to the characterization of bottom fish. Field surveys were conducted during August 2004, May 2005, and August 2005. A total of 179 surveys were completed over ledge bottom (n=92), sparse live bottom (n=51), flat sand (n=20), and rippled sand (n=16). There were three components to each field survey: fish counting, benthic assessment, and quantification of marine debris. All components occurred within a 25 x 4 m belt transect. Two divers performed the transect at each survey site. One diver was responsible for identification of fish species, size, and abundance using a visual survey. The second diver was responsible for characterization of benthic features using five randomly placed 1 m^2 quadrats, measuring ledge height and other benthic structures, and quantifying marine debris within the entire transect.

GRNMS is composed of four main bottom types: flat sand, rippled sand, sparsely colonized live bottom, and densely colonized live bottom (ledges). Independent evaluation of the thematic accuracy of the GRNMS benthic map produced by Kendall et al. (2005) revealed high overall accuracy (93%). Most discrepancies between map and diver classification occurred during August 2004 and likely can be attributed to several factors, including actual map or diver errors, and changes in the bottom type due to physical forces.

The four bottom types have distinct physical and biological characteristics. Flat and rippled sand bottom types were composed primarily of sand substrate and secondarily shell rubble. Flat sand and rippled sand bottom types were characterized by low percent cover (0-2%) of benthic organisms at all sites. Although the sand bottom types were largely devoid of epifauna, numerous burrows indicate the presence of infaunal organisms. Sparse live bottom and ledges were colonized by macroalgae and numerous invertebrates, including coral, gorgonians, sponges, and "other" benthic species (such as tunicates, anemones, and bryozoans). Ledges and sparse live bottom were similar in terms of diversity (H') given the level of classification used here. However, percent cover of benthic species, with the exception of gorgonians, was significantly greater on ledge than on sparse live bottom. Percent biotic cover at sparse live bottom ranged from 0.7-26.3%, but was greater than 10% at only 7 out of 51 sites. Colonization on sparse live bottom is likely inhibited by shifting sands, as most sites were covered in a layer of sediment up to several centimeters thick. On ledge bottom type, percent cover ranged from 0.42-100%, with the highest percent cover at ledges in the central and south-central region of GRNMS.

Biotic cover on ledges is influenced by local ledge characteristics. Cluster analysis of ledge dimensions (total height, undercut height, undercut width) resulted in three main categories of ledges, which were classified as short, medium, and tall. Median total percent cover was 97.6%, 75.1%, and 17.7% on tall, medium, and short ledges, respectively. Total percent cover and cover of macroalgae, sponges, and other organisms was significantly lower on short ledges compared to medium and tall ledges, but did not vary significantly between medium and tall ledges. Like sparse live bottom, short ledges may be susceptible to burial by sand, however the results indicate that ledge height may only be important to a certain threshold. There are likely other factors not considered here that also influence spatial distribution and community structure (e.g., small scale complexity, ocean currents, differential settlement patterns, and biological interactions).

Image 1b. Large school of tomtates.

GRNMS is a popular site for recreational fishing and boating, and there has been increased concern about the accumulation of debris in the sanctuary and potential effects on sanctuary resources. Understanding the types, abundance, and distribution of debris is essential to improving debris removal and education efforts. Approximately two-thirds of all observed debris items found during the field surveys were fishing gear, and about half of the fishing related debris was monofilament fishing line. Other fishing related debris included leaders and spear gun parts, and non-gear debris included cans, bottles, and rope. The spatial distribution of debris was concentrated in the center of the sanctuary and was most frequently associated with ledges rather than at other bottom types. Several factors may contribute to this observation. Ledges are often targeted by fishermen due to the association of recreationally important fish species with this bottom type. In addition, ledges are structurally complex and are often densely colonized by biota, providing numerous places for debris to become stuck or entangled. Analysis of observed boat locations indicated that higher boat activity, which is an indication of fishing, occurs in the center of the sanctuary. On ledges, the presence and abundance of debris was significantly related to observed boat density and physiographic features including ledge height, ledge area, and percent cover. While it is likely that most fishing related debris originates from boats inside the sanctuary, preliminary investigation of ocean current data indicate that currents may influence the distribution and local retention of more mobile items.

Fish communities at GRNMS are closely linked to benthic habitats. A list of species encountered, probability of occurrence, abundance, and biomass by habitat is provided. Species richness, diversity, composition, abundance, and biomass of fish all showed striking differences depending on bottom type with ledges showing the highest values of nearly all metrics. Species membership was distinctly separated by bottom type as well, although very short, sparsely colonized ledges often had a similar community composition to that of sparse live bottom. Analysis of fish communities at ledges alone indicated that species richness and total abundance of fish were positively related to total percent cover of sessile invertebrates and ledge height. Either ledge attribute was sufficient to result in high abundance or species richness of fish. Fish diversity (H`) was negatively correlated with undercut height due to schools of fish species that utilize ledge undercuts such as *Pareques* species. Concurrent analysis of ledge types and fish communities indicated that there are five distinct combinations of ledge type and species assemblage. These include, 1) short ledges with little or no undercut that lacked many of the undercut associated species except *Urophycis earlii*; 2) tall, heavily colonized, deeply undercut ledges typically with *Archosargus probatocephalus, Mycteroperca* sp., and *Pareques* sp.; 3) tall, heavily colonized but less undercut with high occurrence of *Lagodon rhomboides* and *Balistes capriscus*; 4) short, heavily colonized ledges typically with *Centropristis ocyurus, Halichoeres caudalis*, and *Stenotomus* sp.; and 5) tall, heavily colonized, less undercut typically with *Archosargus probatocephalus, Caranx crysos* and *Seriola* sp.. Higher levels of boating activity and presumably fishing pressure did not appear to influence species composition or abundance at the community level although individual species appeared affected. These results indicate that merely knowing the basic characteristics of a ledge such as total height, undercut width, and percent cover of sessile invertebrates would allow good prediction of not only species richness and abundance of fish but also which particular fish species assemblages are likely to occur there. Comparisons with prior studies indicate some major changes in the fish community at GRNMS over the last two decades although the causes of the changes are unknown.

Species of interest to recreational fishermen including *Centropristis striata, Mycteroperca microlepis*, and *Mycteroperca phenax* were examined in relation to bottom features, areas of assumed high versus low fishing pressure, and spatial dispersion. Both *Mycteroperca* species were found more frequently when undercut height of ledges was taller. They often were found together in small mixed species groups at ledges in the north central and southwest central regions of the sanctuary. Both had lower mode size and proportion of fish above the fishery size limit in heavily fished areas of the sanctuary (i.e. high boat density) despite the presence of better habitat in that region. Black sea bass, *C. striata*, occurred at 98% of the ledges surveyed and appeared to be evenly distributed throughout the sanctuary. Abundance was best explained by a positive relationship with percent cover of sessile biota but was also negatively related to presence of either *Mycteroperca* species. This may be due to predation by the *Mycteroperca* species or avoidance of sites where they are present by *C. striata*.

Suggestions for monitoring bottom features, marine debris, and bottom fish at GRNMS are provided at the end of each chapter. The present assessment has established quantitative baseline characteristics of many of the key resources and use issues at GRNMS. The methods can be used as a model for future assessments to track the trajectory of GRNMS resources. Belt transects are ideally suited to providing efficient and quantitative assessment of bottom features, debris, and fish at GRNMS. The limited visibility, sensitivity of sessile biota, and linear nature of ledge habitats greatly diminish the utility of other sampling techniques. Ledges should receive the bulk of future characterization effort due to their importance to the sanctuary and high variability in physical structure, benthic composition, and fish assemblages.

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CHAPTER 1 JUSTIFICATION, OBJECTIVES AND APPROACH

1.1 INTRODUCTION

Baseline characterization of resources and patterns of use is an essential part of marine protected area (MPA) management (Kendall et al. 2004, Quattrini and Ross 2006). An inventory of the bottom features and the abundance, size structure, and habitat associations of organisms is needed to catalog and understand the environment within the MPA. In addition, human use patterns must be understood to support development of management strategies designed to minimize user impacts. Once the MPA's resources and use patterns are adequately characterized, changes can be quantified and monitored through time. Such assessment and regular monitoring are critical to support adaptive management. Gray's Reef National Marine Sanctuary (GRNMS) currently lacks adequate characterization of several topics including bottom fish, benthic invertebrates, and human use patterns (NOAA 2006).

GRNMS is located on the inner continental shelf of the southeastern United States, 32.4 km offshore of Sapelo Island, Georgia (Figure 1.1, NOAA 2006). The ecological importance of this area is related to its location at the transition between tropical and temperate waters, and the existence of a topographically complex system of ledges. The inner shelf area in the Georgia Bight is dominated by tidal currents and riverine runoff and is subject to seasonal variations in temperature, salinity and water clarity (Hanson et al. 1981; NOAA 2006). GRNMS is also influenced by the Gulf Stream along the outer shelf area, which transports deep nutrient-rich and temperate waters as well as tropical fish species to the area. Commonly referred to as "live bottom" areas, the rocky outcroppings within GRNMS support about 300 species of marine invertebrates (Gleason et al. 2005) and about 65 species of macroalgae (Searles 1988). In turn, these benthic communities provide habitat for as many as 150 fish species including several of interest to recreational and commercial fishermen (Sedberry and Van Dolah 1984; Kennedy 1993).

Prior to designation of the sanctuary in 1981, simple characterizations had been conducted in the area (e.g. Hunt 1974). Since then, the sanctuary has been steadily building an inventory of its biological resources and human use patterns. In addition, field guides of the local fish (Gilligan 1989, Parker et al. 1994), algae (Searles 1988), and invertebrates (Gleason et al. 2005) have been produced. While limited in their spatial scope and quantitative rigor, these efforts have been instrumental in furthering knowledge of sanctuary resources. The recent completion of detailed benthic maps of GRNMS (Figure 1.2, Kendall et al. 2005) has led to a more robust and spatially explicit biological inventory and ecological characterization as reported here. Building on these earlier inventory activities, the present assessment was designed to address priority resource management issues as identified in the 2006 Final Management Plan for the sanctuary (NOAA 2006). This plan identified the management needs and goals for the next 5 years at GRNMS and specifically addressed the need for a quantitative, spatial characterization of marine debris, sessile invertebrates, benthic features, and the bottom fish associated with them.

Image 2. Diver studying benthic community with sponge species in the foreground.

1.2 JUSTIFICATION

Below are listed the GRNMS action plan items that were addressed by the present assessment followed by a description of how each item was met.

STRATEGY MRP-3: REMOVE MARINE DEBRIS FROM THE SANCTUARY AND PREVENT NEW DEBRIS FROM ACCUMULATING

Activity A: Clarify regulatory authority to address materials discharged or deposited outside the Sanctuary.

Activity B: Develop and implement a marine debris education and outreach program.

Activity C: Develop and implement a debris assessment and monitoring study.

The present assessment addressed Activities B and C of this strategy. The assessment character-

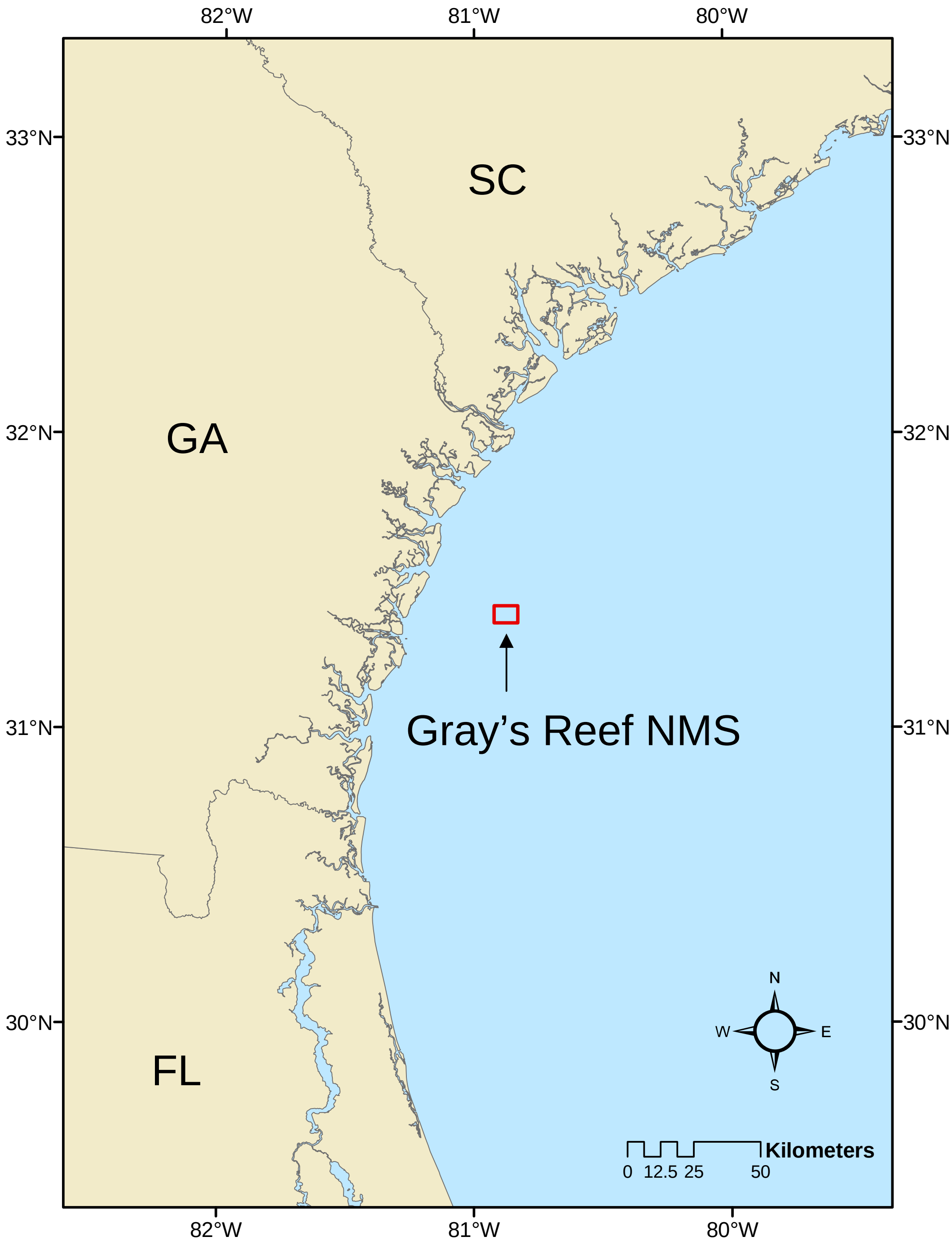

Figure 1.1. Location of Gray's Reef National Marine Sanctuary**.**

ized the type and quantity of marine debris at GRNMS, the type of bottom features it is routinely associated with, and proposed a strategy for continued assessment and monitoring. An understanding of the types and spatial distribution of marine debris in the sanctuary are necessary prerequisites to conduct clean-up and education activities efficiently. Knowledge of the spatial distribution of debris enables the sanctuary to focus clean-up efforts on the most affected areas given limited resources. Knowledge of the types of debris and potential mechanisms of transport and deposition allow education and outreach activities to focus their efforts on primary sources of debris.

STRATEGY RM-3: ASSESS AND CHARACTERIZE SANCTUARY RESOURCES
- Activity A: Develop and update the GIS database.
- Activity B: Characterize benthic habitat.
- Activity C: Develop an invertebrate identification guide.
- Activity D: Develop the sanctuary characterization.

The present assessment addresses Activities A, B, and D of the strategy. Bottom types were evaluated by several variables including biotic and abiotic cover types as well as ledge dimensions and sand characteristics. By linking the characterization of marine debris, benthic habitat, and bottom fish to spatial coordinates and the seafloor map, the data can be easily incorporated into the GIS under development at the sanctuary. This will provide the most current, spatially explicit characterization of sanctuary resources available.

STRATEGY RM-4: MAINTAIN AND ENHANCE MONITORING PROGRAMS

Activity A: Monitor the status and health of fish.
Activity B: Design and implement an invertebrate monitoring program.
Activity C: Develop a comprehensive water quality monitoring program.
Activity D: Develop and implement a sediment analysis and monitoring program.
Activity E: Support and enhance regional ocean observation systems.
Activity F: Expand and update socioeconomic assessment.
Activity G: Synthesize and characterize paleo-environmental information.

The present assessment addresses Activities A and B of this strategy. Quantitative, spatially explicit characterization of fish communities and their associated habitats was a primary goal of this project. This includes species composition, size distribution, and density of each species by bottom type. In addition, recommenda-

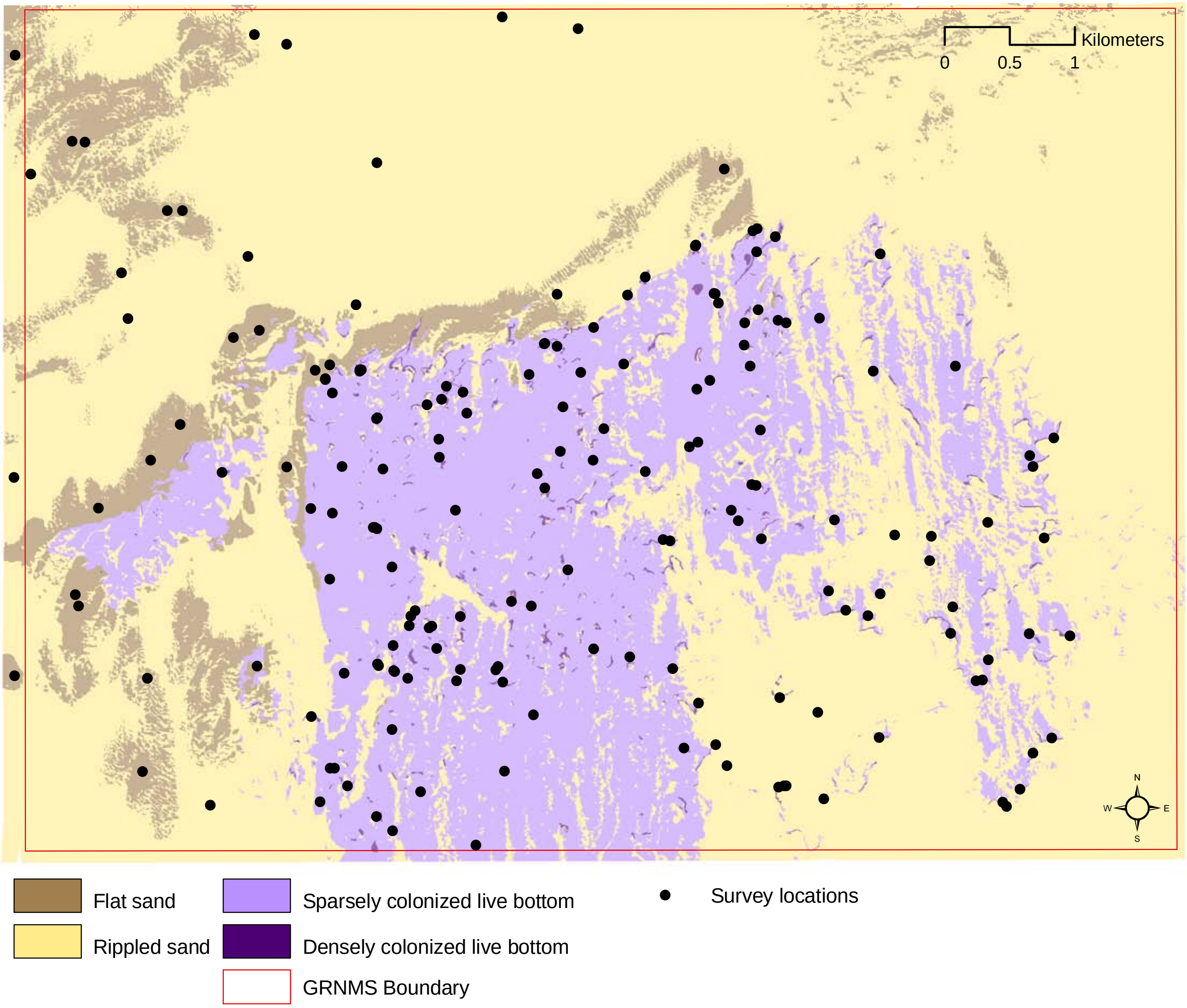

Figure 1.2. Spatial distribution of GRNMS bottom types (classified by Kendall et al. 2005) and survey locations.

tions for periodic assessment of bottom fish and sessile invertebrates are included to enable long term monitoring.

The objectives of this characterization were to characterize the bottom fish, benthic features, marine debris, and the relationships among them for the different bottom types within the sanctuary: ledges, sparse live bottom, rippled sand, and flat sand. Particular attention was given to characterizing the different ledge types, fish communities of ledges, and marine debris associated with them given the importance of this bottom type to the sanctuary.

Image 3. Jackknife fish, *Equetus lanceolatus* and coral.

1.3 METHODS

Site Selection

Field surveys were conducted in August 2004, May 2005, and August 2005 to coincide with the availability of a research vessel and favorable weather conditions. Since sampling periods were separated by only four months, seasonal differences in benthic communities were not explored in depth. Despite big differences in water temperature during May and August, even greater temporal separation of samples and more samples per year than used here would be better suited to characterizing seasonal differences. As a result, data are pooled for all analyses except where noted and the scope of inference is limited to the summer time period.

Most survey effort was devoted to the ledge bottom due to its high diversity and its importance to the sanctuary (Table 1.1). Less effort was devoted to the less diverse, lower complexity, and lower variability bottom types such as sparse live bottom and less still was devoted to the sand areas. Sites were selected randomly from within four bottom categories (flat sand, rippled sand, sparse live bottom, and densely colonized live bottom or ledges) identified in the recently completed benthic maps of GRNMS (Kendall et al. 2005). Sites in the sparse live bottom and sand categories were buffered such that they were a minimum of 30 m from other habitat types to ensure that a 25 m transect conducted along a random heading was contained within a single bottom type. Ledge sites are typically only a few meters wide, therefore surveys in that habitat were not conducted along a random heading. Ledge surveys were instead conducted along the lip of the ledge. Only ledges a minimum of 60 m long were allowed during site selection. A ledge 60 m long was the minimum size (+10 m) to accommodate a 25 m transect assuming that it was begun in the middle of the ledge and then conducted in a randomly chosen direction (i.e. left or right) along the ledge. If the random site selection process resulted in a point on a ledge smaller than 60 m, the nearest ledge of suitable length was surveyed instead. However, this was not a common occurrence, as <5% of the randomly selected sites were located on ledges of unsuitable length. Number of surveys by bottom type and sampling period are provided in Table 1.1, and the spatial distribution of survey locations is shown in Figure 1.2.

Table 1.1. Number of surveys within each bottom type.

Bottom Type	Aug 2004	May 2005	Aug 2005	Total Surveys
Ledge	15	35	42	92
Sparse live bottom	17	20	14	51
Flat sand	4	8	8	20
Rippled sand	8	5	3	16

Field Methods

There were three components to the field survey: fish counting, benthic assessment, and quantification of marine debris, all of which occurred within a 25 x 4 m belt transect for a total survey area of 100 m^2. Two divers surveyed the transect at each survey site. One diver was responsible for visual counts and size estimation of fish species. The second diver characterized benthic features with five randomly placed 1 m^2 quadrats and quantified marine debris within the entire transect. More details on field methods will be provided in subsequent sections.

For all bottom types except ledge, the divers selected a random compass heading (0-360°) along which to conduct the survey. Exceptions were made at sites with a strong current or surge, where the survey was conducted into the current to ease the physical demands on divers. Surveys over ledge habitat were conducted along the ledge face or lip (if undercut) and followed any turns or curves along the ledge. This ensured that the entire survey would be conducted within the ledge bottom type. Once at a site, the fish surveyor attached a tape measure to the substrate or weighted line that was used to mark the site and began the survey. The entire length of the transect survey was conducted at a relatively constant speed and fixed time period (~15 minutes) regardless of bottom type or number of fish present. Detailed survey methods and protocols for data collection for bottom fish, benthic assessment, and quantification of marine debris are provided in the subsequent chapters respectively.

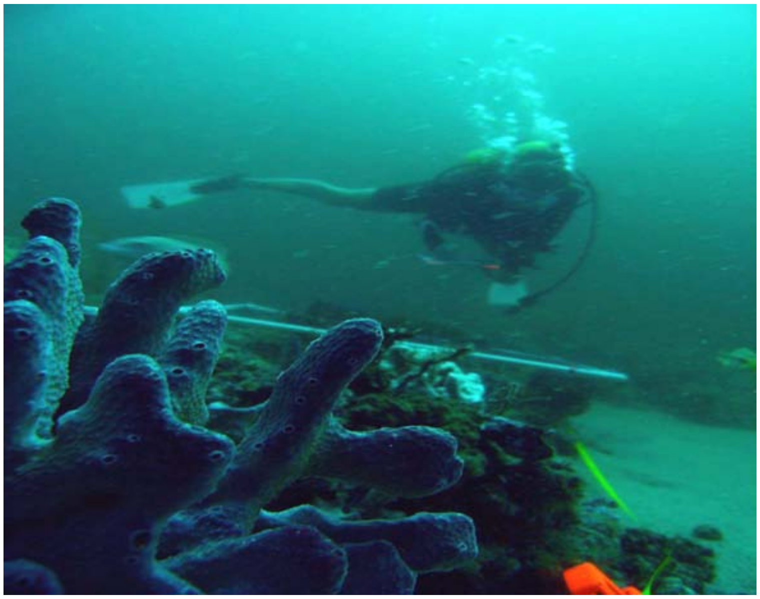

Image 4. Diver conducting habitat survey.

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CHAPTER 2 CHARACTERIZATION OF BENTHIC COMMUNITIES

2.1 INTRODUCTION

Morphologically complex hardbottom outcroppings are interspersed throughout the continental shelf from the coast to the shelf edge along the South Atlantic Bight (Parker et al. 1983; Van Dolah et al. 1994). These rocky features vary from flat, smooth surfaces to exposed vertical scarps and ledges with numerous overhangs, crevices, and slopes (Riggs et al. 1996). Exposed surfaces are colonized to varying extents by algae and sessile and burrowing invertebrates, which in turn provide shelter, foraging, and nursery areas for a large diversity of fish. In addition to providing important habitat, hardbottom substrate is an important source of sand production on sediment-starved areas on the continental shelf (Riggs et al. 1998). Although several studies have examined the distribution (Henry and Giles 1979; Parker et al. 1983; Van Dolah et al. 1994) and geological origins (Riggs et al. 1996) of hardbottom habitats in the South Atlantic Bight, less is known about the benthic flora and fauna communities that inhabit these substrates (but see Wenner et al. 1983; Peckol and Searles 1984).

Gray's Reef National Marine Sanctuary (GRNMS) encompasses approximately 58 km^2, about 75% of which is comprised of unconsolidated sediments, including flat sand plains and rippled sand (Kendall et al. 2005). The remaining substrate consists of outcroppings of carbonate hardbottom formed during the Pliocene era. The hardbottom ranges from areas with little or no vertical relief to areas of irregular, high-relief rocky ledges (> 2 m) where invertebrate growth is abundant (Henry and Giles 1979; Van Dolah et al. 1994; Kendall et al. 2005). The vast majority (~97%) of the hardbottom areas at GRNMS are flat, contain a thin veneer of sand overlying sandstone or limestone rock, and are sparsely colonized by sessile invertebrates. Densely colonized ledges account for <1% of the total bottom.

A recent review of the GRNMS management plan identified the need to assess and characterize sanctuary resources to understand the associations among biological, physical and geological components of the ecosystem being protected (NOAA 2006). To this end, one focus of sanctuary management has been to classify and characterize benthic habitats through mapping activities (Kendall et al. 2005). Benthic maps provide an understanding of the spatial distribution of benthic habitats within GRNMS and a spatial framework for addressing research and management questions such as identifying and protecting essential fish habitats. The premise here is that strong linkages exist between fishes and their habitats and these linkages affect the spatial distribution of these animals. However, benthic maps may be somewhat limited because they comprise a mosaic of habitat patches that are static point-in-time estimates of dynamic properties of the ecosystem they represent (Weins 1976). In addition, habitat patches are assumed to be areas of homogeneous ecological and environmental conditions with discrete boundaries at a specific spatial and temporal scale. For example, all map features labeled as densely colonized ledges are assumed to be identical at the mapped scale but may contain complex spatial patterns in the distribution of resources that are not only variable when examined at the finer scales but also are temporally dynamic. Finer-scale *in situ* assessments and characterizations of benthic substrates are needed to quantify 1) the accuracy of hardbottom delineations, and 2) within and between substrate variability that may be affecting benthic communities and fish assemblages within GRNMS (Kendall et al. 2005).


Image 5. A close-up look at a diverse benthic community.

In addition, the recent management plan calls for activities to maintain and enhance monitoring programs (NOAA 2006). At GRNMS, invertebrates comprise the most diverse, abundant, and conspicuous component on hardbottom habitats, but previous assessments and monitoring attempts have not yielded appropriate data to detect changes in abundance, density or presence/absence over time (NOAA 2006). To fill this data gap, the current study provides a consistent and comprehensive *in situ* assessment of benthic communities, which can be used to design, implement, and maintain an invertebrate monitoring program at GRNMS. Moreover, this study provides data that will help quantify detailed habitat-fish associations, which will be useful in developing quantitative estimates of habitat utilization by fishes and provide the spatial framework needed to address management goals relative to protecting essential fish habitats.

Finally, data collected during this study will be used to evaluate independently the thematic accuracy of the GRNMS benthic map produced by Kendall et al. (2005). Kendall et al. (2005) evaluated the accuracy of the benthic habitat map with video transect data, which showed a very high degree of thematic accuracy. However, due to limitations of the accuracy assessment data set, they were restricted to evaluating only two of the four bottom types, sparsely colonized live bottom and unconsolidated sediment. Utilizing *in situ* classifications of habitat type will enable us to evaluate the accuracy of all four bottom types, including ledges.

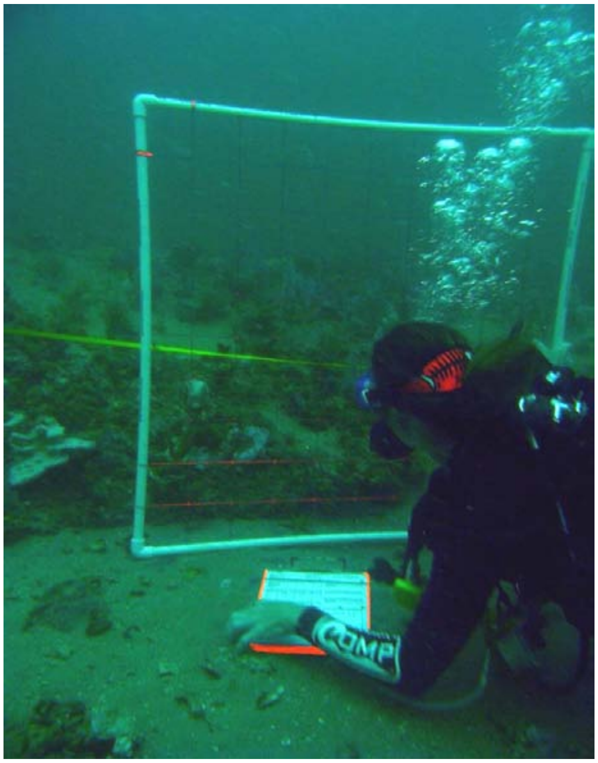

Image 6. Diver measuring ledge dimensions.

This study provides baseline estimates of the composition of four mapped benthic substrates within GRNMS as identified by Kendall et al. (2005). The overall goal of this study was to provide detailed and complete assessments of benthic substrates within GRNMS, especially the ledge bottom types. Specific objectives were as follows:

1. Evaluate independently the thematic accuracy of the GRNMS benthic map produced by Kendall et al. (2005);
2. Characterize the abiotic features of the benthos within each mapped bottom substrate;
3. Characterize the types, distribution, abundance of benthic flora and fauna within mapped substrates; and,
4. Identify abiotic features that may be influencing the spatial distribution, composition and abundance of invertebrate assemblages at ledges.

2.2 METHODS FOR BENTHIC SURVEYS

Using the same classification scheme that was used in benthic maps (Kendall et al., 2005), the diver independently assigned an overall bottom type to each transect based on *in situ* observation. Bottom types were ledge, sparse live bottom, flat sand, or rippled sand. The bottom type was assigned independently of that expected based on the benthic map so that the *in situ* data could be used for map validation. Data on the percent cover of abiotic and biotic composition at each survey site were recorded within five 1 m^2 quadrats along the 25 x 4 m transect. Some sites in August 2005 had only four quadrats evaluated due to scuba diving time limits. The quadrat was placed at each randomly chosen meter mark and systematically alternated from side to side along the transect tape, except on ledges (Figure 2.1). When characterizing the narrow ledges, the quadrats were placed entirely on the ledge rather than on the often bare substrate below it. It is important to note that beyond the scarp and first 1-2 meters of the top of the ledge, the bottom transitions into sparse live bottom. Transects at ledge sites were conducted solely along this ledge edge and not the sparse live bottom behind it. At all sites, several variables were measured to characterize benthic composition and structure (Table 2.1). The quadrat was divided into 100 smaller 10 x 10 cm squares with string (1 small square = 1% cover) to help the diver with estimation of

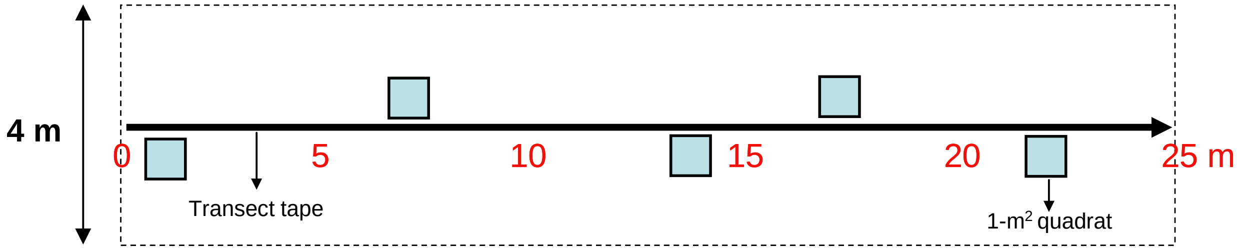

Figure 2.1. Schematic representation of the placement of the 1-m^2-quadrat along a 25-m transect tape during fish and benthic substrate surveys at GRNMS. Broken line represents the total area surveyed (100 m^2).

Table 2.1. Variables measured to characterize benthic composition along fish transects.

Benthic Composition	% Cover	Height (cm)	Abundance (#)
Abiotic			
Hard	x		
Sand	x		
Shell rubble	x		
Fine sediment	x		
Biotic			
Corals			
Branching	x		
Cup	x		
Ball	x		
Encrusting	x		
Other	x		
Gorgonians			
Sea rods / plumes	x	x	x
Sea fans	x	x	x
Sea whips	x	x	x
Macroalgae			
Filamentous / Turf	x		
Fleshy	x		
Other	x		
Sponges			
Ball	x	x	x
Vase	x	x	x
Tube	x	x	x
Finger	x	x	x
Rope	x	x	x
Encrusting	x		
Other benthic macrofauna			
Anemones	x		
Tunicates (Encrusting)	x		
Tunicates (Lobate)	x		
Zoanthids	x		
Other	x		

percent cover. Percent cover was determined by looking at the quadrat from above and visually estimating percent cover in a two dimensional plane. The percent cover (to the nearest 1%) of four abiotic substrate categories was determined first. The categories of abiotic substrates were hardbottom, sand, shell rubble, and fine sediments (Table 2.1). Hardbottom referred to consolidated substrates including those that were covered in a thin veneer of sand less than 10 cm thick and immovable, consolidated shell rock substrates. Shell rubble referred to loose shells or shell fragments that were moveable. Fine sediments were substrates consisting of unconsolidated silt that was easily resuspended and remained in the water column.

Percent cover (to the nearest 0.1 %) of the sessile biota was also determined for major taxonomic groups, which were further subdivided into categories based on morphology (Table 2.1). The maximum height and number of individual colonies were recorded for each sponge and gorgonian morphology. Uncolonized substrata were recorded as bare substrate.

Other specific measurements were made on ledge, sparse live bottom, and sandy bottom types. For ledge sites, the dimensions of ledges were recorded at each quadrat position. Total height was measured from the base of the ledge to the top of the substrate behind it but excluded the height of sessile organisms that were attached to the substrate (Figure 2.2). Undercut width – the distance from

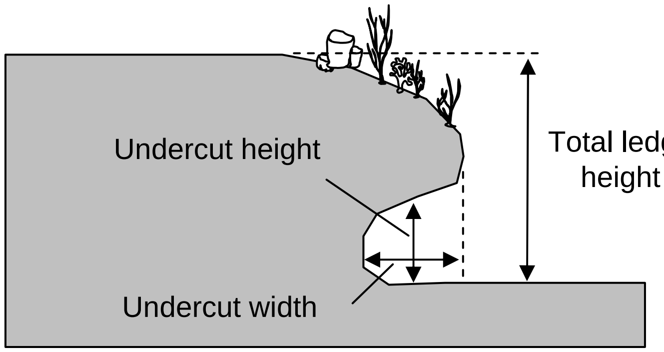

Figure 2.2. Schematic representation of the physical ledge dimensions measured during benthic surveys.

the leading face of the ledge to the farthest recess under the ledge – was visually estimated either by using the tape as a reference or by inserting the quadrat under the ledge (Figure 2.2). Undercut height – the height under the ledge – also was estimated visually with the length of the quadrat as a reference (Figure 2.2). Undercut width and height were recorded as zero for ledges that were not undercut. On sparse live bottom, the depths of sand, shell rubble, or fine sediment (hereafter sand thickness) were measured from the surface to the underlying limestone bottom up to 30 cm deep. On flat and rippled sand, the number of holes from burrowing organisms that occurred within each quadrat was recorded. In addition, on rippled sand, the wavelength and height of sand ripples within each quadrat were recorded.

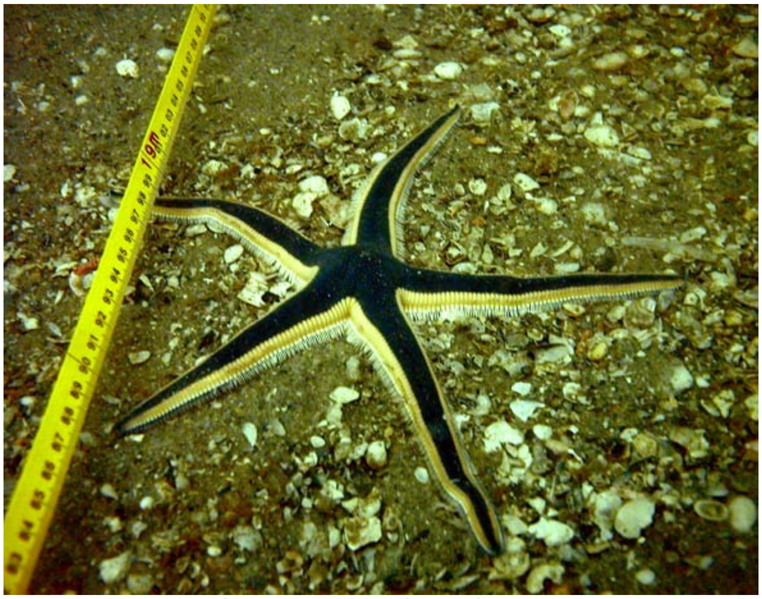

Image 7. Example of sand bottom in GRNMS.

Sites were used as independent sample units and were considered replicates within each bottom type. Multiple quadrat measurements within each site transect were averaged using the equation: $\sum(Q_{i-n})/n$, where Q_i = quadrat i, and n = total number of quadrats. Average site values were then used to calculate means and standard errors of measured variables for each bottom type.

2.3 METHODS FOR DATA ANALYSIS

Thematic accuracy of benthic habitat maps

Thematic accuracy of the benthic map of GRNMS was estimated using diver surveys at all 179 locations. Results including overall accuracy, user's and producer's accuracy, and Kappa statistic (Congalton and Green 1999) are summarized in an error matrix for all four mapped bottom types: flat sand, ledge, rippled sand, and sparse live bottom.

Abiotic features

The mean percent cover of each abiotic substrate category was plotted by bottom type. The hypotheses that 1) the amount of hardbottom varied significantly between ledges and sparse live bottom and 2) the amount of sand and shell rubble varied significantly among flat sand and rippled sand were tested non-parametrically with a Wilcoxon Rank Test (JMP v5.1).

The physical dimensions (total height, undercut height, and undercut width) at all ledge sites were entered into a geographic information system (GIS) and mapped to examine any spatial patterns of these ledge characteristics in the sanctuary. In addition, Spearman's Rho was computed on the ranks of data values to determine if significant pair-wise correlations existed among ledge dimension variables. Rho is a non-parametric correlation parameter that ranges from 1 to -1 with a value of 1 indicating a strong positive relationship and -1 indicating a strong negative relationship between paired variables (Sokal and Rohlf 1995). Then hierarchical clustering (Ward's minimum variance method) was used to identify groups of ledge sites with similar *in situ* physical dimensions (JMP v5.1). The stability of the clusters was checked by running the cluster analysis with multiple fusion strategies. The sites and their corresponding clusters were plotted against total height, undercut height, and undercut width.

Estimates of ledge height for all ledges within GRNMS were derived previously from a GIS analysis of sonar bathymetry by Kendall and Eschelbach (2006). Briefly, they determined ledge height for each polygon using a 2 meter resolution bathymetry grid of the sanctuary. All depth values from the bathymetry grid around each polygon were extracted from the bathymetry data and the deepest and shallowest values were subtracted to determine the maximum depth change or height for each ledge. To assess the accuracy of the GIS height estimates, the maximum ledge height determined by Kendall and Eschelbach (2006) was compared with maximum ledge height recorded *in situ*. *In situ* estimates of ledge height from the present study were plotted against GIS estimates from Kendall and Eschelbach (2006) and a nonparametric Spearman's Rho correlation was computed on the ranks of the data.

A frequency histogram was used to determine the distribution of data on sand thickness from sparse live bottom sites. Data on sand characteristics (sand ripple height and wavelength) were calculated for rippled sand. The number of burrows on flat and rippled sand was compared with a one-way ANOVA test.

Image 8. Sparsely colonized live bottom (with bat fish) in GRNMS.

Finally, we examined how ledge characteristics differ across regions of varying human use. Discussions with recreational fishermen indicated that they tend to target ledges that are tall and large in area. Indeed, larger and taller ledges also contained significantly greater amounts of marine debris, which is additional evidence of fishing (Chapter 3). Several ledge metrics, such as area (measured through GIS analysis) ledge height, undercut height, undercut width, and percent cover of benthic organisms, were therefore quantified and compared between areas of high and low boat density, as identified in Chapter 3, using parametric one-way ANOVA tests (JMP v5.1).

Biotic cover

The percent cover of each biotic category was plotted by bottom type and interquantile (25^{th}, 75^{th}) statistics were calculated. The relative total percent cover was the sum of all quadrat measurements (converted to a percentage) of each biotic category across all sites within each bottom type. The hypotheses that the biotic cover varied among bottom types was tested non-parametrically with Kruskal-Wallis Tests (JMP v5.1) and Dunn's multiple comparison tests. Similarly, height and abundance of sponges and gorgonians were plotted by bottom type and interquantile (25^{th}, 75^{th}) statistics were calculated. The hypothesis that height and number of individuals varied among bottom type was tested non-parametrically with Kruskal-Wallis Tests (JMP v5.1) and Dunn's multiple comparison tests.

Percent cover of main cover types at all sites was mapped in a geographic information system (GIS). Pie chart symbology was used to depict percent cover of corals, gorgonians, macroalgae, sponge, "other", and bare substrate at each site. Location of sites was occasionally adjusted slightly to prevent chart overlap. In addition, detailed maps were made for ledge bottom to show percent cover of subcategories within each main cover type. For each main cover type, bar charts were used to depict percent cover of subcategories at each ledge site. Two maps of this type were made for the "other" category. Due to the importance of tunicates as a sanctuary resource, the subcategories devoted to tunicates (encrusting and lobate) were mapped separately to better discern spatial patterns of tunicate cover. The second map included the remaining subcategories (anemones, benthic dwelling zoanthids, and other).

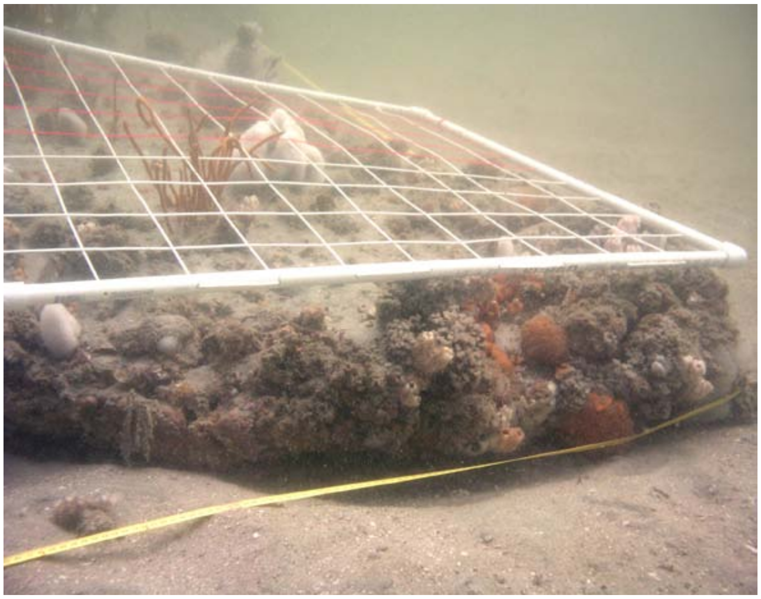

Image 9. Short ledge with 1x1 m quadrat.

Shannon-Weiner diversity (H') of biotic cover for each site was calculated using the detailed (non-aggregated) morphology types as:

$$H' = -\sum_{i=1}^{x} p_i \ln(p_i)$$

where x is the total number of morphological types (see Table 2.1 for list of all types) and p_i is the proportion of area covered by morphological type i. The hypothesis that diversity varied among bottom types was tested non-parametrically with a Kruskal-Wallis Test (JMP v5.1) and Dunn's multiple comparisons tests.

Biotic data were also analyzed by hierarchal clustering using Ward's minimum variance method. The percent cover variables, aggregated by cover type (corals, gorgonians, macroalgae, sponge, and other), were the basis for the analysis. A scree plot was used to help determine the number of well-separated clusters from the dendrogram. The stability of the clusters was checked by running the cluster analysis with multiple fusion strategies. In addition, the clustering procedure was conducted for ledges only using the same methods.

Abiotic effects on biotic composition

Finally, the relationship between the benthic community structure and abiotic ledge characteristics was assessed. Graphical methods and non-parametric tests were utilized to examine whether the percent cover, number of individuals, and height of benthic organisms varied among the three ledge categories (short, medium, and tall), which were determined from the cluster analysis of abiotic variables (see Results- Abiotic features). Percent cover of each biotic type (total, coral, gorgonians, macroalgae, sponge, and other organisms) was plotted by ledge category and interquantile (25^{th}, 75^{th}) statistics were calculated. The

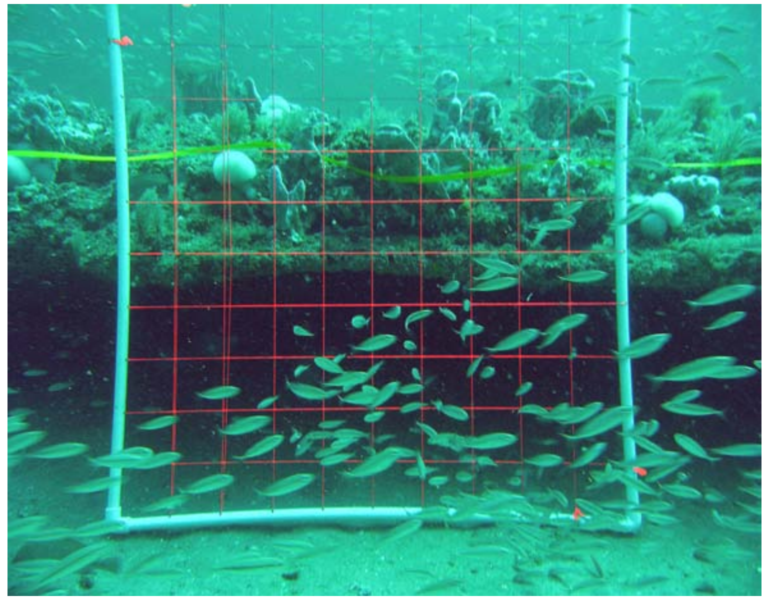

Image 10. Example of a tall, undercut ledge in GRNMS. A 1x1 m quadrat is shown for scale.

Table 2.2. Error matrix for habitat classification from diver surveys at the Grays' Reef National Marine Sanctuary. U = user's accuracy and P = producer's accuracy.

Mapped bottom type	Count	Diver assessed bottom type: Flat sand	Ledge	Rippled sand	Sparse live bottom	Total
	Flat sand	18 100% (U) 85.7% (P)	0	0	0	18
	Ledge	0	92 91.1% (U) 100 % (P)	2	7	101
	Rippled sand	3	0	13 81.3% (U) 86.7% (P)	0	16
	Sparse live bottom	0	0	0	44 100 % (U) 86.3 % (P)	44
	Total	21	92	15	51	179

*Overall accuracy = (167/179)*100% = 93.3%
Kappa = 0.89 ± 0.03

Table 2.3. A list of misclassified sites based on diver surveys (n = 12).

Site	Date	Mapped Bottom Type	Diver Assessed Bottom Type	Diver Notes
D19	Aug 04	Ledge	Rippled sand	change in depth, sparse, surveyed sand nearby
D22	Aug 04	Ledge	Sparse live bottom	None
D23	Aug 04	Ledge	Sparse live bottom	small ledge nearby
D27	Aug 04	Ledge	Rippled sand	change in depth, surveyed rippled sand nearby
D30	Aug 04	Ledge	Sparse live bottom	None
D4	Aug 04	Ledge	Sparse live bottom	None
D42	Aug 04	Ledge	Sparse live bottom	None
D8	Aug 04	Ledge	Sparse live bottom	small ledge nearby
D9	Aug 04	Ledge	Sparse live bottom	None
RS1	Aug 05	Rippled sand	Flat sand	None
RS7	Aug 05	Rippled sand	Flat sand	many echinoderms, >15
RS9	Aug 05	Rippled sand	Flat sand	None

hypothesis that the percent cover varied among ledge categories was tested non-parametrically with Kruskal-Wallis Tests (JMP v5.1) and Dunn's multiple comparison tests.

Similarly, height and abundance of sponges and gorgonians were plotted by ledge category and interquantile (25^{th}, 75^{th}) statistics were calculated. The hypothesis that height and number of individuals varied among ledge category was tested non-parametrically with Kruskal-Wallis Tests (JMP v5.1) and Dunn's multiple comparison tests. The mean and standard error of Shannon diversity was calculated for each ledge

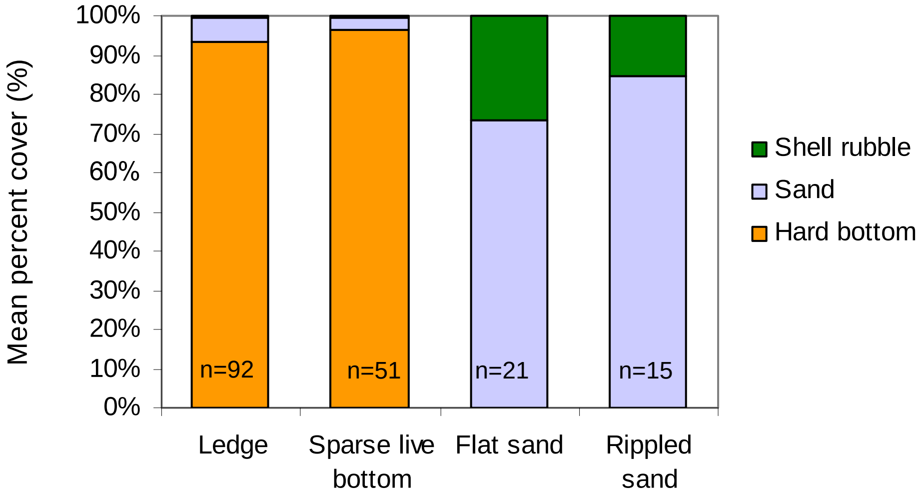

Figure 2.3. Stacked histogram plot of average abiotic substrate composition (relative total percent cover) by substrate bottom type.

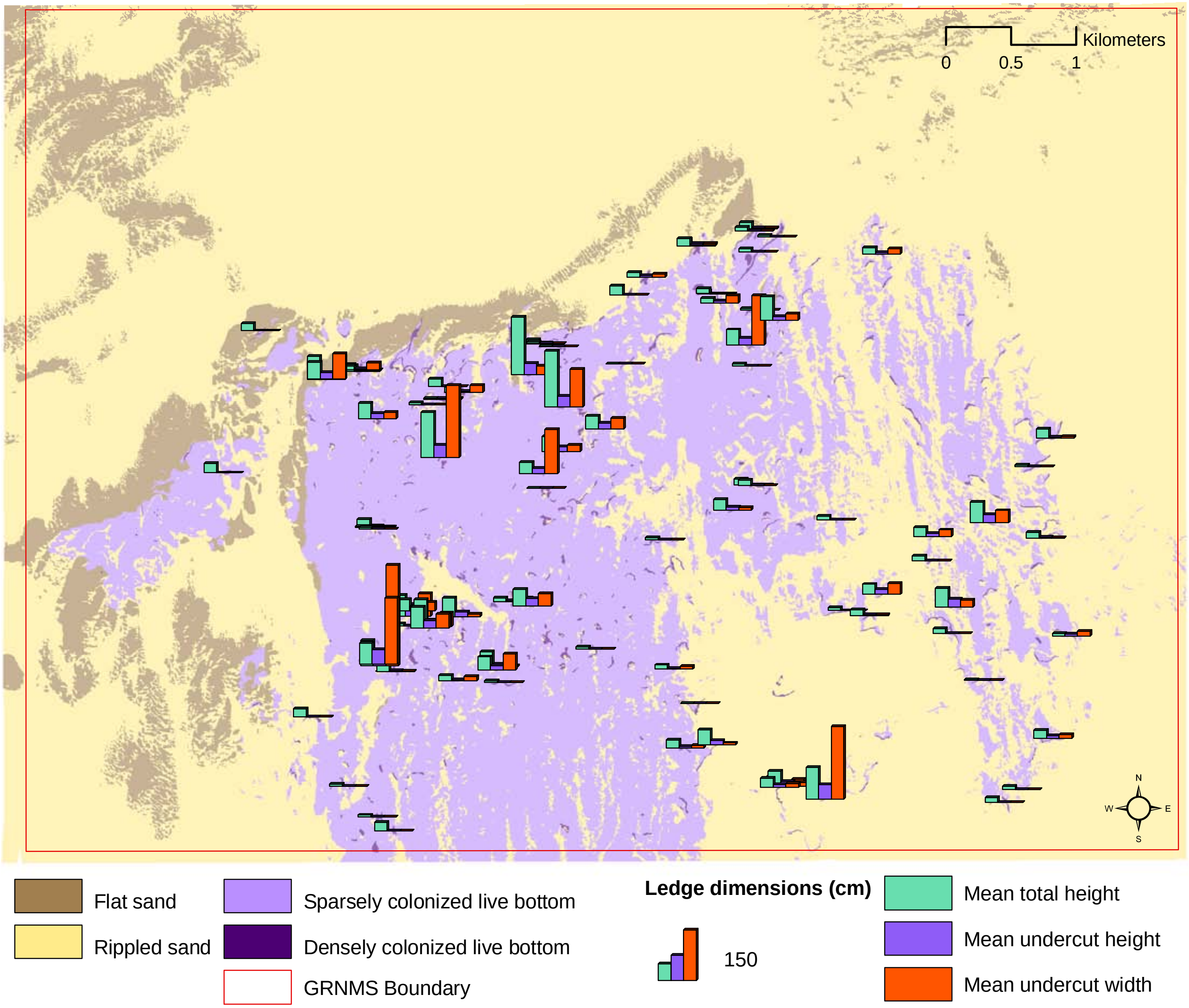

Figure 2.4. Ledge dimensions (total height, undercut height, undercut width) at ledge sites in GRNMS. The tallest bar in the legend represents 150 cm.

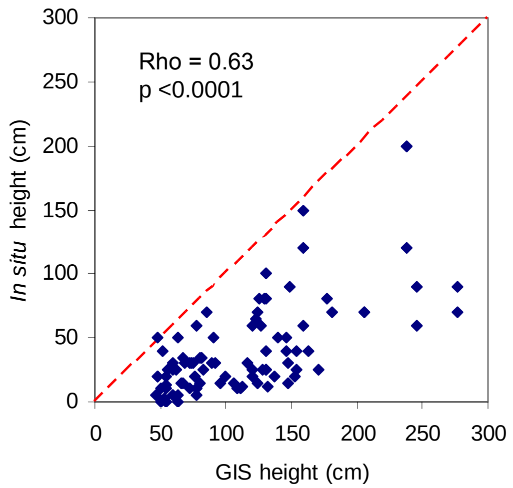

Figure 2.5. Comparison of maximum ledge height measured in situ and determined through GIS analysis of sonar data. The red dashed line represents the theoretical 1:1 ratio. Statistics for Spearman's rank correlation are provided.

height category and the hypothesis that diversity varied between ledge height classes was tested using a one-way ANOVA test (JMP v5.1).

2.4 RESULTS

Thematic accuracy

Overall map accuracy was quite high (93.3%), with 167 of 179 sites being correctly classified (Table 2.2). Kappa was 0.89 ± 0.03 indicating that the classification in the map is ~89% better than that expected if bottom types were randomly assigned to each polygon. A user of the benthic map can expect nearly 100% accuracy for flat sand and sparse live bottom, 81.3% for rippled sand, and 91.1% for ledge. Three sites classified in the map as rippled sand were identified as flat sand by divers. Nine of the sites classified as ledges in the map were identified as other bottom types by divers. Two such ledge sites were identified as rippled sand and the other seven were identified as sparse live bottom. A list of all misclassified sites along with relevant diver notes is given in Table 2.3.

Abiotic features

Ledge and sparse live bottom sites were dominated by hardbottom substrates, with very small amounts of sand or shell rubble cover (Figure 2.3). Mean cover of hardbottom did not vary significantly between ledge and sparse live bottom sites (X^2 = 0.5991, df = 1, p = 0.44). No hardbottom was observed at either flat or rippled sand sites

Table 2.4. Spearman coefficients (rho) computed for pair-wise correlations among ledge dimensions for 92 ledge sites.

Variable	by Variable	Rho	Pr>Rho
Undercut width (cm)	Total height (cm)	0.7029	<.0001
Ave. Undercut height (cm)	Total height (cm)	0.7269	<.0001
Ave. Undercut height (cm)	Undercut width (cm)	0.9673	<.0001

Table 2.5. Mean values and S.E. for dimensions of GRNMS ledge clusters determined from hierarchical clustering (Ward's minimum variance).

Cluster	N	Group	Total Height	Undercut Width	Undercut Height
1	60	Short	12.3 (1.0)	3.0 (0.7)	1.4 (0.3
2	26	Medium	45.5 (2.9)	34.0 (6.9)	15.5 (1.3)
3	6	Tall	115.8 (18.9)	175.1 (38.5)	38.4 (2.1)

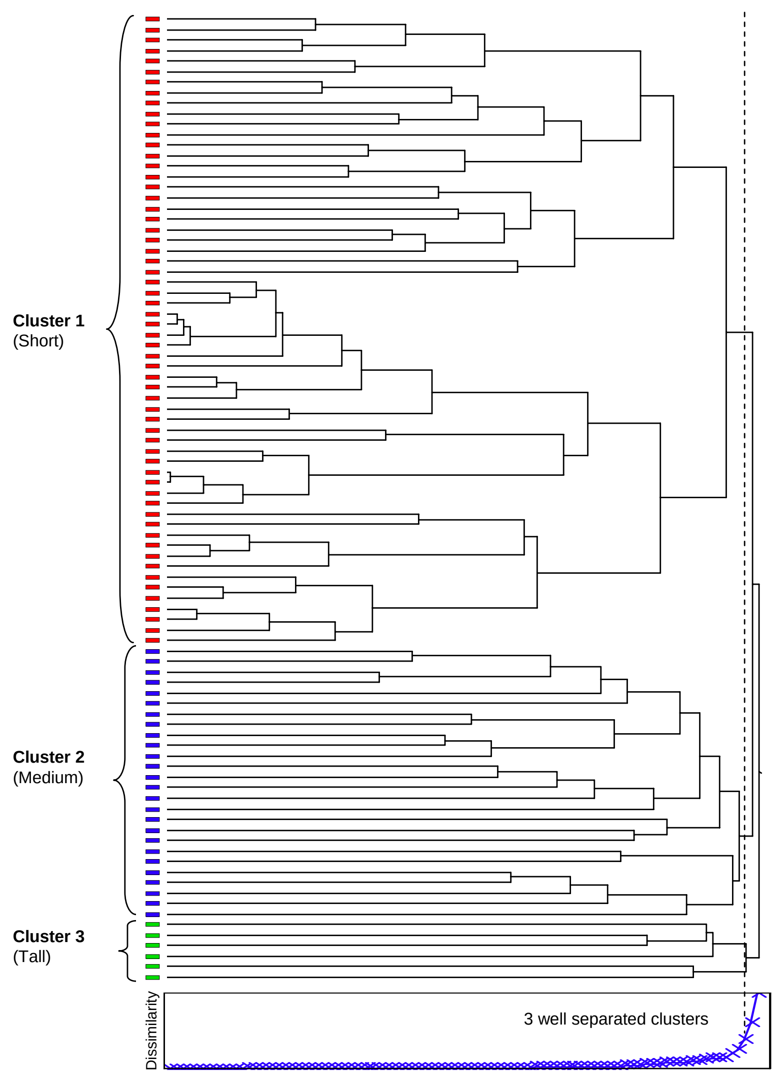

Figure 2.6. Dendrogram produced from hierarchical clustering of ledge sites based on three mean ledge dimensions (total height, undercut height, and undercut width).

(Figure 2.3). Sand and shell rubble dominated flat and rippled sand bottom sites (Figure 2.3). Shell rubble generally occurred in the troughs of sand waves on rippled sand sites. Ranking of mean sand and shell rubble values was not significantly different between flat sand and rippled sand sites ($X^2 = 0.56$, df = 1, p = 0.45). Fine sediment was not observed at any site surveyed.

The physical dimensions of the ledges surveyed exhibited wide variation and did not exhibit distinct spatial patterns (Figure 2.4). Strong positive pair-wise correlations occurred among ledge dimensions such that an increase in total height also correlated with an increase in undercut height and undercut width (Table 2.4). In particular, undercut height was highly correlated with undercut width (Table 2.4) Total height explained 70 and 72% of the variability in average undercut width and height, respectively. *In situ* maximum height correlated with maximum ledge height determined from the GIS analysis of sonar bathymetry (rho = 0.63, p < 0.0001). However, with the exception of one case, GIS derived heights were always higher than *in situ* field measurements (Figure 2.5).

Hierarchical clustering identified three groups of ledge sites based on their physical dimensions (Figure 2.6). Cluster one (hereafter "short") was the largest group and contained 60 short ledge sites with little or no undercut (Figure 2.6, Table 2.5). Cluster two (hereafter "medium") contained 23 ledge sites that were of medium height and moderate undercut, while Cluster 3 (hereafter "tall") had six tall ledges. A three dimensional plot of ledge sites against their

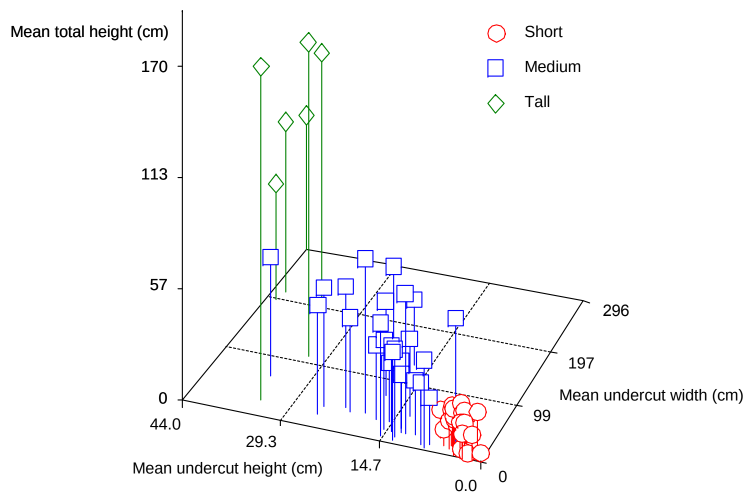

Figure 2.7. Three-dimensional plot of ledge clusters against ledge dimensions. Ledge sites from GRNMS were classified into three groups by hierarchical clustering using the Ward's minimum variance method.

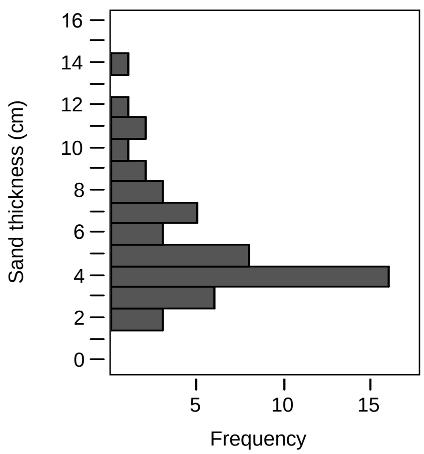

Figure 2.8. Histogram of average sand thickness on sparse live bottom sites.

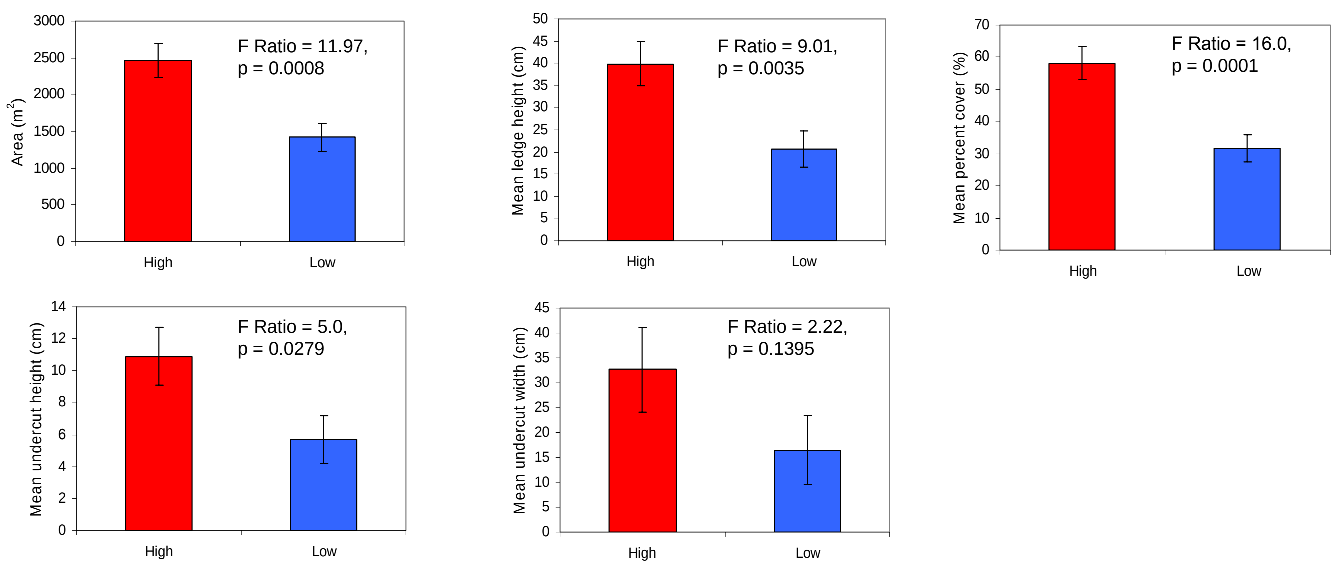

Figure 2.9. Means (± SEM) of ledge variables in areas of high and low boat density. Results of one-way ANOVA tests are provided (df = 91, α = 0.05).

Table 2.6. Summary statistics for biotic composition by bottom types. Blank cells indicate that zero organisms were observed.

			Ledge		Sparse live bottom		Flat sand		Rippled sand	
COVER TYPE	Morphology	Biotic variable	Mean	S.E.	Mean	S.E.	Mean	S.E.	Mean	S.E.
Corals	Ball	% Cover								
	Branching	% Cover	1.2	0.2	<0.1	<0.1				
	Cup	% Cover	<0.1	<0.1	<0.1	<0.1				
	Encrusting	% Cover	<0.1	<0.1	<0.1	<0.1				
	Other	% Cover	0.1	0.1	<0.1	<0.1				
Gorgonians	Sea fans	# Individuals	<0.1	<0.1	<0.1	<0.1				
		% Cover	<0.1	<0.1	<0.1	<0.1				
		Ht (cm)	1.4	0.5	1.1	0.4				
	Sea rod/plume	# Individuals	3.3	0.4	4.9	0.5	<0.1	<0.1	<0.1	<0.1
		% Cover	1.3	0.2	1.5	0.2	<0.1	<0.1	<0.1	<0.1
		Ht (cm)	13.5	1.4	19.4	1.5	0.7	0.8	1.2	0.9
	Sea whips	# Individuals	0.1	<0.1	0.1	<0.1	<0.1	<0.1		
		% Cover	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1		
		Ht (cm)	2.0	0.6	3.6	1.1	<0.1	<0.1		
Macroalgae	Filamentous/turf	% Cover	18.1	2.5	0.3	0.1	<0.1	<0.1		
	Fleshy	% Cover	<0.1	<0.1	0.1	<0.1				
	Other	% Cover	<0.1	<0.1						
Other	Anemones	% Cover	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Other	% Cover	4.6	1.2	0.5	0.2	<0.1	<0.1	<0.1	<0.1
	Tunicates (Encrusting)	% Cover	2.9	1.0	0.3	0.2				
	Tunicates (lobate)	% Cover	6.3	1.1	0.7	0.1				
	Zoanthids (benthic dwelling)	% Cover	0.4	<0.1	<0.1	<0.1				
Sponge	Ball	# Individuals	0.8	0.1	0.4	<0.1				
		% Cover	0.3	<0.1	0.1	<0.1				
		Ht (cm)	1.7	0.2	0.9	0.2				
	Encrusting	% Cover	2.4	0.4	0.4	0.2				
	Finger	# Individuals	0.4	<0.1	1.5	0.5				
		% Cover	0.2	<0.1	0.3	<0.1				
		Ht (cm)	1.3	0.2	2.0	0.4				
	Rope	# Individuals	0.2	<0.1	0.3	<0.1				
		% Cover	0.1	<0.1	0.1	<0.1				
		Ht (cm)	2.1	0.4	2.3	0.6				
	Tube	# Individuals	0.9	0.1	0.8	0.2				
		% Cover	0.7	0.1	0.2	<0.1				
		Ht (cm)	3.4	0.5	2.7	0.9				
	Vase	# Individuals	2.2	0.3	0.5	<0.1				
		% Cover	3.5	0.4	0.4	0.1				
		Ht (cm)	12.1	1.0	2.6	0.5				

dimensions revealed interesting differences among the ledge clusters (Figure 2.7). The three ledge clusters were well separated along the mean undercut height axis such that the tallest ledges generally had the highest undercut height and the shortest ledges had the shortest undercuts. The tallest ledges generally also had the largest average undercut width, but there were exceptions to this trend (Figure 2.7).

The mean numbers of burrows in flat and rippled sand were 0.92/m^2 ± 0.20 SE and 0.74/m^2 ± 0.23 SE, respectively. There was not a significant difference in the number of burrows between the two bottom types (F = 0.3553, df = 35, p = 0.55). Mean sand thickness on sparse live bottom was 5.4 cm ± 0.4 SE and ranged from 1.6 cm to 14.4 cm (Figure 2.8). The measured sand thickness (i.e. within quadrats) ranged from 0 cm to 30 cm, which was the maximum depth of sand measured. There was a large mode in mean thickness at 4 cm, with 50% of the sites having a mean thickness between 3.6 and 6.6 cm.

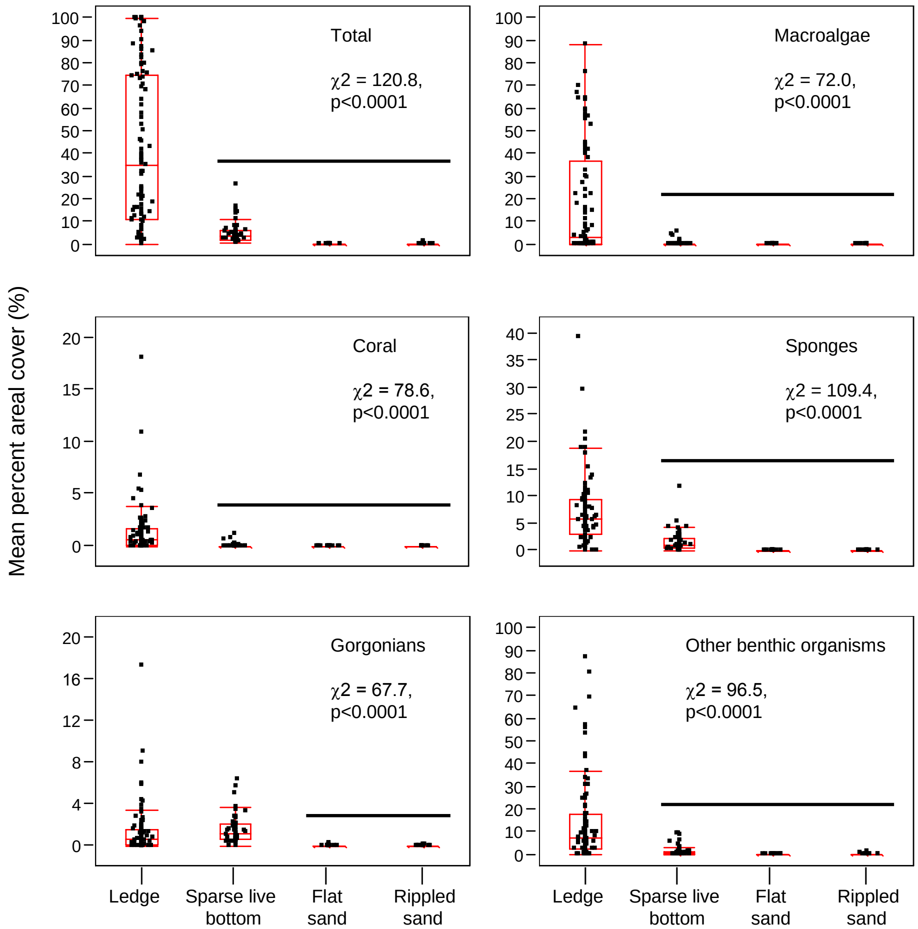

Figure 2.10. Box plots of percent cover of benthic organisms on four bottom substrates at GRNMS. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (df = 3, alpha = 0.05). Solid horizontal lines join groups that are not significantly different from each other.

Ledges in the area of high boat density were significantly larger in area, taller, more undercut, and more densely covered by benthic organisms than ledges in the low boat density area (Figure 2.9). Undercut width was more variable, as exhibited by the high standard error, and was not statistically different between the two regions.

Biotic cover

Summary statistics for biotic composition by bottom type are displayed in Table 2.6. Multiple comparison tests indicated that cover of coral, macroalgae, sponges, and other benthic organisms was significantly greater on ledges than the other bottom types (Figure 2.10). Flat sand and rippled sand bottom types were characterized by low percent cover (0-2%) of benthic organisms at all sites (Figure 2.10, Figure 2.11). Percent biotic cover at sparse live bottom ranged from 0.7-26.3%, but was only greater than 10% at 7 out of 51 sites (Figure 2.12). On ledge bottom type, percent cover ranged

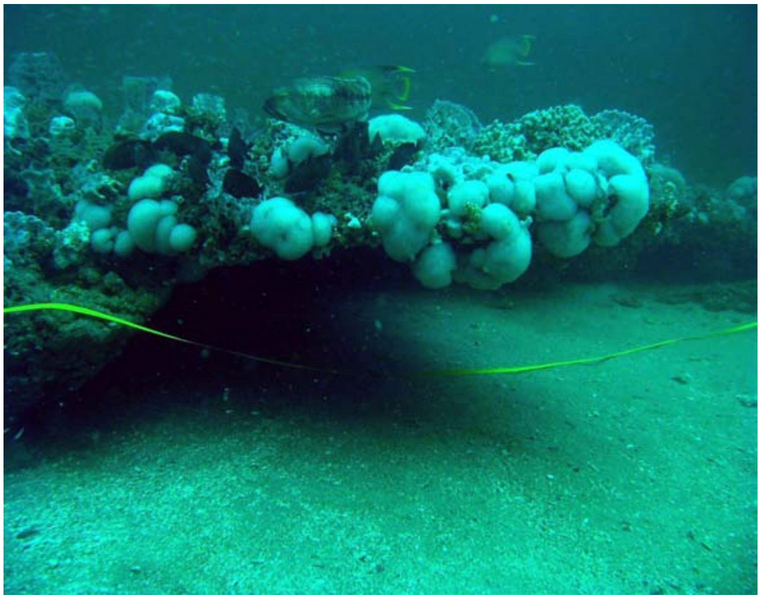

Image 11. Undercut ledge densely colonized by tunicates and other benthic organisms.

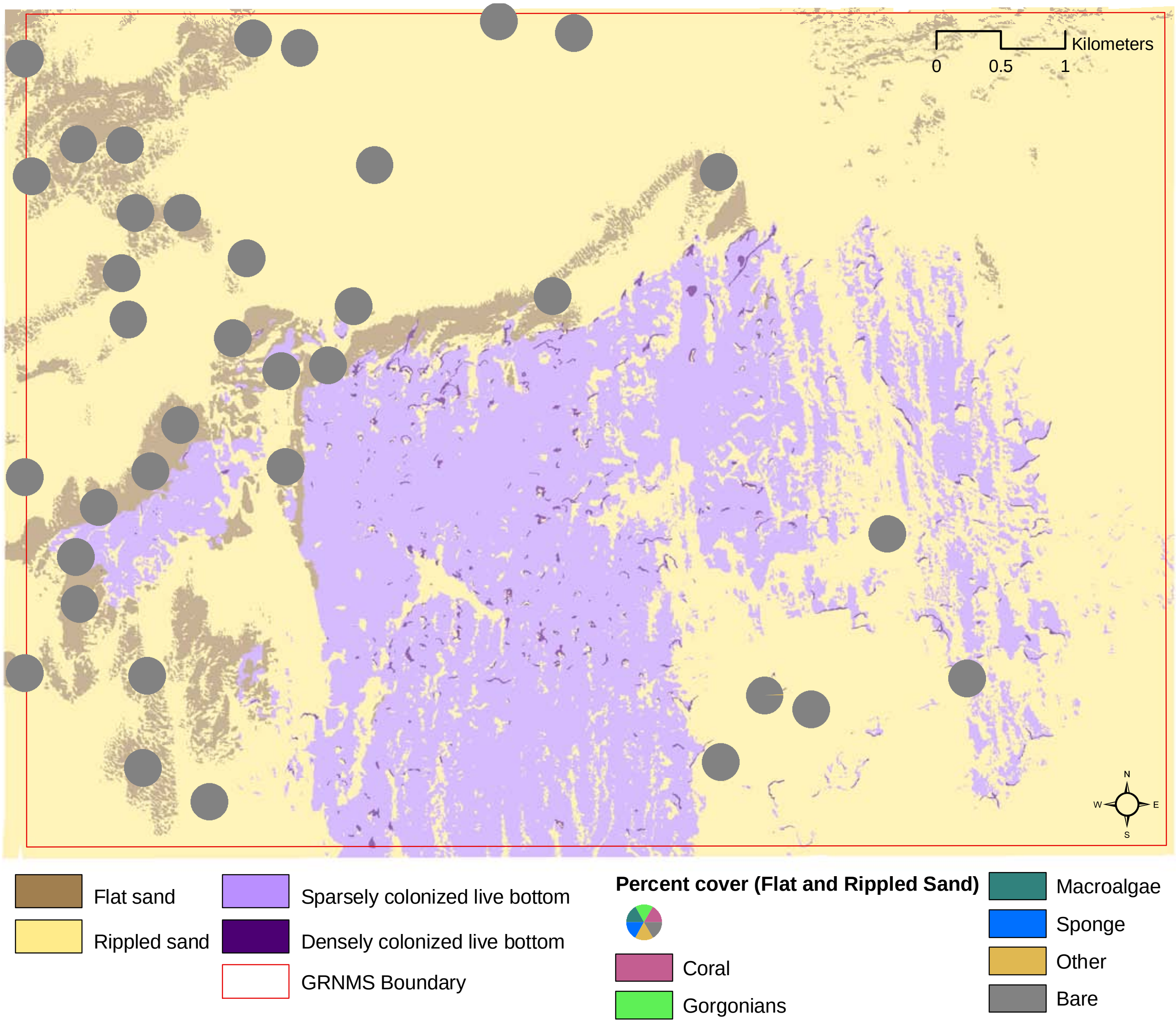

Figure 2.11. Percent cover of biotic cover groups on flat and rippled sand bottom sites.

from 0.42-100%, with the highest percent cover at ledges in the central and south-central region of GRNMS (Figure 2.13). However, percent cover of gorgonians and mean number of gorgonians did not vary significantly different between ledge and sparse live bottom sites (Figure 2.10, Figure 2.14). Although a significant difference was detected in the height of gorgonians among the four bottom types, no pair-wise tests were significant (Figure 2.15). In contrast, sponges were significantly more numerous and taller on ledges than on sparse live bottom (no sponges were found on either sand bottom type) (Figure 2.15). Shannon-Weiner diversity of biotic types was significantly greater at ledge and sparse live bottom than at either sand bottom type (Figure 2.16).

Cover of corals and gorgonians were generally low (range = 0-18%, mean = 1.35%). Branching coral was the most frequently encountered coral type (Figure 2.17), and sea rod/plumes were the most frequently encountered gorgonians (Figure 2.18). A high cover of filamentous macroalgae was typical at many of the densely colonized ledges (Figure 2.13, Figure 2.19), while several of the northernmost ledges were characterized by high cover of sponges, tunicates, and miscellaneous species (including bryozoans, molluscs, barnacles, and other unclassified taxa) within the “other” category (Figure 2.20-2.22). Numerous sponge types were observed throughout the sanctuary, including encrusting, tube, and vase sponges (Figure 2.20).

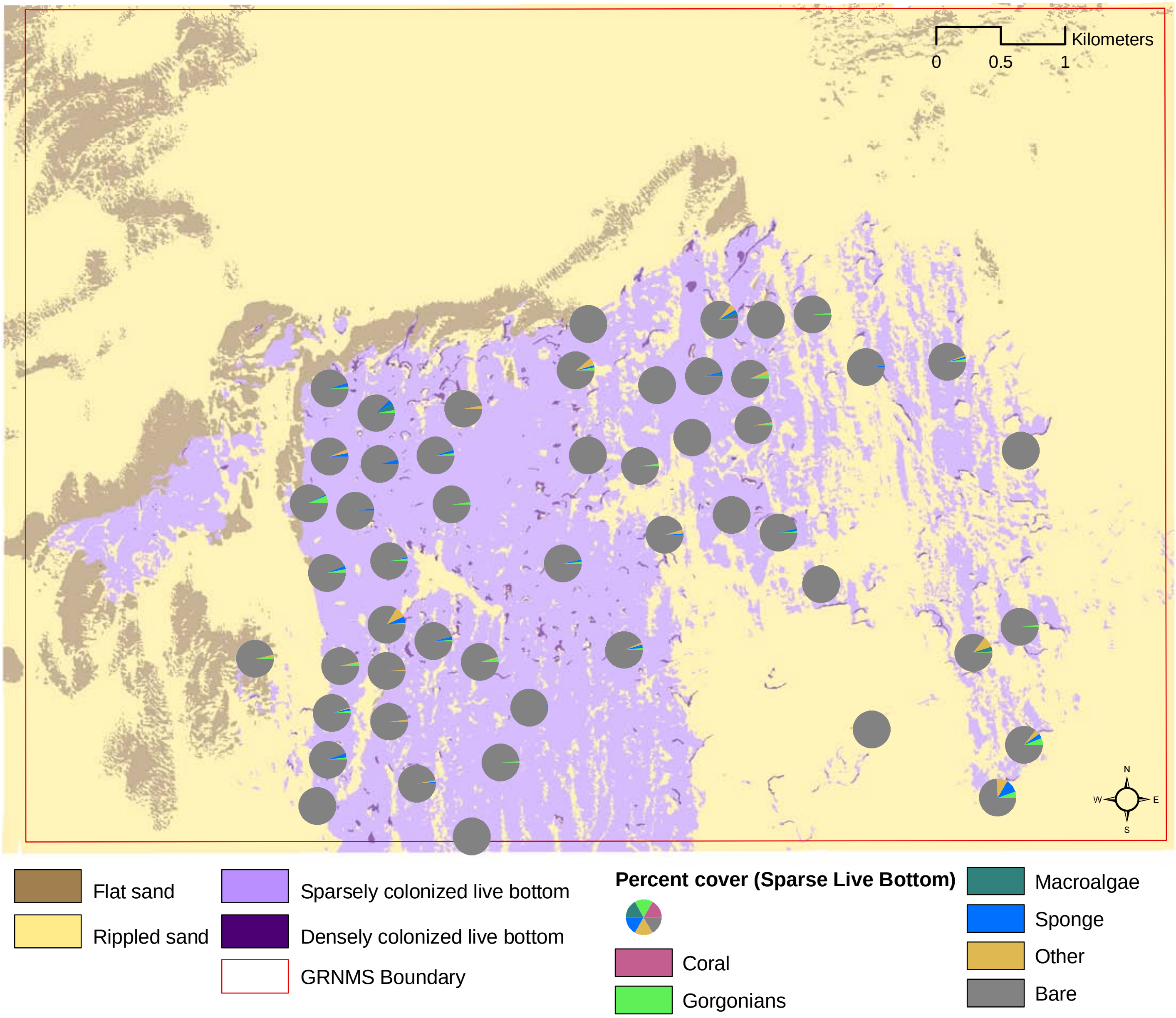

Figure 2.12. Percent cover of biotic cover groups at sparse live bottom sites.

Cluster analysis of percent cover data for all sites revealed the presence of eight distinct groups of sites (Figure 2.23). Mean percent cover of the aggregated cover types for each cluster is displayed in Figure 2.24. Cluster 1 was composed primarily of ledge sites and was characterized by the highest mean percent cover of sponges (mean = 23 ± 3% SE). In addition, it has a moderately high (mean = 22 ± 6% SE) mean cover of species within the "other" category. Cluster 2 was a larger cluster, again composed of mostly ledges. Total percent cover averaged just under 30% and was typified by macroalgae, sponges, and other species. Clusters 3-6 contained only ledge sites. Clusters 3 and 5 were "outliers" as they contained only one site each and were characterized by highest percent cover of coral and gorgonians, respectively. Sites within Cluster 4 typically were characterized by the highest percent macroalgal cover. Sites within Cluster 6 were also highly colonized, but these sites were dominated by organisms within the "other" category such as tunicates. All of the flat sand and rippled sand sites were included in Cluster 7, in addition to several ledges and numerous sparse live bottom sites. Sites within this cluster were characterized by low percent cover of all organism types (mean total cover = 1.8 ± 0.3% SE). Mean total cover in Cluster 8, which contained ledge and sparse live bottom sites, was the second lowest among the clusters (mean total cover = 8 ± 1% SE) but mean gorgonian cover was higher than many of the other clusters. There were no obvious spatial patterns in the distribution of clusters.

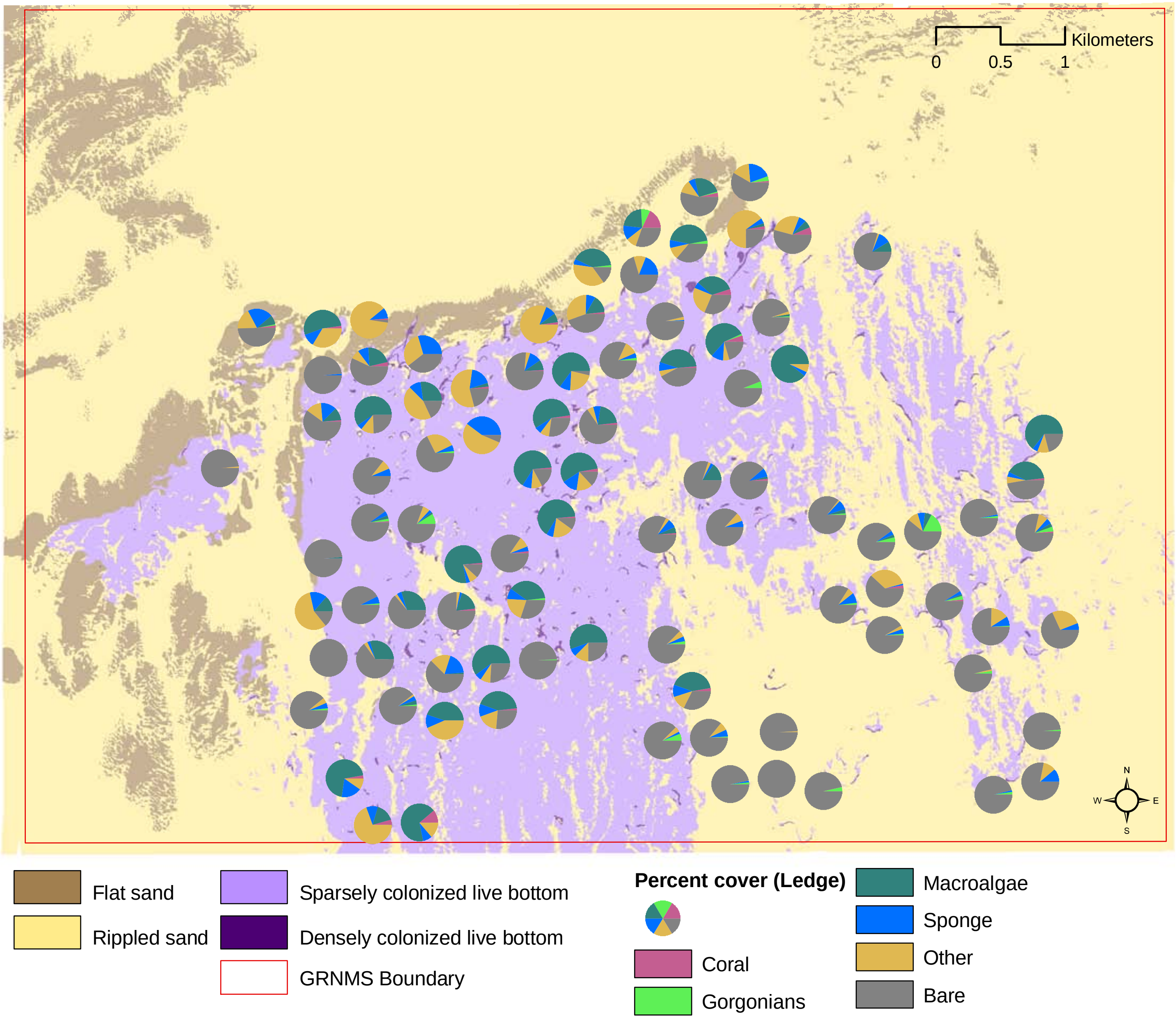

Figure 2.13. Percent cover of biotic cover groups at ledge sites.

Cluster analysis of only ledges resulted in six well separated clusters (Figure 2.25). The resulting clusters were very similar to those in the first analysis that encompassed all bottom types, with the primary difference being a larger cluster containing sites that had been previously dispersed among a few clusters. Similar to the first analysis, two clusters (4 and 5) contained only one site each that had high percent cover of corals and gorgonians, respectively (Figure 2.26). Cluster 1 was characterized by the highest mean percent cover of sponges of all clusters, as well as moderate-high cover of species within the other category. Cluster 2, containing 52 ledges, was characterized by a mean total cover of 28.6 % (± 4.4 SE). Sites in Cluster 3 were densely colonized, particularly by macroalgae. Cluster 6 was characterized by the highest mean cover of "other" species, primarily tunicates.

Abiotic effects on biotic composition

The effect of ledge height on individual cover types was examined through the use of nonparametric Kruskal-Wallis tests. Results revealed significant differences in total biotic cover for all cover types among ledge size categories determined from cluster analysis of abiotic variables (Figure 2.27). Median total percent cover was 97.6%, 75.1%, and 17.7% on tall, medium, and short ledges, respectively. The majority of the ledges classified as medium or tall tended to have high overall percent cover. All tall ledges (n=6) had >50% total cover, compared with 65% of medium ledges (n=26), and 22% of short ledges (n=60). Short ledges had significantly lower percent cover than medium or tall ledges, but there was not a significant difference between medium and tall

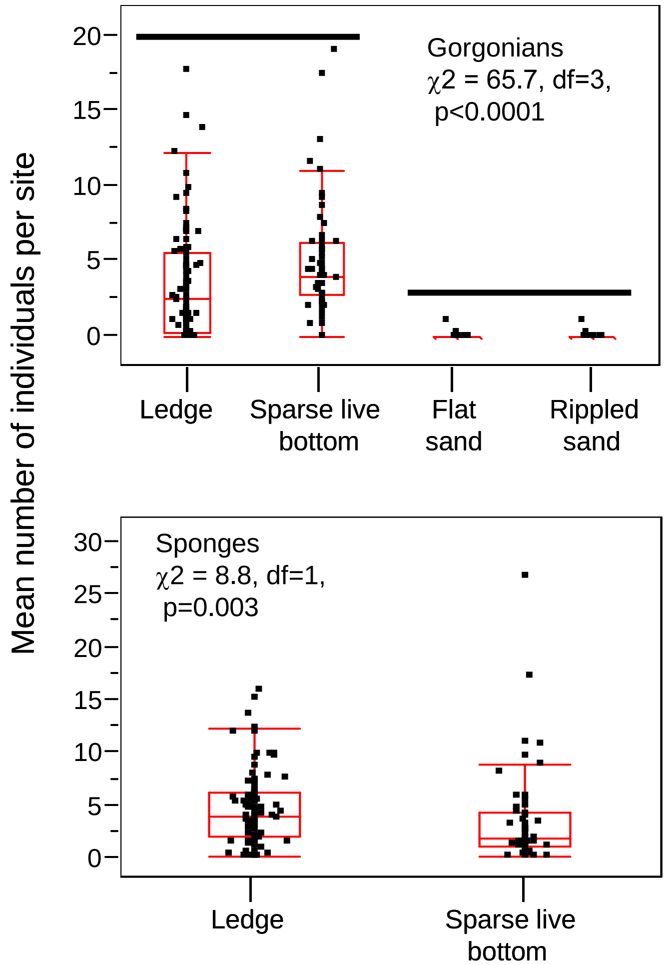

Figure 2.14. Box plots of number of gorgonians and sponges on four bottom substrates at GRNMS. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (alpha = 0.05). Sponges were not observed on flat or rippled sand bottom types. Solid horizontal lines join groups that are not significantly different from each other.

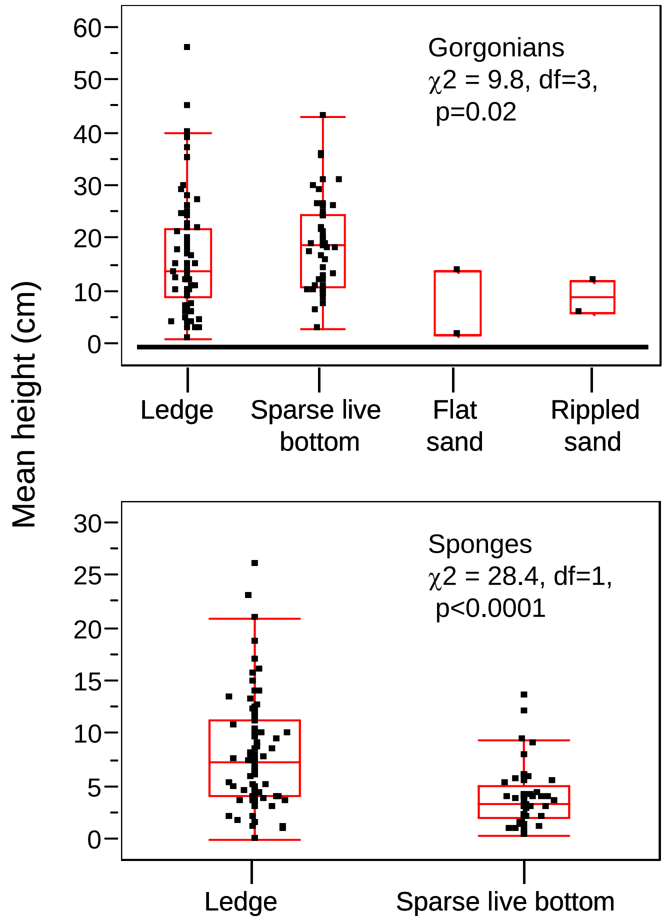

Figure 2.15. Box plots of height of gorgonians and sponges on four bottom substrates at GRNMS. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (alpha = 0.05). Sponges were not observed on flat or rippled sand bottom types. Solid horizontal lines join groups that are not significantly different from each other. Although the overall test was significant for gorgonian height, no pairwise comparison tests were significant.

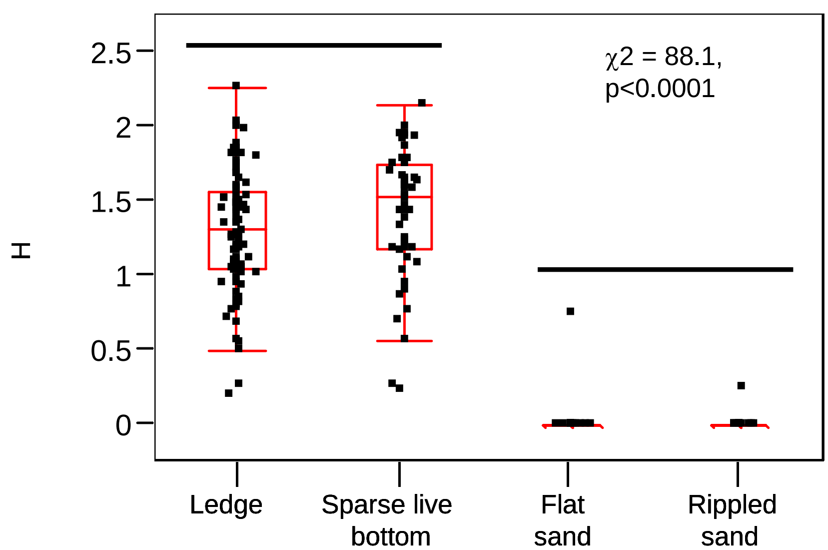

Figure 2.16. Box plots of Shannon diversity index (H) by bottom type. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (df = 3, alpha = 0.05). Solid horizontal lines join groups that are not significantly different from each other.

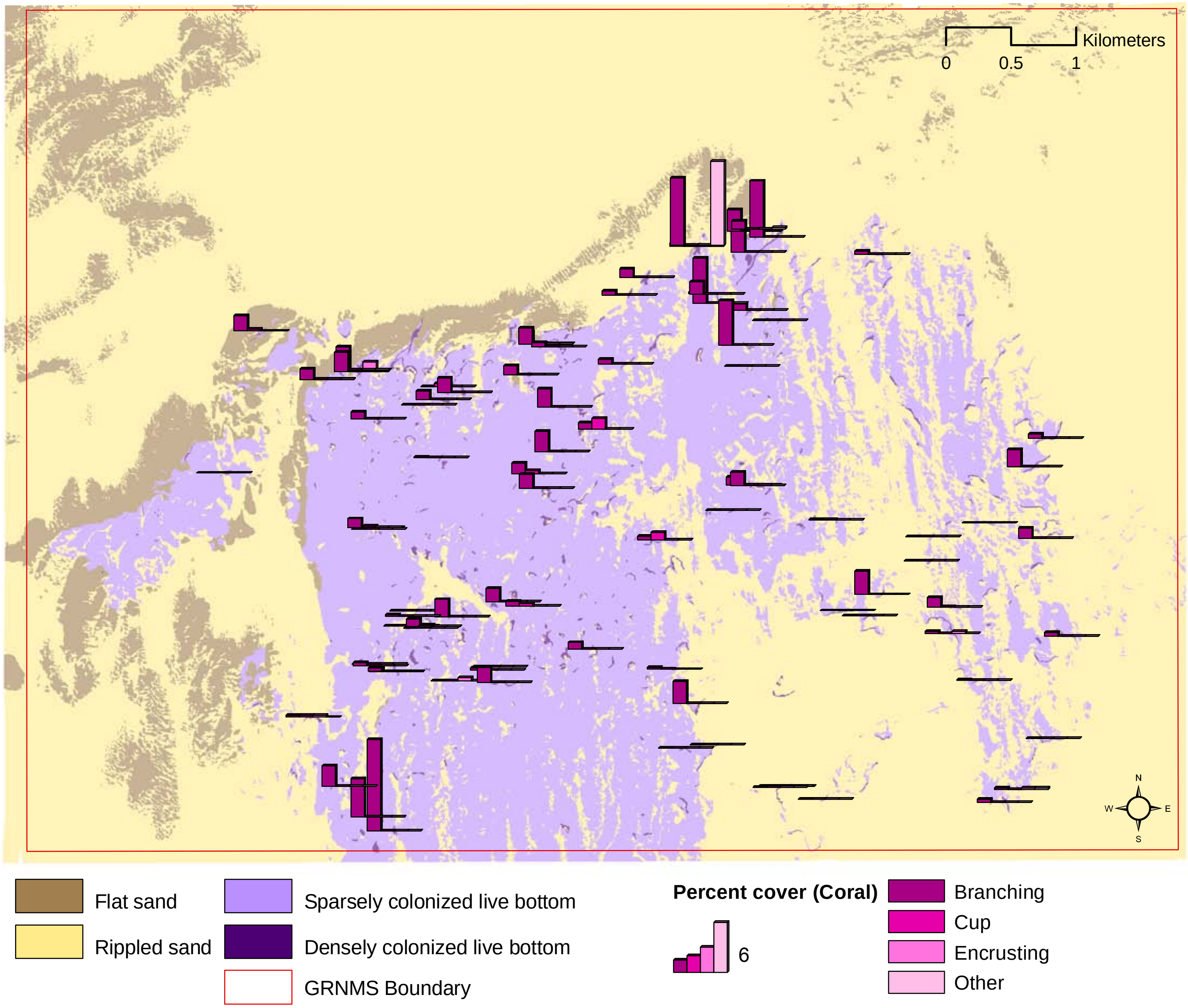

Figure 2.17. Percent cover of coral types at ledge sites. The tallest bar in the legend represents 6% cover.

ledges. Median coral cover was low (<2%) for all ledge types, but was significantly higher on medium than short ledges. Percent cover of gorgonians was significantly higher at short ledges when compared with medium or tall ledges. Macroalgal cover ranged from 0-76.2% (median = 0.8%) on short ledges, 0-88.4% (median = 21.44%) on medium ledges, and 7.6-64.5% (median = 29.9%) on tall ledges. Sponge cover ranged from 0-21.6% (median = 4.35%) on short ledges, 2.84-39.4% (median = 7.9%) on medium ledges, and 8.2-15.2% (median = 10.0%) on tall ledges. Cover of other benthic species ranged from 0-33.3% (median = 4.6%) on short ledges, 0.8-86.7% (median = 13.2%) on medium ledges, and 21.8-80.3% (median = 38.4%) on tall ledges. Cover of macroalgae, sponges, and other benthic organisms was significantly higher at medium or tall ledges when compared with short ledges, but there was not a significant difference between medium and tall ledges.

The number of individual gorgonians was greater at short ledges than at medium or tall ledges (Figure 2.28). Short ledges were also characterized by significantly fewer sponges. The number of sponges or gorgonians was similar on medium and tall ledges. There was no significant difference in the height of gorgonians between short and medium ledges (Figure 2.29); tall ledges were excluded from this analysis because gorgonians were only present on one tall ledge. In contrast, sponges were significantly shorter on short ledges compared with the other ledge types (Figure 2.29). Shannon diversity did not vary significantly between short, medium, and tall ledges ($F = 0.24$, $df = 91$, $p = 0.79$).

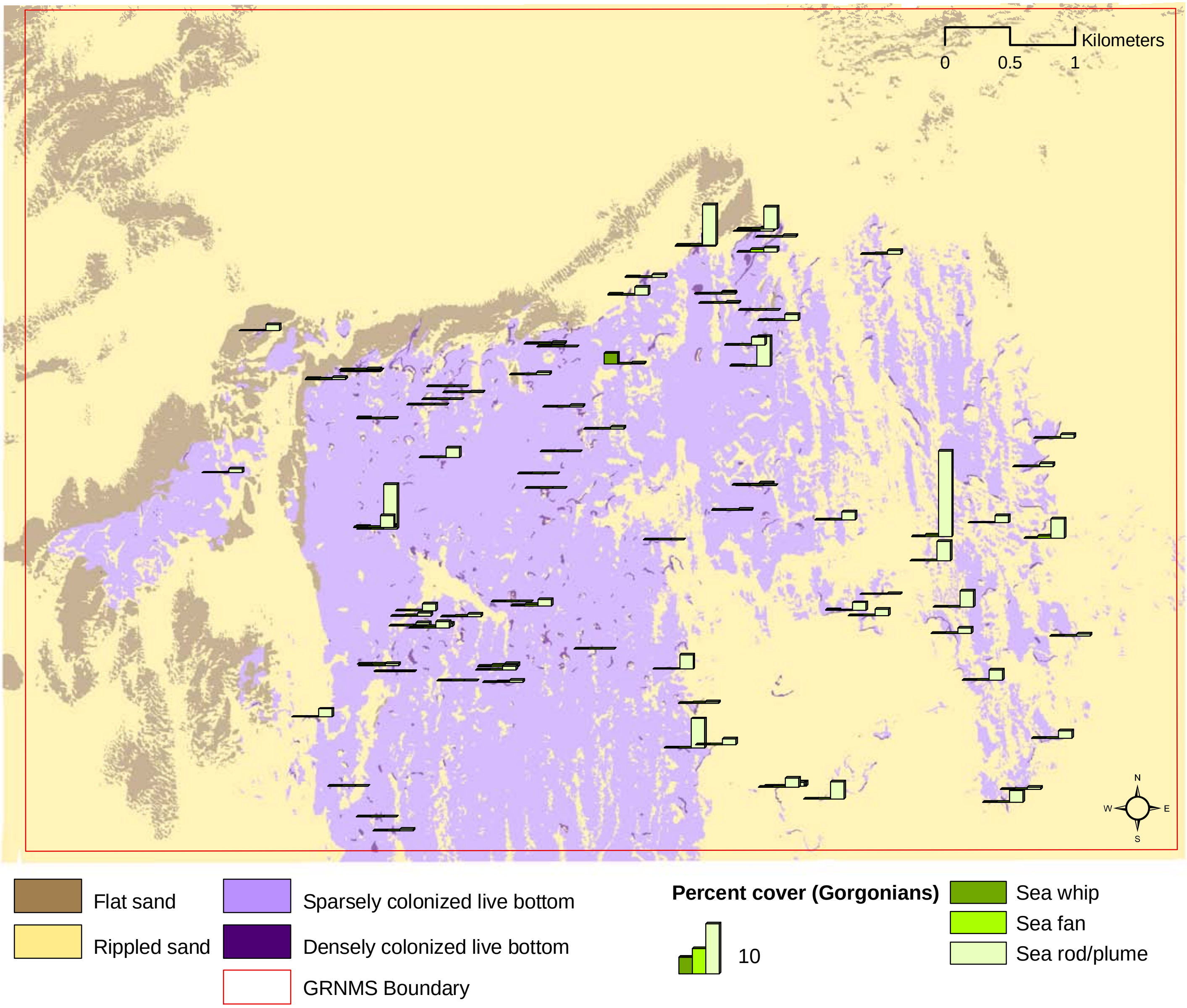

Figure 2.18. Percent cover of gorgonian types at ledge sites. The tallest bar in the legend represents 10% cover.

2.5 DISCUSSION

GRNMS is composed of four main bottom types that have distinct physical and biological characteristics. In support of ongoing management of sanctuary resources, the overall goal of this component of the characterization was to quantify abiotic features and cover of benthic species. This study builds on previous work of benthic habitats in GRNMS, which includes benthic habitat mapping (Kendall et al. 2005), a guide to invertebrates (Gleason et al.), macroalgae (Searles 1988), a characterization of soft-bottom macrobenthos (Hyland et al. 2006) and several studies that surveyed individual species or communities associated with live bottom within GRNMS (Hopkinson et al. 1991; Ruzicka 2005; Wagner 2006). The primary difference between this characterization and prior surveys is that the present study encompassed all habitat types and quantified both abiotic characteristics and epibenthic communities at a large number of site locations throughout the sanctuary.

Our first objective was to assess the accuracy of the habitat maps by Kendall et al. (2005). Overall map accuracy was excellent at 93.3% as measured in the present study. Kendall et al. (2005) previously estimated a similarly high level of overall thematic accuracy at 94.8% correct although quite different methods were used. While the present assessment used random stratified points and diver based assessments, Kendall et al. (2005) used randomly placed video transects and spatial statistics. Kendall et al. (2005) were limited to assessing sand (both rippled and flat combined) and sparse live bottom due to the nature of the transect and video based data. Quantitative assessment of the accuracy of the ledge category was not possible. Considering only sparse live

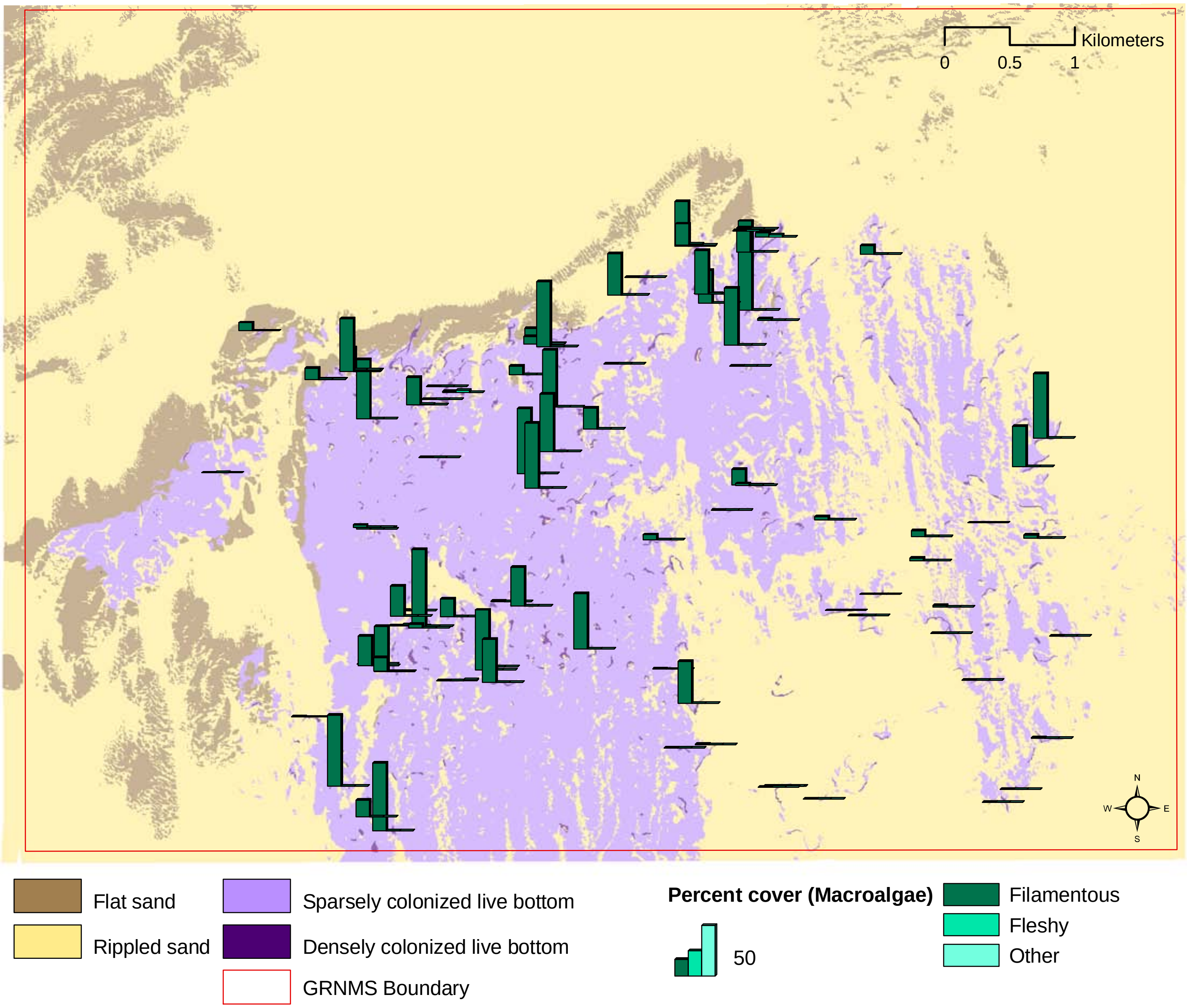

Figure 2.19. Percent cover of macroalgae types at ledge sites. The tallest bar in the legend represents 50% cover.

bottom and sand, similarly high values were found by Kendall et al. (2005) and in the present study despite quite different methods. For sparse live bottom, Kendall et al. (2005) found user's and producer's accuracies of 90.9% and 93.0% respectively, compared to 100% and 86.3% in the present study. For sand, Kendall et al. (2005) found user's and producer's accuracies of 96.7% and 95.7% respectively whereas in the present study we found values of 100% and 94.4% (when results from rippled and flat sand were combined). In the present study, user's and producer's accuracies of the ledge category were 91.1% and 100%, respectively. The combined findings of these two studies demonstrate a robust and complete accuracy assessment of all the bottom types at GRNMS.

All nine errors in the ledge category of the present assessment occurred in the August 2004 sampling period. At two sites which were surrounded by large areas of sand on all sides, divers' notes indicated the presence of a deflection in bathymetry that was sparsely colonized with sessile benthic invertebrates. These ledges were probably better defined in 2001 when the sonar data were collected, but were now in the process of being covered by shifting sands. Further along the length of these features, the ledge may have been better defined. However, because a ledge was not readily observable at either of these two sites, the divers noted that they moved off a short distance and did a survey over rippled sand in order to not waste the dives. At two other sites identified as sparse live bottom, the divers noted that ledges were nearby but that the survey was conducted on sparse live bottom. No special notes were made for five other ledge sites identified as sparse live bottom. After this first sampling period it became apparent that some small ledges could be missed by divers searching for them un-

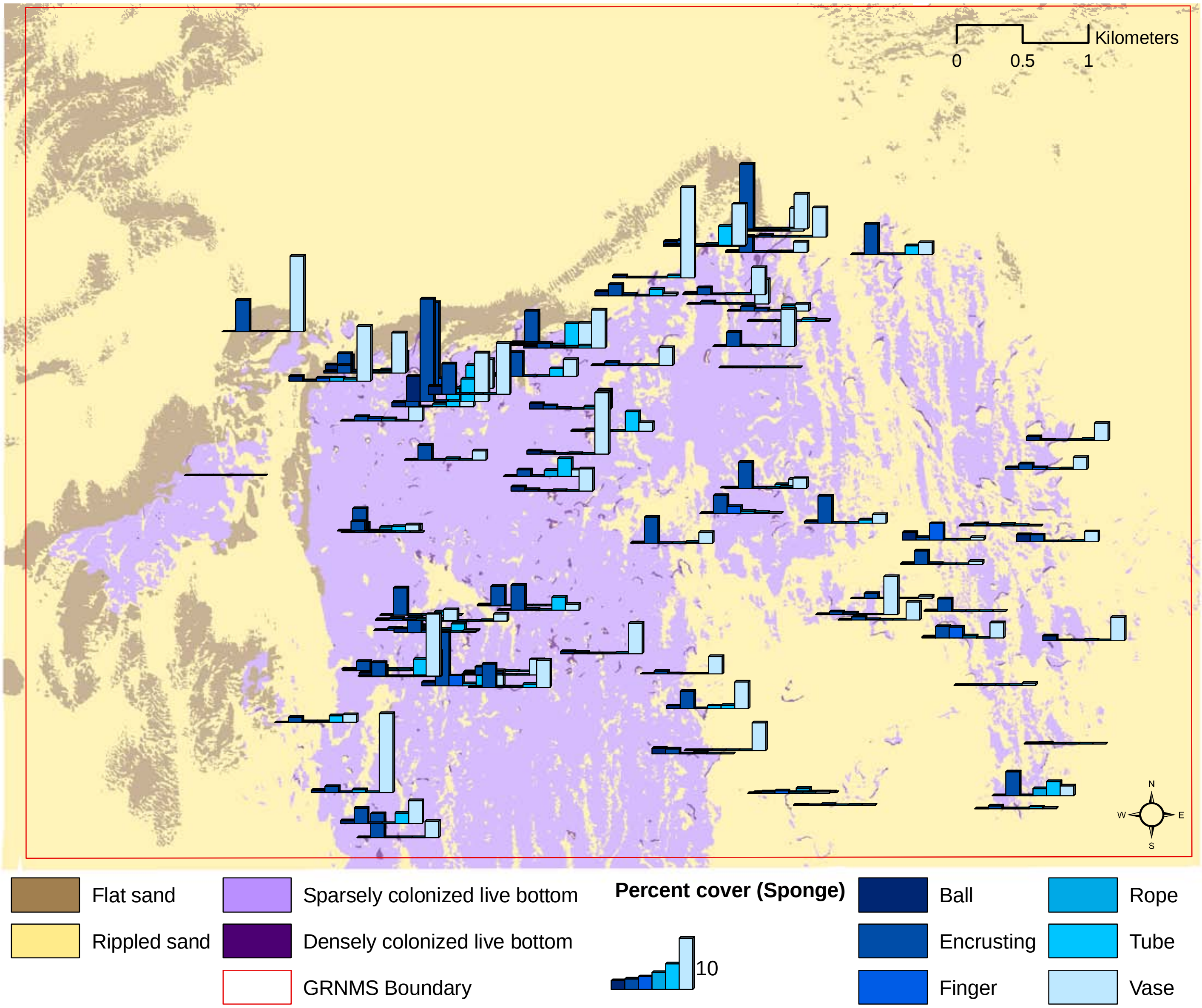

Figure 2.20. Percent cover of sponge types at ledge sites. The tallest bar in the legend represents 10% cover.

derwater due to the often limited visibility at GRNMS. For later sampling trips, the starting point of each randomly selected ledge was moved based on sonar images to a segment of the ledge that was likely to be more easily located underwater. Once on a ledge it can be followed more easily through areas even where it is less prominent. Indeed no other ledges were missed in the subsequent two sampling periods once this modification to site selection was made. Some combination of actual map errors, ledges being covered by sand, and diver error is probably responsible for the large number of discrepancies between map and diver opinion in the August 2004 sampling period.

All three remaining errors were in the sand category and occurred during the August 2005 sampling period. This most recent of the sampling periods was four years and two months after the sonar data used to develop the benthic maps were collected in June 2001. This time gap would allow time for bottom altering forces such as bioturbation to rework the surficial sediments (Sisson et al. 2002) and for localized water movements to create or remove sand ripples. Indeed, the presence of many echinoderms reworking the surface was noted at one site that was mapped based as rippled sand (2001 data) but was later identified as flat sand in 2005.

In situ ledge height estimates confirmed sonar derived estimated of ledge heights. Ledge height estimated from GIS analysis was positively correlated with maximum ledge height measured *in situ* although GIS height was always higher than *in situ* estimates. There are two possible explanations for this discrepancy. First, *in situ* ledge

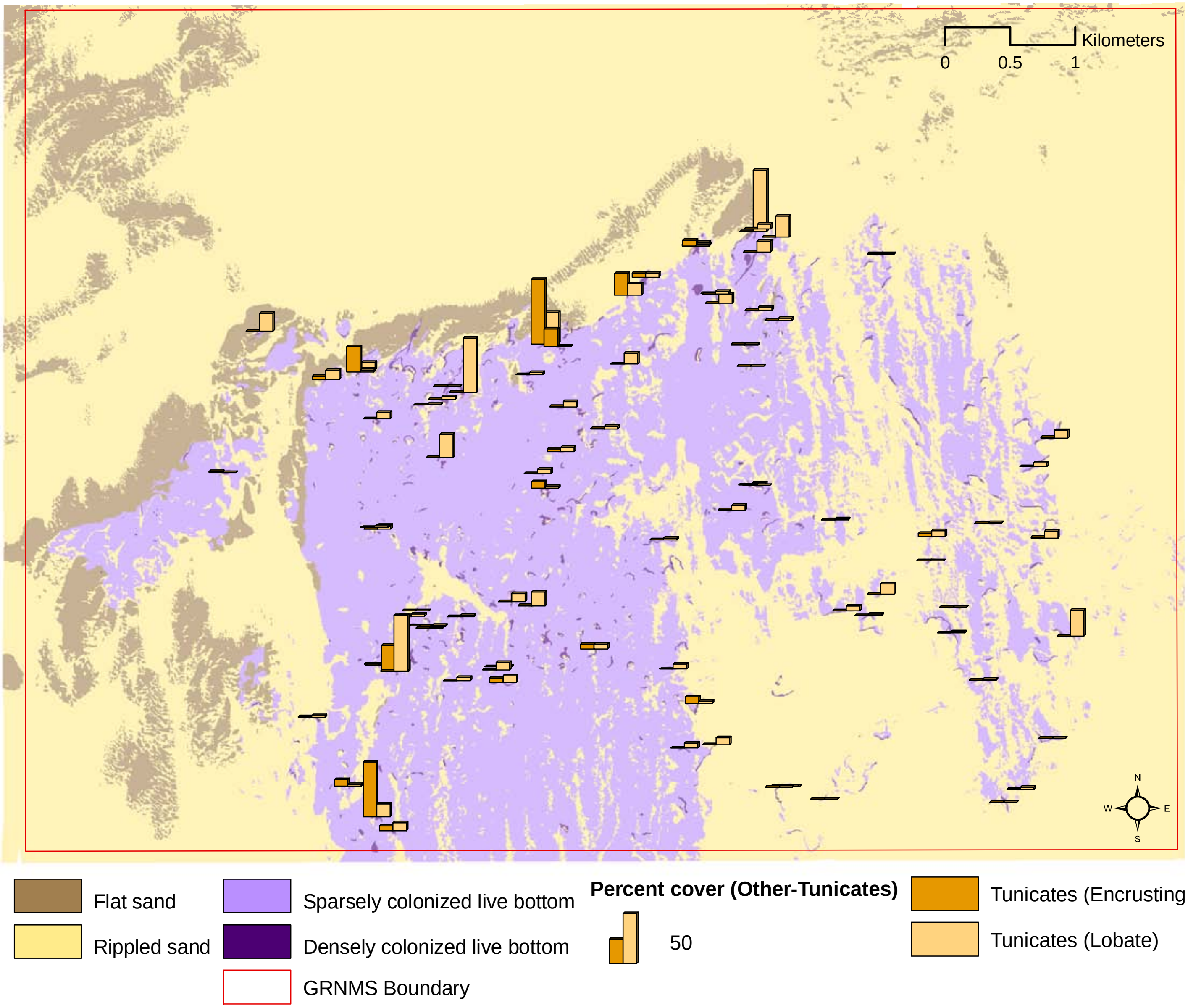

Figure 2.21. Percent cover of tunicates at ledge sites. The tallest bar in the legend represents 50% cover.

height was only measured at five points along a 25 m transect. Many ledges were longer than this and it is quite possible that the tallest part of the ledge simply wasn't measured. Second, differences in height estimates may be a product of the way GIS height was determined. Height was calculated as the difference between the deepest and shallowest bathymetry values. In the case of a broadly sloping ledge, it is likely that these points would be located at opposite ends of the ledge. In such a case, height measured by a diver at any location along the ledge would be lower than the maximum GIS height.

Biological and physical processes work to continually shape the sand and hardbottom features. The sand and shell rubble observed on sparse live bottom sites may have been deposited through sand movement from nearby sandy areas or from weathering of hardbottom. Fine sediments were not observed, which is consistent with previous records of sediment distribution on the mid-continental shelf in the South Atlantic Bight (Milliman et al. 1972; Riggs et al. 1996; Hyland et al. 2006). Large storms and seasonal storm patterns can cause sediments to shift, which may alter benthic communities or result in an import/export of sediments to the system (Riggs et al. 1998). This constant shifting of sediments likely prevents the flat hardbottom from becoming more densely colonized by epibenthic fauna. The sediment layer covering the bottom was usually several centimeters thick (up to 18 cm) which would prevent larvae from settling, or bury recent recruits. The most common cover type on sparse live bottom was sea rods/plumes, which are often quite tall (mean height = 19.4 cm), making them less vulnerable to burial. Furthermore, these gorgonians may have colonized the sparse live bottom areas when such

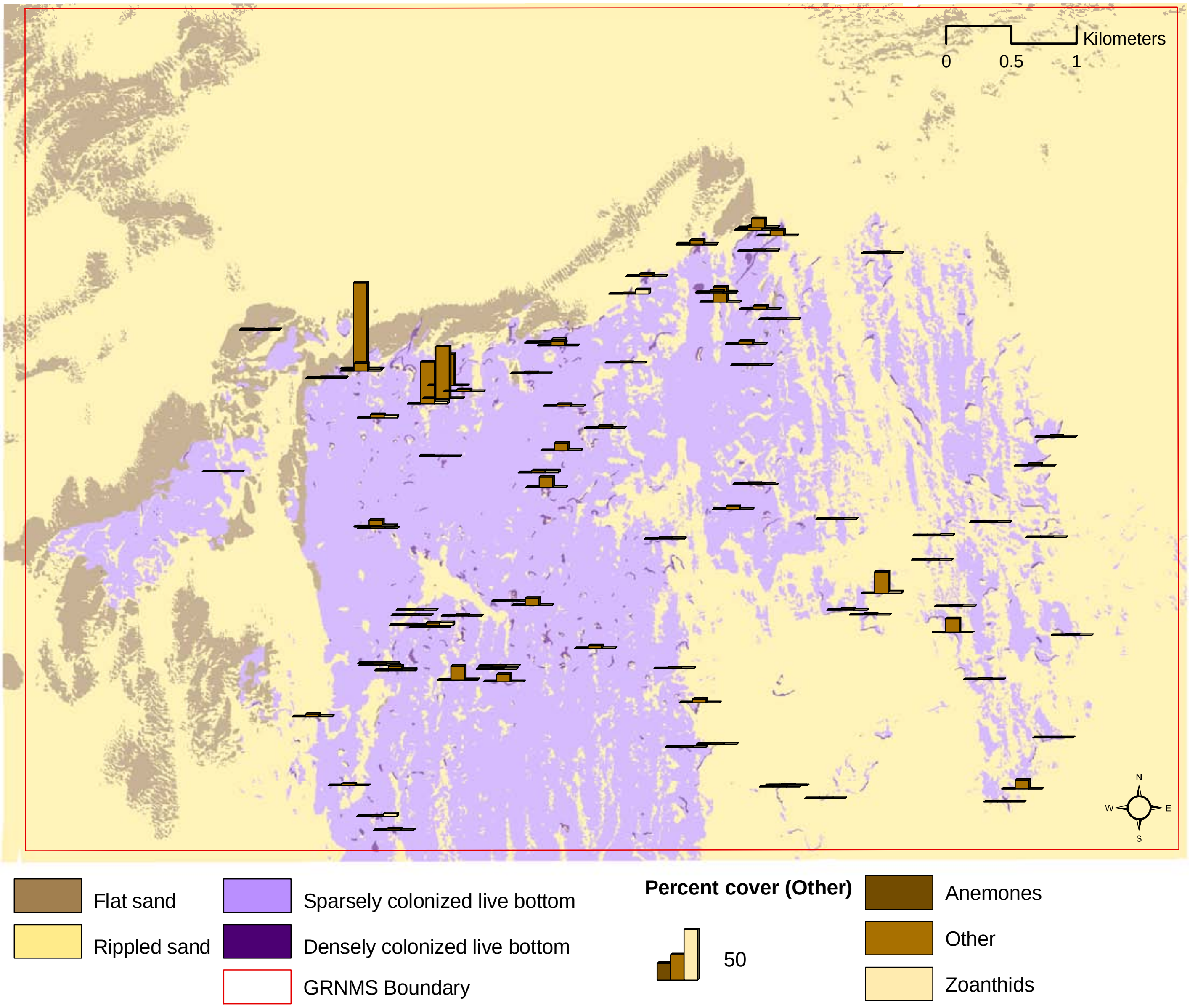

Figure 2.22. Percent cover of "other" benthic cover types at ledge sites. The tallest bar in the legend represents 50% cover.

areas were uncovered by sand or may have growth rates that exceed the rate of sand deposition on hardbottom. At some sites, divers cleared away sand that covered sparse live bottom and noted living sponges and ascidians that may have recently been buried by sand. In addition, the mean number of sponges on sparse live bottom was not significantly different from ledges, but sponges were smaller and covered a smaller percentage of the substrate on sparse live bottom. Sponge morphology also differs between different bottom types. In a recent study at GRNMS and nearby J Reef, Ruzika (2005) documented distinct sponge communities at ledge "scarps" (ledges in the present study) and "plateaus" (similar to sparse live bottom in the present study). The majority of species occurring on the scarps were amorphous or encrusting species, while the plateaus were characterized by branching, penduncculate, or digitate sponges (Ruzika 2005).

Numerous cover types were observed on ledges, including macroalgae, sponges, tunicates, coral, and gorgonians. High diversity of macrofauna in Gray's Reef and other stations in the inner and mid-shelf was also observed by Wenner et al. (1983). Although that survey was conducted using dredge and trawl methods, the taxonomic groups of major importance included sponges, bryozoans, corals, anemones, tunicates, and echinoderms. Hopkinson et al. (1991) documented similar taxa in GRNMS in association with a survey of community metabolism at an east-central site along the northern rim of ledges and hardbottom. Dominant morphology types included sponges, corals, and miscellaneous species (bryozoans, hydroids, ascidians, and mussels). Hopkinson et al. (1991) also found higher coral cover than was observed at any site in the present study; however, the one area sampled may have been a hot spot for coral cover. Thus, it may be inappropriate to compare our average estimates of coral cover to that reported by Hopkinson et al. (1991). In addition, in the previous study, mean macroalgal cover did not exceed 9% at low, medium, and high density areas (Hopkinson et al. 1991).

Linking biological community structure to the environment is a major goal of ecology but often is difficult to assess (Clarke and Ainsworth 1993). Geological differences in substrate type or morphological complexity have been linked to community structure, but the patterns are not always universal (Davis et al. 2003; Beaman et

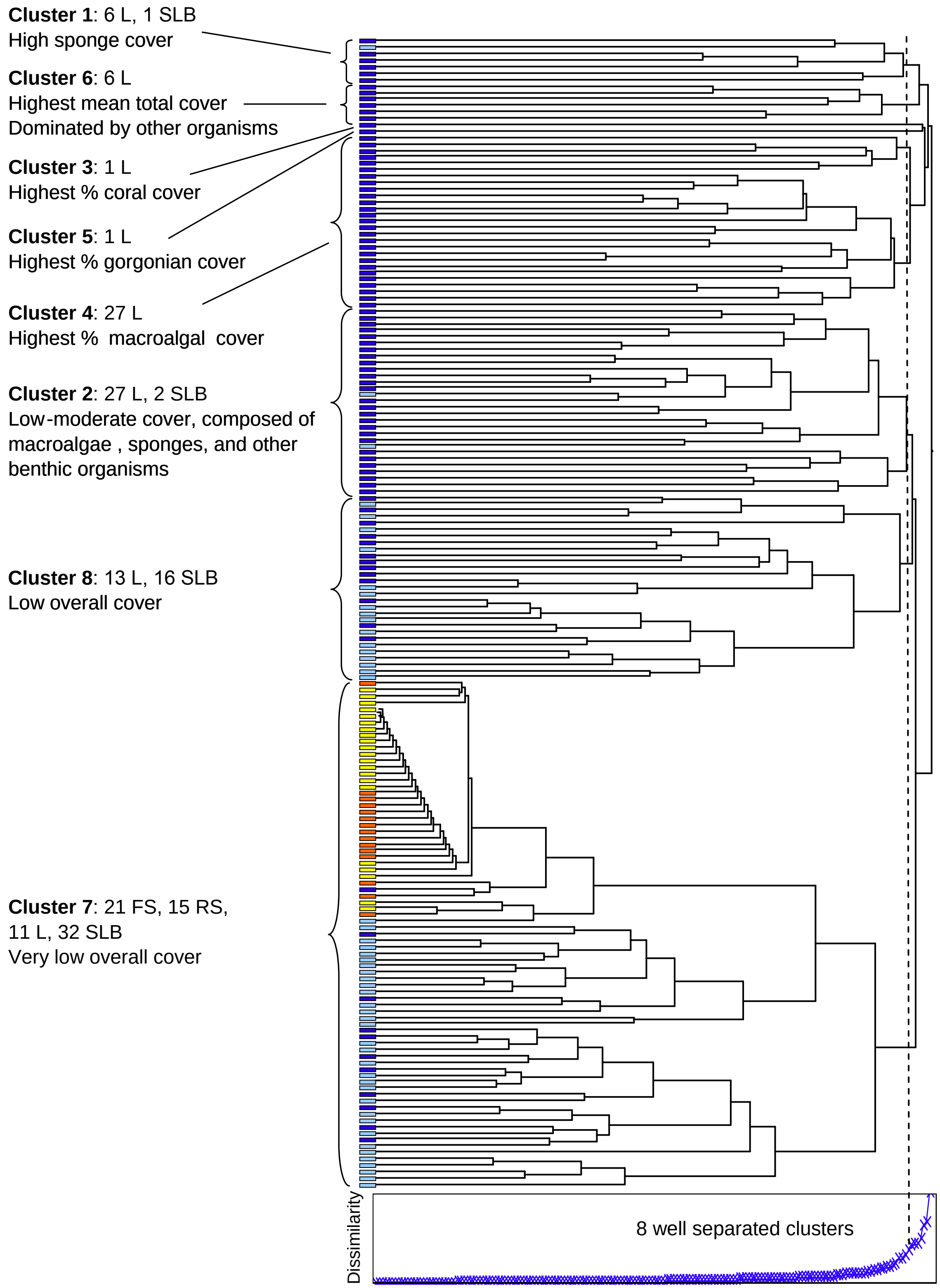

Figure 2.23. Dendrogram from cluster analysis of all sites based on percent cover for aggregated cover types (corals, gorgonians, macroalgae, sponge, other). The scree plot indicates that there are eight well separated clusters. Sites are color coded by bottom type (dark blue=ledge, light blue=sparse live bottom, yellow=flat sand, orange=rippled sand).

al. 2005). The majority of ledges surveyed in GRNMS were short with little or no undercut, while ledges classified as medium or tall exhibited varying amounts of undercut. Although undercut dimensions were positively correlated with ledge height, there were exceptions to this trend (Figure 2.7). For example, the tallest ledge surveyed (mean height = 170 cm) had relatively little undercut (mean undercut height = 33.8 cm, mean undercut width = 25 cm). Tall ledges with small undercuts may result from physical and bioerosional processes that may weaken portions of the ledge overhangs over time, eventually causing them to fall off and form rock rubble in the ledge openings (Riggs et al. 1996; Riggs et al. 1998).

In general, medium and tall ledges did not differ in total biotic cover or the cover of individual morphological groups. It is possible that height may only be important to a certain threshold and that ledges above a certain height are simply less likely to be routinely buried and unburied by sediments. There was also a large degree of variability in cover on short ledges. Despite the low median cover, a few short ledges had total cover exceeding 50%. However, excluding gorgonians and coral, cover of other groups was significantly less on short ledges. Compared to tall ledges, low relief ledges would likely be more subject to burial by shifting sediments, which could inhibit colonization by organisms. Several of these short ledges with low cover are located in the southeast corner of the sanctuary and are otherwise surrounded by sand. This would be a good area to investigate sand migration rates and the associated impacts on ledges. Gorgonians and several sponge types (finger, rope, and

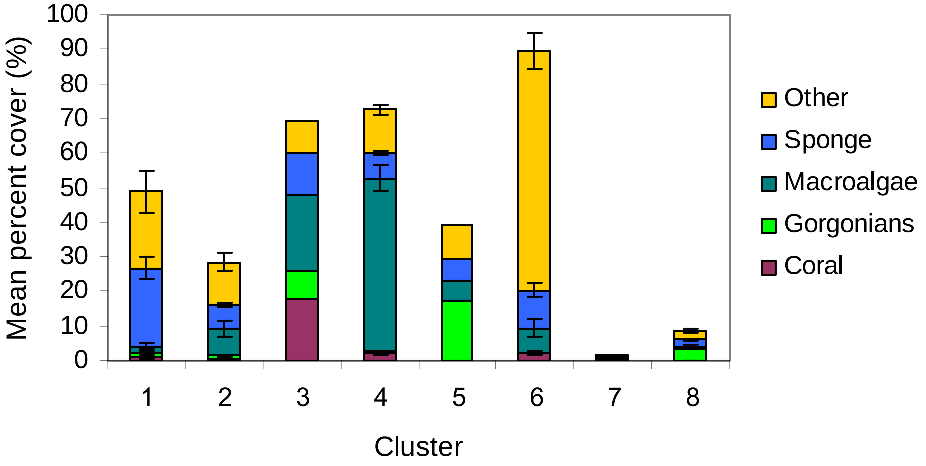

Figure 2.24. Mean percent cover of benthic organisms (±SEM) by clusters determined from hierarchal cluster analysis in Figure 2.23.

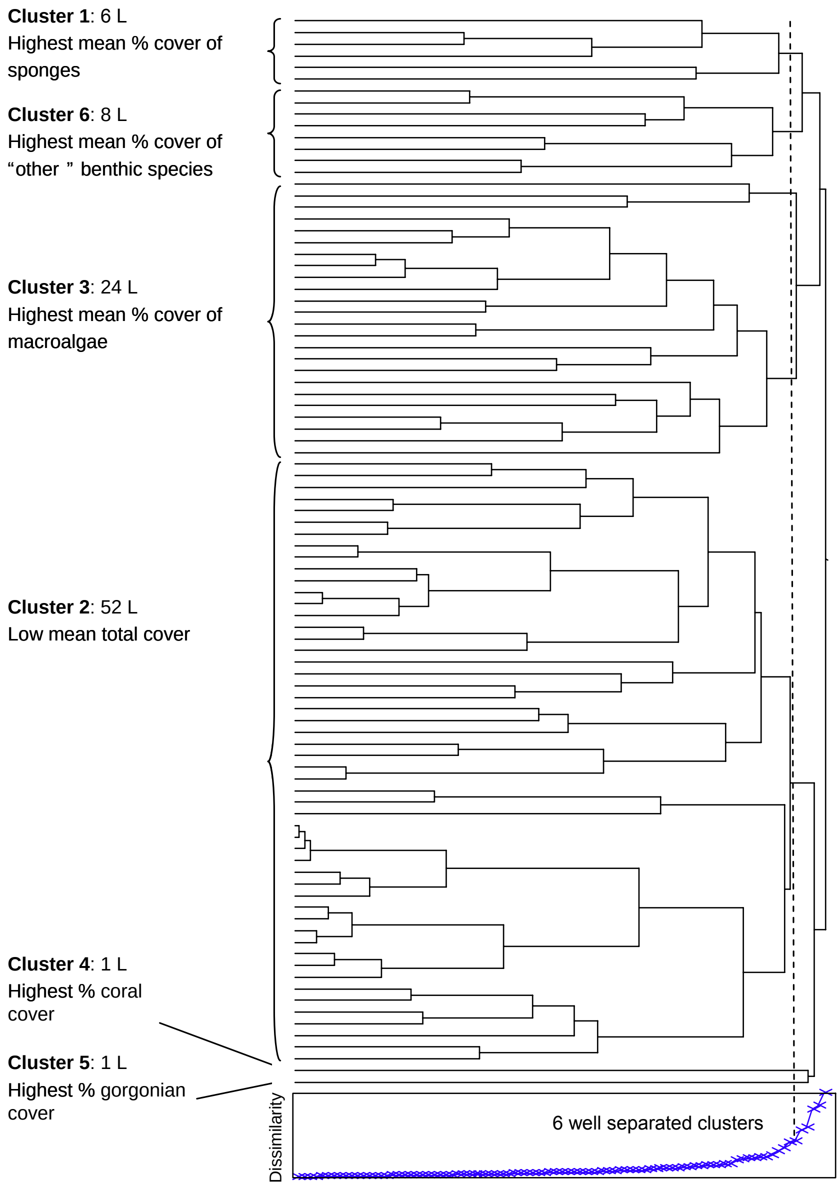

Figure 2.25. Dendrogram for cluster analysis of the 92 ledge sites based on percent cover for aggregated cover types (corals, gorgonians, macroalgae, sponge, other). The scree plot indicates that there are six well separated clusters. The numbers representing each site denote total mean percent cover.

tube) appear to be less limited than other invertebrates and were found on sparse live bottom or short ledges with similar or greater frequency than on medium or tall ledges. While many of the ledges located in the southeast region were characterized by low overall cover, gorgonians and a low density of sponges were nearly always present in this area.

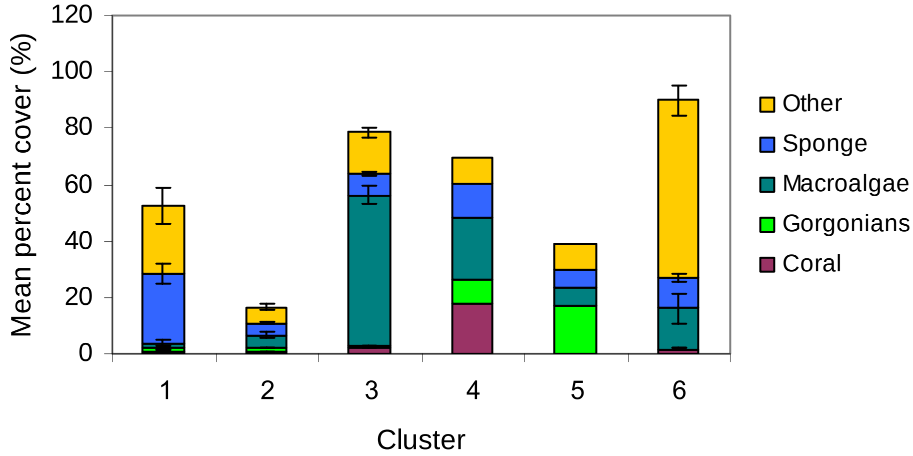

Figure 2.26. Mean percent cover (±SEM) by cluster determined from hierarchal clustering of ledges (Figure 2.24).

Conversely, taller ledges and slopes would be less susceptible to sand burial and can support shorter colonies. Total cover increased with ledge height, but examination of spatial patterns and cluster analyses by biotic type indicate that a diversity of benthic community combinations occur regardless of ledge height. The most densely colonized ledge sites were generally situated in the central region of the sanctuary, particularly sites located among the northern rim of ledges and a group of ledges to the south (Figure 2.13). Highest cover of coral, macroalgae, sponges, and tunicates tended to be located in these regions as well (Figures 2.13, 2.17-2.21).

The reasons for these spatial patterns are not clear. Many of the densely colonized ledges were also tall in height, but this was not always the case. Why some ledges were dominated by macroalgae, and others of similar height by tunicates is unknown. It is likely that other factors not considered in this study, such as small scale rugosity or complexity, ocean currents, other environmental variables, and biological interactions (e.g., differential grazing or settlement patterns) work in concert to influence spatial distribution and community structure. Osman (1977) notes five major factors important to the development of an epifaunal benthic

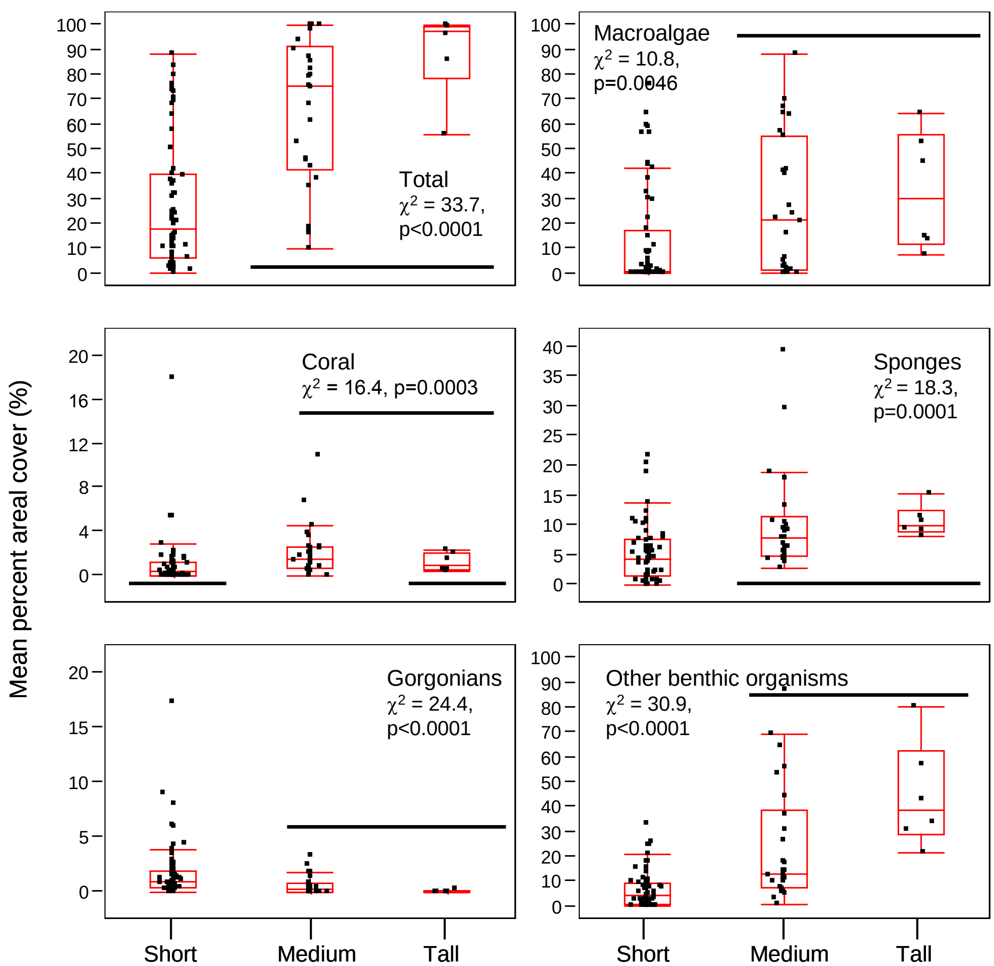

Figure 2.27. Box plots of percent cover of benthic organisms on three ledge groups determined by cluster analysis. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (df = 2, alpha = 0.05). Solid horizontal lines join groups that are not significantly different from each other.

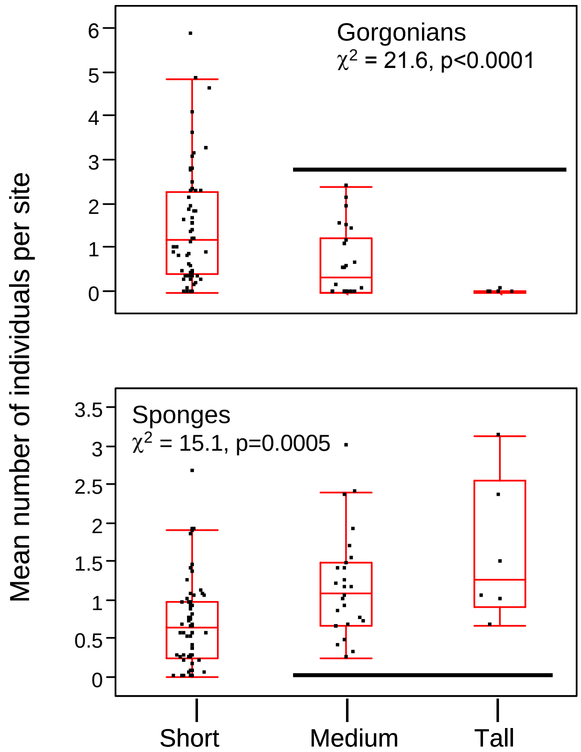

Figure 2.28. Box plots of mean number of gorgonians and sponges on three ledge groups determined by cluster analysis of abiotic ledge variables. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (df = 2, alpha = 0.05). Solid horizontal lines join groups that are not significantly different from each other.

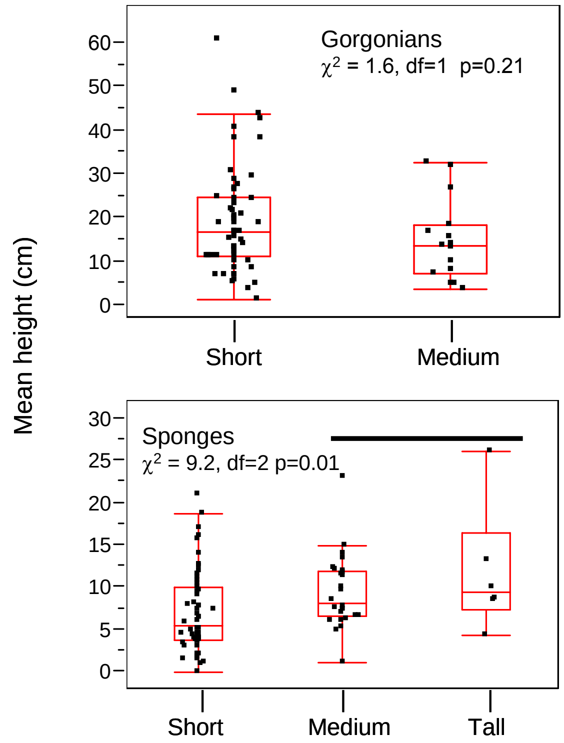

Figure 2.29. Box plots of mean height of gorgonians and sponges on three ledge groups determined by cluster analysis. Results of nonparametric ANOVAs (Kruskal-Wallis tests) and Dunn's multiple comparison tests to determine significant differences among mean ranks are provided (alpha = 0.05). Only short and medium ledges were considered for the analysis of gorgonian height. Solid horizontal lines join groups that are not significantly different from each other.

community and species distribution, including larval selection of settlement location, seasonal fluctuation in the climate and larval abundance, biological interactions (predation, intra and inter-specific competition), substrate size, and physical disturbance. In particular, the structural complexity of ledges is difficult to quantify, but it may contribute greatly to species diversity and variability between different patches. For example, within a small area (e.g. < 100 m^2) numerous microhabitats may exist (e.g., crevices, overhangs, bare rock, sand patches) that may allow a large number of species to co-exist due to differential larval settlement and survival patterns (Wenner et al. 1983).

Although flat and rippled sand bottom types were largely devoid of epibenthic invertebrates and macroalgae that settle on hardbottom, this does not mean that this habitat is not important ecologically. Numerous burrows indicate the presence of benthic infauna. Indeed, Hyland et al. (2006) documented 349 different infaunal taxa, including polychaetes, crustaceans, echinoderms, and mollusks from sediment grabs in GRNMS. Patterns in species composition and abundance varied among bottom types. The diversity and densities of macroinfauna were higher in rippled sand than flat sand, and were also high in sediments close to or overlying live bottom (Hyland et al. 2006). Macroinfauna serve as important prey items for numerous fish in GRNMS, including grunts and *Pareques* species. Fish such as these are closely associated with ledges but often forage over adjacent sand bottoms, resulting in a "halo effect" of decreased infaunal abundance closer to reef ledges (Posey and Ambrose 1994).

Although this study was not designed to detect seasonal patterns, invertebrates and particularly macroalgae are prone to both seasonal and year-to-year variability (Peckol and Searles 1984). Seasonal and inter-annual differences can be attributed to multiple sources, including fluctuating environmental conditions (Peckol and Searles 1984), storm events (Renaud et al. 1997), and success in larval settlement and growth (Osman 1977). GRNMS lies at the boundary between the inner and middle continental shelf and tropical and temperate water masses, and hence experiences seasonal fluctuations in temperature, salinity, and water clarity (NOAA 2006). Coastal circulation patterns in the South Atlantic Bight are also prone to seasonal variation (Bumpus 1955). Mean water temperature at the GRNMS data buoy was 30°C in August 2005, two degrees higher than the previous August. Mean water temperature in May 2005 was much cooler at 23.4°C (data obtained from the NOAA Station 41008 buoy located in GRNMS, http://www.ndbc.noaa.gov/, accessed Sept. 30, 2006). Although mean cover for most groups was similar across the three sampling periods, there is some indication of temporal patterns for macroalgae. At Gray's Reef, macroalgae generally reaches peak abundance in July and August before dying back in the fall and winter (Searles 1988). In the present study, mean macroalgal cover on ledges varied from 0.6% in August 2004 to 1.3% in May 2005 to 11.6% in August 2005. No ledges sampled in August 2004 or May 2005 had a mean macroalgal coverage exceeding 25%. Conversely, 16 ledge sites sampled in August 2005 were covered by macroalgae in excess of this amount. Results from cluster analysis also indicated some temporal differences, as all but one site located in the "macroalgae" cluster was surveyed in August 2005. Due in part to this macroalgal bloom, the seven most densely colonized ledges (99-100% total cover) were documented in August 2005. The causes for the large difference in macroalgae in the two successive summers are unknown, but in addition to interannual variation in environmental conditions and storm events, macroalgal growth is also sensitive to variability in nutrient levels and grazing pressure (Miller and Hay 1996). Similarly, Peckol and Searles (1984) detected strong interannual differences in macroalgal cover on North Carolina reefs, but less so for invertebrates. In addition, it cannot be ruled out that observed differences in macroalgal cover in the present study were partially attributed to the random sampling design as the same sites were not characterized across all three surveys. More work is needed to accurately assess temporal patterns in macroalgae and epifaunal cover and responsible control mechanisms.

Image 12. Flamingo tongue and gorgonian.

Temperate reefs such as those in GRNMS differ from coral reefs in other National Marine Sanctuaries (Florida Keys, Flower Garden Banks, NWHI) in numerous ways, including geologic origin (Harding and Henry 1990) and dominant biota (Miller and Hay 1996). Unlike tropical reefs, temperate reefs consist of pre-existing, submerged rocky outcrops that are colonized by epibenthic organisms (Harding and Henry 1990). Corals are less common on temperate reefs and tend to form smaller colonies then in tropical regions (Miller and Hay 1996). The latitudinal limits of coral are thought to be attributed not only to lower temperatures but also increased competition with macroalgae, which are favored in higher nutrient waters (Johannes et al. 1983). *Oculina arbuscula*, the primary coral species in GRNMS, ranges from the Carolinas to Florida (Humann 1993) and has a wide temperature tolerance, although highest growth occurs in warm water under high light conditions (Miller 1995). The distribution of *Oculina* on temperate reefs in North Carolina is limited by macroalgae through both direct competition and indirectly by restricting the coral to deeper, lower lit environments where *Oculina* growth is not as favorable (Miller and Hay 1996). Recent work by Wagner (2006) on the population genetics of *O. arbuscula* in GRNMS and surrounding hardbottoms provide evidence for local recruitment, perhaps due to the nature of the patchy reef environment. In the present study, coral was commonly observed at 75% of all ledge sites, however, it generally contributed a small percentage to total percent cover.

In contrast, sponges represent an important component of the benthic community in GRNMS, accounting for as high as 39% cover. Usually multiple morphological types and species were present in a single quadrat at an individual ledge. Although less studied, sponges often exceed corals and algae in terms of diversity on coral reefs (Diaz and Rutzler 2001), and some species may compete with coral for space (Aerts 1998). Compared to tropical reefs, temperate SAB reefs appear to have lower species diversity, but higher density of species and individuals, particularly for encrusting species (Ruzika 2005).

The South Atlantic Bight is occasionally affected by tropical cyclones and strong winter storms, which can result in strong current overflow and turbulence over ledge outcrops, particularly near the lip of the ledge (Peckol and Searles 1984). Although Peckol and Searles (1984) found reduced colonization by perennial macroalgae in this environment compared to several meters back from the face of the ledge, sessile invertebrates appeared to be less restricted and colonized this region heavily. In addition, surveys of North Carolina reefs following Hurricane Diana found little damage to the benthic invertebrate communities, which suggests that benthic communities are resilient to the impacts of strong storms and bottom currents (Kirby-Smith and Ustach 1986; Vaughan et al. 1987). Furthermore, although storms can negatively affect algae and invertebrates through dislodgement or scouring, they may also create favorable conditions for settlement by exposing hardbottom that had previously been covered by sediments (Renaud et al. 1997). Although insufficient data is available to investigate this further, differential storm patterns between years is one possible factor that may have contributed to the differences in cover of macroalgae in 2004 and 2005.

Concerns were raised about potential human impacts on the sanctuary resources in the recently updated GRNMS management plan (NOAA 2006). Compared to other hardbottom habitats, regulations afford the sanctuary protection from trawling and dredging, which have been shown to damage sponges, gorgonians and corals (Van Dolah et al. 1987). However, recreational activities can also negatively impact benthic fauna. For example, our surveys found fishing line entangled in oculinid coral (Chapter 3). Ledges within the area of high boat density were on average larger in area, taller, and had a higher percent cover than in the area where less boat activity was observed. This is not surprising as fishermen are more likely to detect larger, taller ledges on their depth finder (personal communication), and these ledges are more likely to harbor larger fish densities (Chapter 4). However, this finding is significant to management because it indicates that areas with the highest amount of live bottom may be disproportionately more vulnerable to human impacts (e.g., anchoring, derelict fishing gear).

2.6 RECOMMENDATIONS FOR MANAGEMENT AND MONITORING

Monitoring sanctuary resources on an annual basis is crucial to understand year-to-year variations in abundance and presence or absence of epibenthic flora and fauna, and to assess any changes in condition of biological communities over time. This work provides a baseline assessment and a foundation for long-term monitoring of the benthic community in GRNMS. Surveys of the benthos can be conducted in conjunction with the transect surveys for fish using the procedures outlined in the field methods of this document. We recommend conducting the annual survey in the summer of each year, as this is when annual species such as macroalgae are likely to be highest. Should additional resources remain, a survey could also be conducted during another time of the year to address seasonal variations. Ledges should receive a majority, if not all, of the effort due to the high abundance and diversity of sessile flora and fauna and associated fish (Chapter 4). Ledges of all sizes and heights should be surveyed to further characterize the relationship of invertebrate communities with their environment. Although diversity was also high on sparse live bottom, cover of most biota, with the exception of gorgonians, was significantly lower on this bottom type.

Information from this baseline survey can be used to adjust field methods in the future. For example, due to the prevalence of tunicates on ledges, tunicates could be given their own category (with subcategories lobate and encrusting) rather than subcategories under “other” benthic cover types. Other potential categories/subcategories that were not included on data sheets, but were occasionally noted, include barnacles and particularly bryozoans. One factor that was not measured at ledge sites was the thickness of overlying sediment, but as this is important to community development and

Image 13. Undercut ledge densely colonized by coral, sponges, and other benthic organisms.

maintenance, quantifying this variable may shed additional light on the dynamics of benthic community patterns.

The field survey method applied in this study is advantageous in that it allows researchers to survey a large number of sites within a short period of time. To date, this was the most spatially comprehensive characterization of benthic communities at GRNMS and yielded a substantial amount of information on the abundance and distribution of benthic invertebrates within GRNMS and their association with major bottom types. However, the method is not without drawbacks. For example, due to time constraints, invertebrates and macroalgae were identified by morphology rather than species. Additional surveys could focus on a subset of sites and specific cover types (e.g. sponges, corals) to identify individuals to a lower taxonomic level. In addition, studies pertaining to recruitment, settlement, and population dynamics of invertebrate species in GRNMS (e.g., Wagner 2006) should be continued. The invertebrate species database (http://www.bio.georgiasouthern.edu/GR-inverts/, Gleason et al.) is a valuable public-accessible resource that should continue to be updated over time.

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CHAPTER 3: CHARACTERIZATION OF THE MARINE DEBRIS

3.1 INTRODUCTION

The accumulation of debris in the marine environment is an increasing problem worldwide. Marine debris is aesthetically displeasing, can be a nuisance to boaters and the shipping industry, and can negatively impact marine biota (Derraik 2002). The abundance and spatial distribution of marine debris is dependent upon several factors, including its origin/source (e.g., terrestrial vs. maritime), ocean currents, wind patterns, and physiographic characteristics (Galgani et al. 2000; Donohue et al. 2001). Depending upon their composition, individual debris items may persist for a long time in the marine environment. In particular, plastics, which are the dominant debris type in numerous marine systems (Derraik 2002), tend to break down slower in the ocean than items on land due to lower temperatures and fouling by marine organisms (Andrady 2000).

Derelict fishing gear is a common debris type of maritime origin, and areas with concentrated fishing activity may contain elevated amounts of debris (Hess et al. 1999; Galgani et al. 2000). Derelict fishing gear and other marine debris can impact environments in several ways. Floating debris may facilitate the spread of non-native species to new areas by providing a means of transportation (Aliani and Molcard 2003). Plastic items are often ingested by or entangle marine organisms, including fish, seabirds, sea turtles and marine mammals (Laist 1997). Lost fishing gear, such as monofilament nets and traps, may affect marine organisms both by direct injury to benthic habitats and organisms (Donohue et al. 2001) and by continuing to catch fish and invertebrates ("ghost fishing", Dayton et al. 1995).

Although smaller in size than large monofilament nets, hook and line is a prevalent gear type, particularly among recreational fisheries, and can also be detrimental to marine organisms (Chiappone et al. 2005). Effort is often concentrated at popular fishing sites, and consequently hook and line fishing may affect small areas but also inflict a high amount of damage within the affected areas (Asoh et al. 2004). Fishing line entangles readily in coral, which may lead to progressive fouling by algae and eventually, coral death (Schleyer and Tomalin 2000; Yoshikawa and Asoh 2004). Chiappone et al. (2005) documented numerous cases of tissue abrasion in branching gorgonians, milleporid hydrocorals, and sponges in the Florida Keys NMS.

A key challenge to marine debris mitigation is effectively assessing the distribution and density of debris in order to prioritize removal efforts. Traditional methods such as beach surveys are economical, widespread, and easy to implement (Rees and Pond 1995), but are limited to intertidal areas. Other survey techniques, including *in situ* underwater surveys, trawling, aerial flyovers, and remote sensing represent innovative approaches that are gaining increasing utilization. For example, SCUBA diving surveys have been employed to describe the distribution of derelict fishing gear in coral reefs within the Florida Keys National Marine Sanctuary (Chiappone et al. 2004) and in the Northwestern Hawaiian Islands in conjunction with cleanup efforts (Donohue et al. 2001). Using oceanographic modeling and remote sensing techniques, the "GhostNet" program in the Pacific Ocean is developing tools to track debris and identify likely locations of accumulation of derelict fishing nets and other marine debris (http://www.highseasghost.net, accessed May 16, 2006).

Understanding the sources and processes that drive marine debris distribution patterns is crucial to remediation efforts. High concentrations of debris are often found in areas of concentrated fishing activity, shipping channels, or riverine outflows (Galgani et al. 2000). Further, wind and currents can transport debris to areas far from the original location of loss or dispersal. For example, oceanic convergence zones in the North Pacific Ocean are thought to contribute to the accumulation of debris in the NWHI (Donohue et al. 2001; Donohue 2005).

Image 14. Net entangled in live bottom.

Recently, there has been increased concern about the potential accumulation of marine debris in Gray's Reef National Marine Sanctuary (GRNMS). Since the establishment of GRNMS in 1981, the population of neighboring coastal counties has increased substantially (~40% from 1980-2000), and has been forecast to increase an additional 32% by 2015 (CGRDC 2006). Coincident with this population increase, the use of the sanctuary for boating and fishing activities has also increased. In 1983, aerial flyovers documented 106 vessels in the sanctuary during 62 overflights (1.7 boats/flight); in 1999, 527 boats were observed during 90 overflights (5.9 boats/flight) (NOAA 2006). While most commercially employed gear has been prohibited in the sanctuary, Gray's Reef is a popular recreational fishing site both for king mackerel and bottom fish such as red snapper, grouper, amberjack, and especially black sea bass. Hook and line is the dominant gear type to target these species, although spearfishing with non-power spearheads is also conducted (NOAA 2006). Several sport fishing tournaments take place off of the Georgia coast each year, with Gray's Reef being a premier location (Ehler and Leeworthy 2002). Current regulations prohibit the deposition of most materials in the sanctuary, with the exception of fish parts, bait and chumming materials, effluent from marine sanitation devices, and vessel cooling water (NOAA 2006). The extent of external inputs from sources outside the sanctuary is unknown but also of concern.

The characteristics of bottom features in Gray's Reef may influence the accumulation and spatial distribution of debris in the sanctuary. Kendall et al. (2005) estimated that the GRNMS seafloor is comprised of approximately 75% sand, 25% sparsely colonized live bottom, and less than 1% densely colonized rock outcroppings or ledges. However, despite their limited area, ledges may be most vulnerable to debris accumulation. The abundance of sessile benthic organisms and structurally complex features such as overhangs and caves provide ample opportunities for debris items to become lodged or entangled. In addition, ledge features are targeted by fishermen due to the high abundance and diversity of target fishes that reside there.

The most recent management plan calls for specific measures to assess, monitor, and remove debris from targeted areas within the sanctuary (NOAA 2006). Activities were proposed to a) clarify regulatory authority to address materials discharged or deposited outside the sanctuary, b) develop and implement a marine debris education and outreach program, and c) develop and implement a debris monitoring and assessment study. In addition, GRNMS organizes divers to remove debris from targeted locations within the sanctuary through the annual "Sweep the Reef, Sweep the Beach" World Ocean Day Cleanup.

Understanding the amounts, distribution, and types of debris in the sanctuary is the first step to improving cleanup efforts and will aid managers in prevention and education efforts. To date, the types of debris, and its distribution and abundance have not been quantified. The objectives of this component of the characterization were to:

1. Describe the abundance, types, and spatial distribution of marine debris in GRNMS,
2. Determine whether debris presence is associated with bottom type,
3. Determine the causes of observed spatial patterns of debris at ledges by identifying what factors, such as ledge height and area and observed boat activity, are related to debris presence and abundance,
4. Predict debris densities at unsampled locations within GRNMS, and
5. Explore relevance of ocean currents in GRNMS to debris accumulation patterns.

Finally, the results will be used to recommend a strategy for identifying high priority sites for targeted debris removal, and conducting periodic monitoring to determine rates of debris accumulation in different areas and bottom types within the sanctuary.

3.2 METHODS FOR MARINE DEBRIS SURVEYS

Sampling for marine debris occurred along a 100 m^2 transect at randomly selected sites as outlined in Chapter 1. Marine debris was recorded for the entire 100 m^2 transect. Debris was defined as any man-made object and was separated into two main categories, fishing gear and non-gear. Subcategories of fishing gear were not always noted but included monofilament line, leaders, spear gun parts, and other/undescribed (e.g. jigs or lead weights). Subcategories of non-gear marine debris included cans, bottles, and other (e.g. clothing, twine, tennis ball, wood plank, lift bag). Rope and mesh bags were found at a few sites and were scored as non-gear even though they may have been associated with fishing (e.g., rope could be used to mark ledge sites and mesh bags could be used for chumming). Fishing line that crossed the transect, but was not completely within it, was counted as a single item. Monofilament line with a leader attached was counted as a single piece of gear in the leader category.

3.3 METHODS FOR DATA ANALYSIS

Quantity, types, and spatial distribution of debris

Survey statistics for the quantity and types of debris were calculated for the entire survey domain and according to bottom types (Table 3.1, Table 3.2). Observed density of total debris, fishing gear, and non-gear items were entered into a Geographic Information System (GIS) and mapped according to geographic position of survey transect in ArcView v9.1.

Image 15. Miscellaneous debris items.

Effect of bottom type

First, the hypothesis that presence of debris varies significantly by bottom type was tested. For this analysis, flat sand and rippled sand were combined into a single “sand” category due to the low number of sampling locations in these bottom types compared to ledge and sparse live bottom. Bottom type (ledge, sand, sparse live bottom) was identified for each site based on diver observations. Debris was classified as “present” or “absent” at each site and the presence/absence data were modeled using logistic regression (Proc Logistic, SAS v9.1). Bottom type was included as a class variable. If the main effect was significant at the alpha =0.05 level, contrast statements were then constructed in Proc Logistic to test for differences in debris density among each pair of bottom types.

Influence of ledge characteristics and boat density on debris

Given that 90% of the observed debris was found on ledges, additional descriptive statistics were calculated and tests were performed to identify ledge characteristics that were associated with higher amounts of marine debris. The occurrence of debris on ledges according to the ledge area and height categories previously classified by GIS analysis (Kendall and Eschelbach 2006) were summarized in pie charts. Briefly, ledges were categorized as short (<58.5 cm), medium (58.5-89.2 cm), or tall (>89.2 cm) by rank ordering their heights and assigning 1/3 of the ledges to each category (Kendall and Eschelbach 2006). Area calculations were used to categorize ledges as small (<316.5 m^2), medium (316.5-731.4 m^2), or large (>731.4 m^2), again by assigning 1/3 of the ledges to each category (Kendall and Eschelbach 2006).

Ledge characteristics that were suspected to be positively associated with debris accumulation were identified and included mean ledge height measured *in situ*, ledge area (m^2) based on GIS analysis, mean undercut width (m) measured *in situ*, and percent cover of benthic organisms measured *in situ*. Total debris (per 100 m^2) was plotted against each of these ledge variables and a non-parametric Spearman Rho rank order correlation statistic was calculated (SAS v9.1, Proc Corr).

An additional factor that may influence the distribution and abundance of debris is the level of fishing and boating activity. Positions of boats in GRNMS from 1998 to 2004 were determined from multiple sources including national reconnaissance systems and entered into a GIS. Positional accuracy was within 26 m and boats were classified as either moving or stationary. Both stationary and moving boats from all seasons were included for two reasons. First, to eliminate potential bias from king mackerel fishing tournaments, the boat data was initially separated by season and status (stationary vs. moving) to determine whether use patterns differed among bottom and pelagic fishers. However, regardless of how data was partitioned, the overall spatial patterns in boat density were consistent. Second, any boat could dispose of debris at sea, regardless of whether they were bottom fishing, trolling for pelagics or bait, or not fishing at all. To determine how the intensity of activity varies over space, the sanctuary was divided into 0.25 km^2 cells (500 m x 500 m) and the number of boats within each cell was calculated. Spearman correlation was used to examine the association between the number of boats and the average number of debris in each cell (SAS v9.1, Proc Corr). After exploring several spatial scales (1 km^2, 0.25 km^2, 0.09 km^2, and 0.01 km^2), the 0.25 km^2 scale was considered most appropriate for GRNMS. The 1 km^2 scale was found to be too coarse to capture potentially meaningful small scale variability. Conversely, the finest scale options resulted in too many cells that contained no sample locations. We used the information on boat distribution patterns to divide the sanctuary into areas of “low” versus “high” boat density. A frequency histogram of boats per cell was used to help determine a cut-off between low and high density areas.

Image 16. Aluminum beverage container.

Next, we modeled debris data to determine if ledge characteristics and boat density were significant predictors of the presence and abundance of debris at ledge sites. Due to the presence of numerous sites with zero debris items, the data was analyzed using a two-step conditional model that is often used for zero-inflated data (Cunningham and Lindenmayer 2005). This approach separates variables that determine whether or not debris is present from variables that determine the amount of debris, given presence. The variables included the boat density (low, high), mean ledge height (m), ledge area (m^2), mean undercut width (m), and percent cover of benthic species. In the first step, the debris was treated as present or absent and the presence/absence data were modeled using logistic regression (Proc Logistic, SAS v9.1). In the second step, only sites in which debris was present were considered. At sites where debris was present, the number of debris items was modeled with a generalized linear model (Proc Genmod, SAS v9.1) with a negative binomial distribution and a log link. The negative binomial variance distribution was chosen because it requires fewer assumptions than the normal or Poisson distribution and is appropriate for modeling skewed count distributions (White and Bennetts 1996). A Pearson’s Chi-Square test was used to assess the goodness of fit of the negative binomial model to the data. At both stages, only main effects were considered, and parsimonious models were selected by using backward elimination of non-significant variables (α=0.05).

Predicting debris density

Ideally, it would be most beneficial to use the two-part conditional model to generate a map of expected debris density at ledges throughout GRNMS. However, estimates of the covariates undercut width and percent cover were not available for all ledges. Instead, we used ordinary kriging, an interpolation method, of observed debris data to predict debris density at ledges throughout GRNMS. The procedure is based only on the observed values and does not explicitly take into account other variables that were found to influence debris patterns. In this approach, the spatial covariation among all possible sample points is used to develop an estimate of debris density at unsampled locations, based on appropriate weightings of observed values at neighboring sites. Variogram fitting and ordinary kriging were conducted in SAS to make predictions over a 25 m grid scale, which was deemed to be an appropriate scale based on the size distribution of ledges within GRNMS. The interpolated debris density was mapped in ArcView v9.1 for cells that were completely within or crossed the boundary of a ledge. In addition, a 25 m buffer was added to each ledge to aid in visualization of the predicted values.

Ocean currents at GRNMS

Finally, the potential influence of tidal currents on debris distribution was explored. Tidal currents may not only affect the patterns of debris that originated within GRNMS, but may also be responsible for depositing debris at GRNMS that originated elsewhere. Ocean current profile data from September 1, 2005 to February 28, 2006 were obtained from the NOAA Station 41008 buoy located in GRNMS (http://www.ndbc.noaa.gov/, accessed March 23, 2006). Current speed and direction was measured at hourly intervals with a surface Acoustic Doppler Current Profiler (ADCP) mounted to the buoy. The direction the current is flowing is measured from 0-360º, where 360º is due north, and 0º means that no current was measurable. Measurements were made at 1 m intervals from surface to bottom. The general direction of bottom currents were examined by plotting the frequency of direction measurements at 15 m depth, the deepest reliable measurements available for GRNMS.

3.4 RESULTS

Quantity, types, and spatial distribution of debris

A total of 93 items were found during field surveys at GRNMS. Debris was present at 32 out of the 179 survey sites. The number of debris items found within a 100 m^2 transect ranged from 0 to 10 items. Approximately two-thirds of all observed debris items were fishing gear, and about half of the fishing-related debris was fishing line (Table 3.1). Other fishing related debris included leaders and spear gun parts. Non-gear debris included cans, bottles, and rope. Other debris, classified as non-gear, included such items as wood, electrical wire, and a pair of pants pockets. The spatial location of total observed debris and fishing gear density are shown in Figure 3.1a-c. Highest incidence of debris occurred at ledges in the center of the sanctuary.

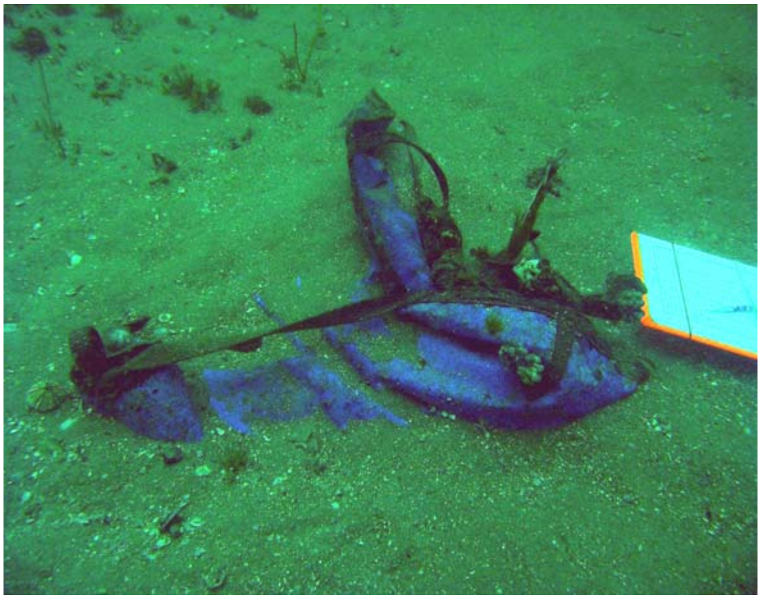

Image 17. Weight belt used for SCUBA diving.

Effect of bottom type

Out of the 32 sites where debris was present, all except three sites were classified as ledge bottom type (Table 3.2, Figure 3.2). Only non-fishing gear items were found on sand bottom types. Results from the logistic regression indicated that the presence of debris varied significantly by bottom type (Table 3.3). The probability of debris presence on ledges was 0.32 (n = 92), which was significantly greater than the probability of presence on sparse live bottom (0.02, n = 50) and sand bottom types (0.06, n = 37). There was no significant difference in the presence of debris between sparse live bottom and sand.

Influence of ledge characteristics and boat density on debris

The highest debris counts were encountered on ledges that had previously been classified as “tall” in height and “large” in area (Figure 3.3). The number of debris items present was positively correlated with ledge height (Spearman’s Rho = 0.44, Figure 3.4). Debris was present at all of the five tallest ledges surveyed. In addition, the number of debris items increased with increasing percent cover (Spearman’s Rho = 0.48, Figure 3.5), undercut width (Spearman’s Rho = 0.41, Figure 3.6) and ledge area (Spearman’s Rho = 0.40, Figure 3.7).

The number of boats per 0.25 km^2 cell ranged from 0-99, with higher boat densities observed in the central part of the sanctuary (Figure 3.8). In nearly half of the sanctuary (107 out of 234 cells), no boats were recorded, while in much of the remaining cells, only a few boats were observed. A natural break in frequency of cells occurred between density classes 4 and 5 (Figure 3.9a). Only 33 cells had an estimated density of ≥5 boats, and further, these cells were clustered in the center of the sanctuary. Therefore, cells with <5 boats were labeled as having low boat density and cells with ≥5 boats were labeled as having high boat density (Figure 3.9b).

The number of boats per 0.25 km^2 cell was positively correlated with the observed average debris density (number/100 m^2) (Spearman’s Rho = 0.42, Figure 3.10). The majority of debris items (80 out of 93) were found in the area that was defined as having high boat density (≥5 boats/0.25 km^2 cell), even though more than twice as many sites were sampled in the region of low boat density (n = 122 compared to n = 57, respectively). In addition, the com-

Table 3.1. Frequency of debris types pooled across all GRNMS survey sites (n=179).

Debris type	Total number	% of total debris
Fish line	31	33.3
Leader	10	10.8
Spear gun parts	1	1.1
Non-descript/Other gear	21	22.6
Total gear pieces	**63**	**67.7**
Cans	14	15.1
Bottles	2	2.2
Rope	4	4.3
Other	10	10.8
Total non-gear	**30**	**32.3**
Total debris	**93**	**100**

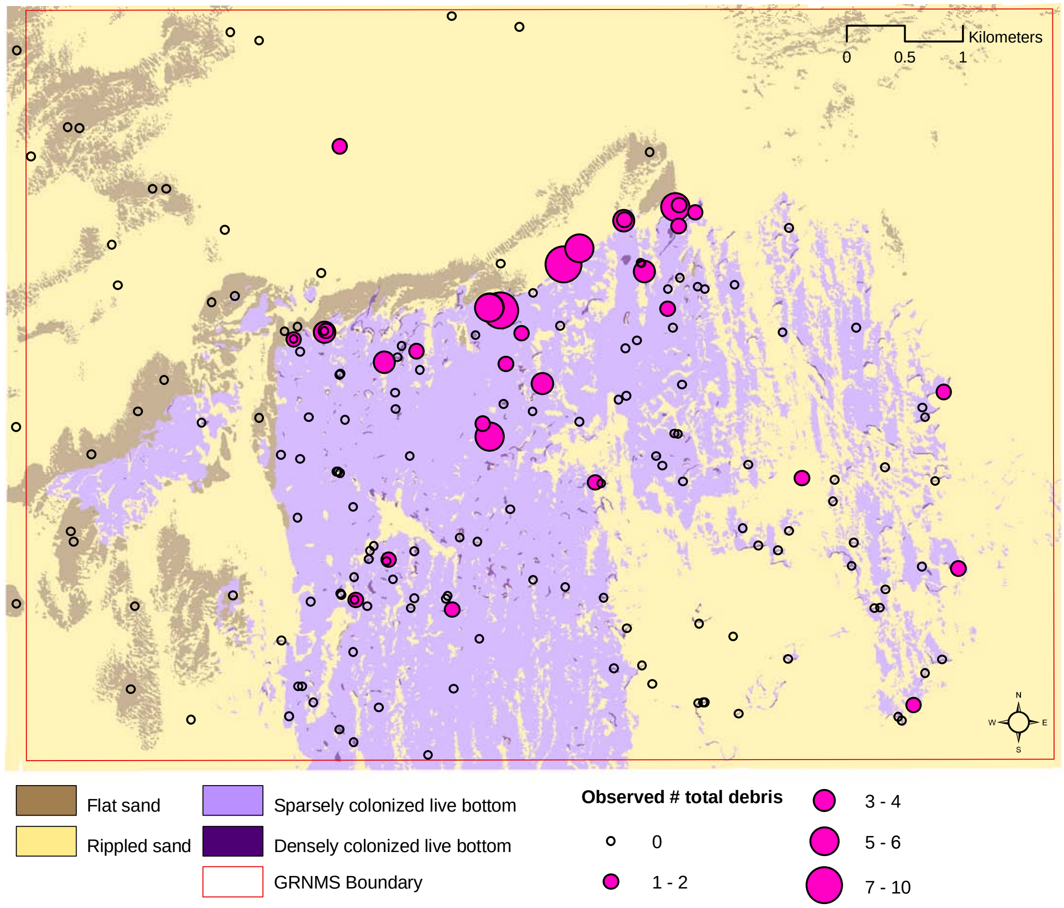

Figure 3.1a. Spatial distribution of total debris (number per 100 m²).

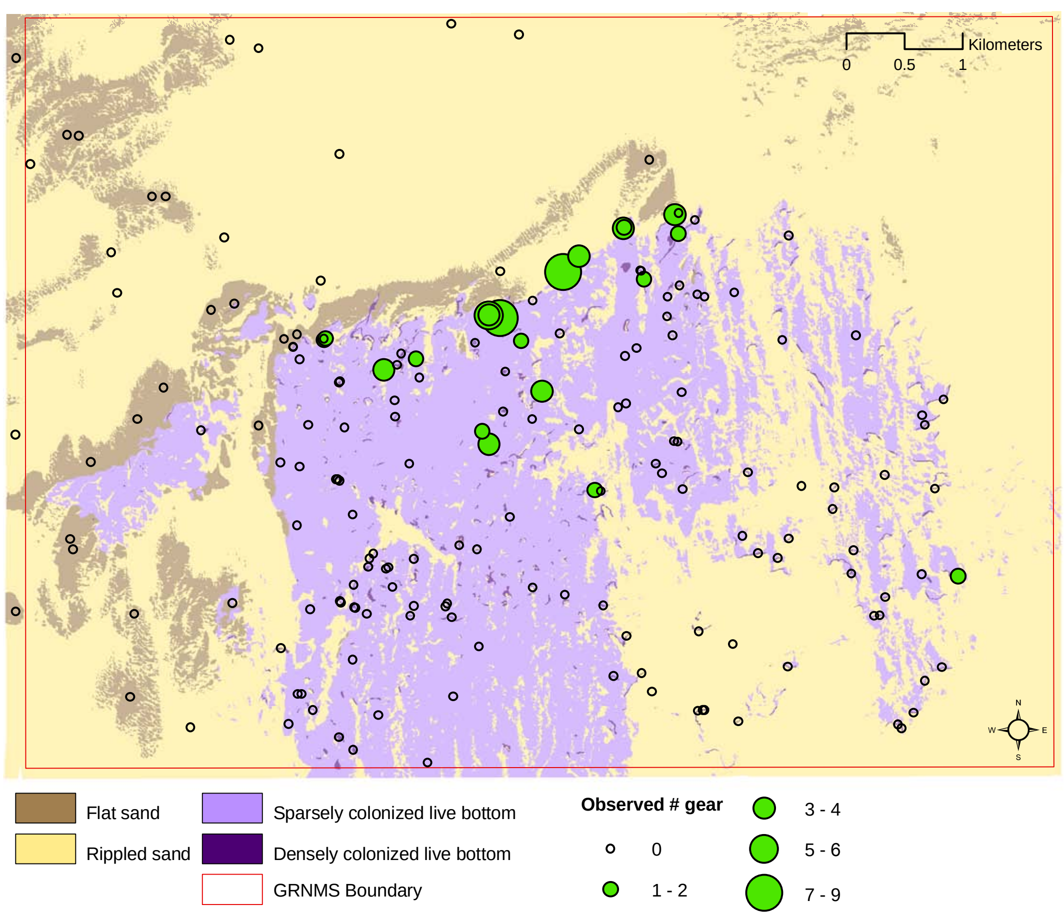

Figure 3.1b. Spatial distribution of fishing gear (number per 100 m²).

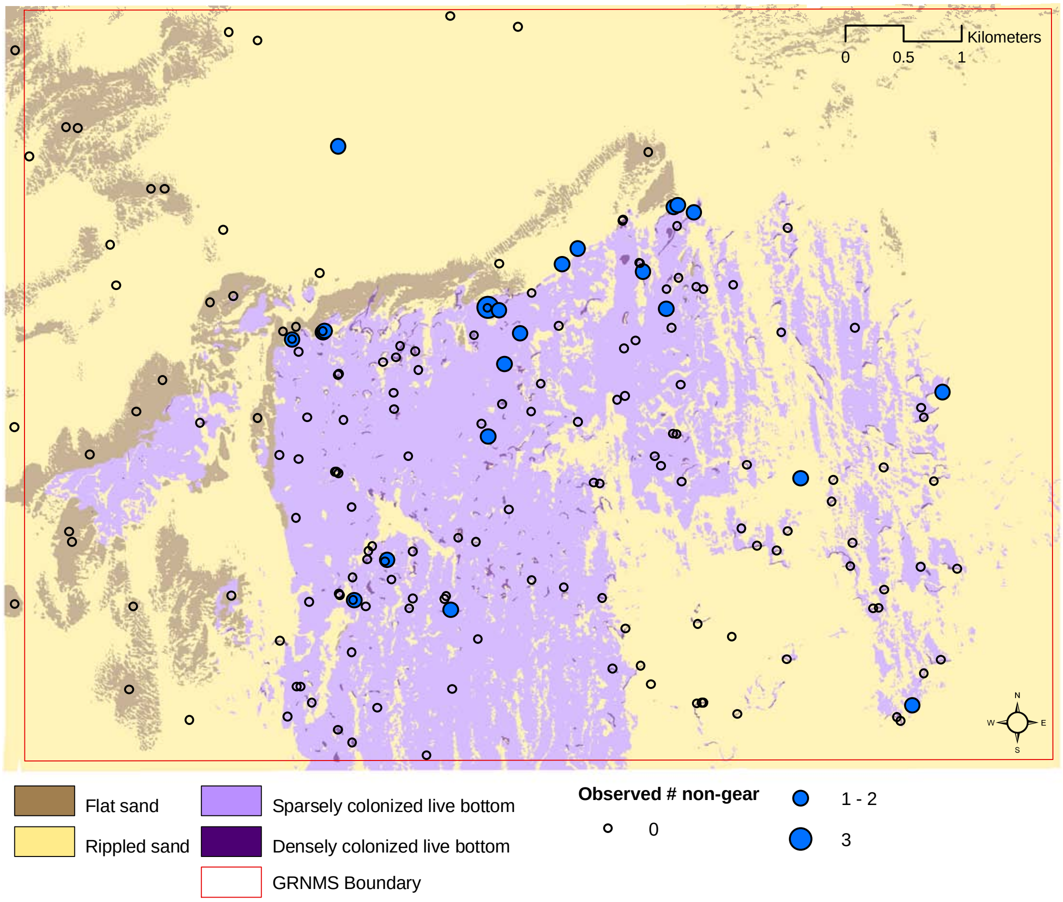

Figure 3.1c. Spatial distribution of non-gear (number per 100 m^2).

Table 3.2. Presence and average number of debris items per 100 m^2 by bottom type.

Bottom type	Total Sites	Number of sites with debris	Total # debris	Average # debris (±SE) /100m^2 transect
Ledge	92	29	89	0.97 (±0.21)
Sparse live bottom	50	1	2	0.04 (±0.094)
Flat sand	22	0	0	0.00
Rippled sand	15	2	2	0.13 (±0.09)
All	179	32	93	0.52 (±0.11)

Table 3.3. Contrast estimates, standard errors, and chi-square statistics from logistic regression of presence of marine debris in GRNMS by bottom type.

Variable	df	Parameter Estimate	SE	95% Wald Confidence Limits		Wald Chi-Square	Pr>ChiSq
				Lower	*Upper*		
Bottom type	2	-		-	-	15.5	0.0004
Ledge vs. Sparse Live Bottom	1	3.14	1.03	1.11	5.16	9.2	0.002
Ledge vs. Sand	1	2.06	0.76	0.57	3.55	7.3	0.007
Sand vs. Sparse Live Bottom	1	1.08	1.24	-1.36	3.52	0.8	0.386

position of debris varied between the two regions. For example, 75% (60 out of 80 items) of the debris in the high boat density area was fishing gear. In comparison, 23% (3 out of 13 items) of the debris found in the low boat density area was fishing gear. Two out of the three fishing gear items found in this region were observed at a site just outside the boundary of the high density boat area.

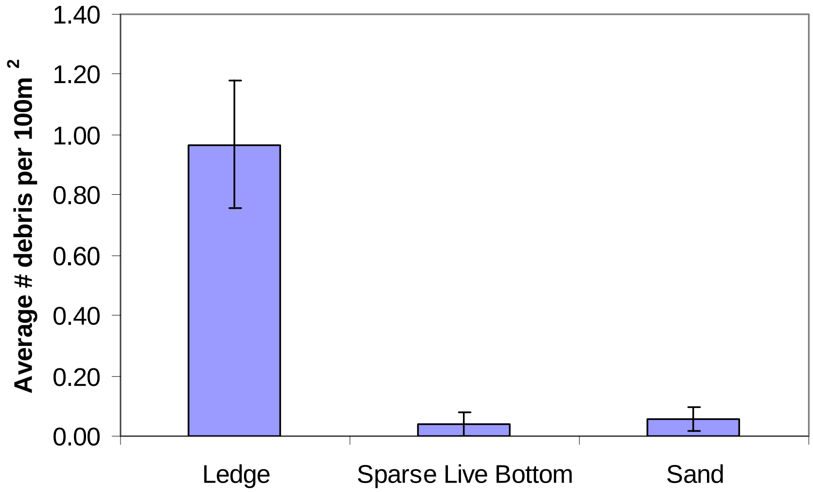

Figure 3.2. Average # debris items (±SE) per 100 m^2 transect by bottom type.

Results from the two-part conditional model indicate that multiple characteristics of ledge features and boat density influence observed distribution patterns of debris. Boat density was a significant predictor for presence of debris and abundance of debris, given presence (Table 3.4). Additionally, ledge area and percent cover were significant predictors of presence of debris, and mean ledge height was a significant predictor of abundance of debris, given presence. There was a higher probability of encountering debris with increasing ledge height. However, at both stages of the model, the estimates for the significant ledge variables were small. The Pearson Chi-Square test statistic indicated that the negative binomial distribution was appropriate. The null hypothesis of this test was that the data fit the model, and we were unable to reject this hypothesis (X^2 = 28.05, df = 26, p = 0.356).

Predicting debris density

Interpolated density of debris at ledges is displayed in Figure 3.11. Highest predicted densities of up to 8.4 pieces/100 m^2 occurs in the center of the sanctuary where highest numbers of debris items were observed. Moderate amounts of debris are expected to occur in regions east, west, and south of this area. In much of the sanctuary, a density of zero items/ 100 m^2 is predicted.

Ocean currents at GRNMS

Direction of bottom currents was bimodal (Figure 3.12a), consistent with an ebb and flow tidal cycle. Arrows pointing in the direction of the two modes, 305 and 125 degrees, were overlaid on the GRNMS map (Figure 3.12b). Thus, the tidal currents appear to flow in a SE-NW direction, perpendicular to the orientation of the northernmost line of ledges. Although we did not have enough information to test for the significance of currents on debris distribution, this pattern indicates that currents may be favorable to accumulation of debris at some locations where densities were highest. For example, debris originating north of the northernmost ledge line could travel south over sandy bottom with the tide until it encounters a ledge. The potential role of currents in mitigating distribution of debris will be discussed further in the following section.

Table 3.4. Two part conditional model for ledge bottom type to test for the effects of boat density (low, high) and ledge characteristics (ledge area (m^2), mean ledge height, mean undercut width, and percent cover of benthic organisms) on presence and abundance, given presence, of marine debris in GRNMS. The first stage models presence-absence with logistic regression, while the second stage predicts density, given presence, with a generalized linear model with a negative binomial distribution. P-values less than 0.05 were considered to show a significant effect, and models were reduced by backward elimination to remove non-significant variables.

	Variable	Parameter Estimate	SE	Wald Chi-square	Pr>ChiSq
Stage 1	Boat density (high vs. low)	0.65	0.29	5.1	0.024
	Ledge area	0.0004	0.00021	3.94	0.047
	Percent cover	0.024	0.0089	7.79	0.006
Stage 2	Boat density (high vs. low)	0.82	0.35	5.41	0.020
	Ledge height	0.006	0.002	6.29	0.012

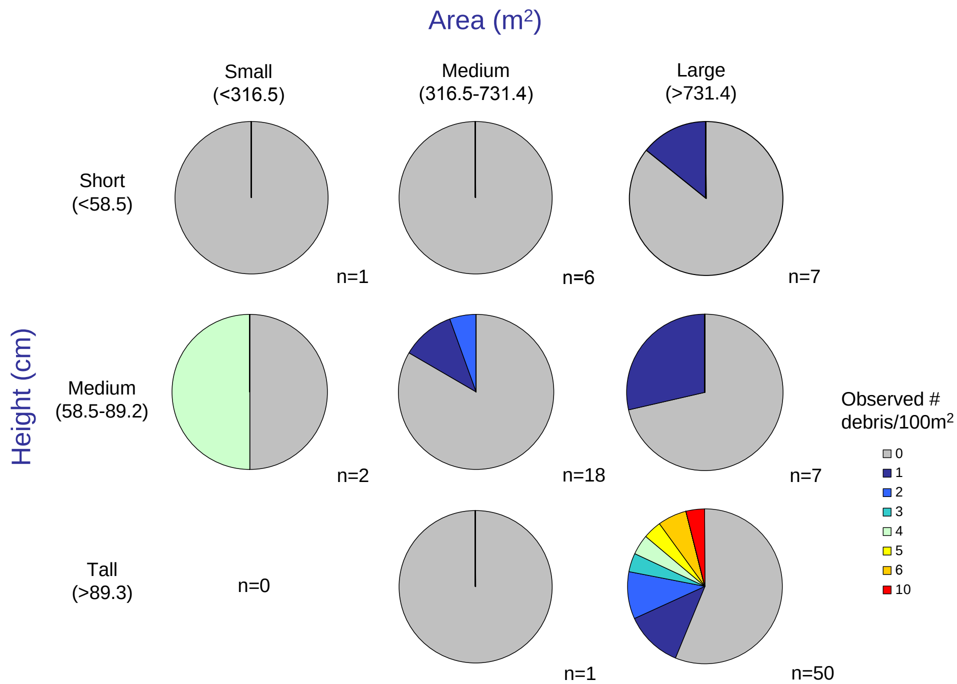

Figure 3.3. Frequency of debris at ledge sites by area and height class combinations as determined by Kendall and Eschelbach (2006). See methods for further description. The number of ledges within each area-height combination is noted by n=i.

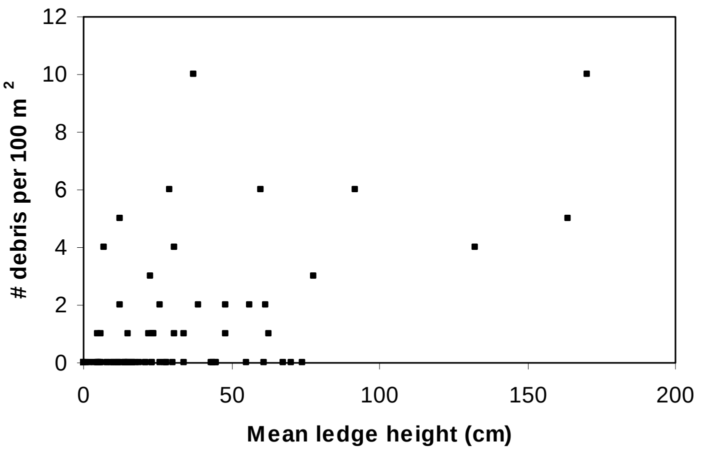

Figure 3.4. Relationship of observed number of debris items (per 100 m²) with ledge height (measured *in situ*).

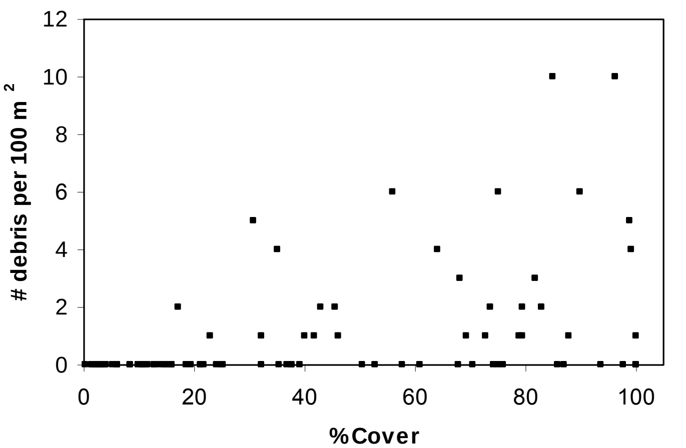

Figure 3.5. Relationship of observed number of debris items (per 100 m²) with percent cover of benthic organisms (measured *in situ*).

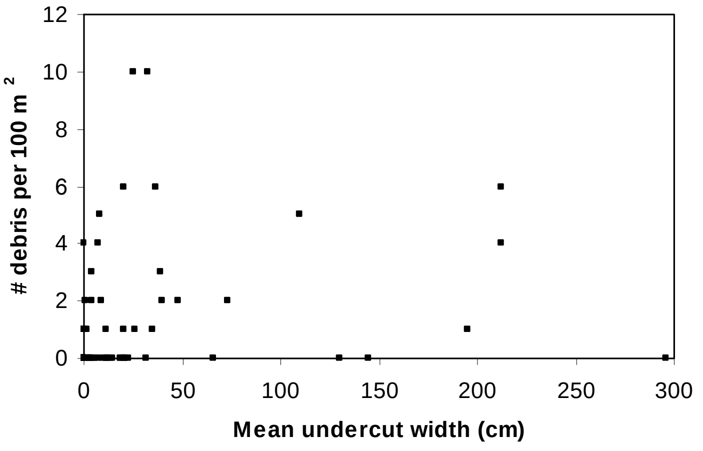

Figure 3.6. Relationship of observed number of debris items (per 100 m²) with undercut width (measured *in situ*).

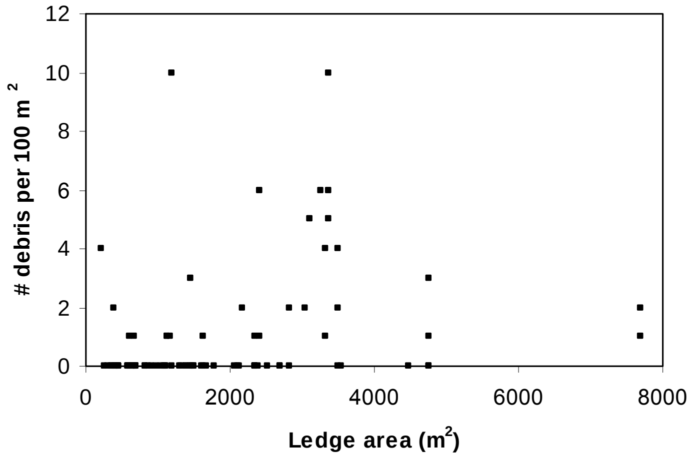

Figure 3.7. Relationship of observed number of debris items (per 100 m²) with ledge area (determined from GIS analysis).

3.5 DISCUSSION

The purpose of this study was to characterize debris patterns in GRNMS to support cleanup and monitoring of debris in the sanctuary. To our knowledge, this was the first study to quantify the types and amount of debris in offshore waters Georgia. A variety of debris items, including plastics, Styrofoam products, metal, glass, and fishing-related items, have been observed and removed during beach surveys in coastal Georgia (Gilligan et al. 1992). While fishing gear constituted a small portion of the total debris found on the beaches, Gilligan et al. (1992) noted that the impact of small items such as fishing line and string may have a disproportionately large effect due to the potential for entanglement of the benthic substrate, organisms, and other debris items. In contrast, in terms of number of debris items, fishing gear was more common than consumer related items (e.g., bottles, cans, packaging, etc.) in GRNMS, which is not surprising given the popularity of recreational fishing in the sanctuary. The types of debris observed in GRNMS are similar to those found in coral reef habitats in the Florida Keys National Marine Sanctuary (FKNMS). Both sanctuaries have a large recreational fishing contingent. Lost hook and line gear is the dominant debris type in both sanctuaries, although lost lobster traps also are common in FKNMS (Chiappone et al. 2004).

The distribution and abundance of marine debris in GRNMS is related to the bottom type, the level of boating/fishing activity, and local characteristics of benthic features. There is a significantly greater probability of presence of debris at ledges compared to other bottom types. Several factors may contribute to this observation. First, the abiotic features of ledges (e.g., crevices, changes in relief, overhangs) provide numerous places for fishing line and other debris to snag or become trapped. Ledges also tend to be densely colonized with corals, sponges, and other biota (Chapter 2), creating further opportunities for debris entanglement. For example, although association with corals was not routinely recorded, divers noted several instances where fishing line was found tangled in branches of oculinid coral. Second, due to the association of recreationally important fish species with ledges (Chapter 4), these bottom features are often targeted by fishermen. Even in areas with many boat observations, there were almost no occurrences of debris at sand and sparse live bottom sites. This is probably due to the concentration of fishing effort at ledges, and because the low complexity of sand bottom types is less conducive to debris entanglement and accumulation.

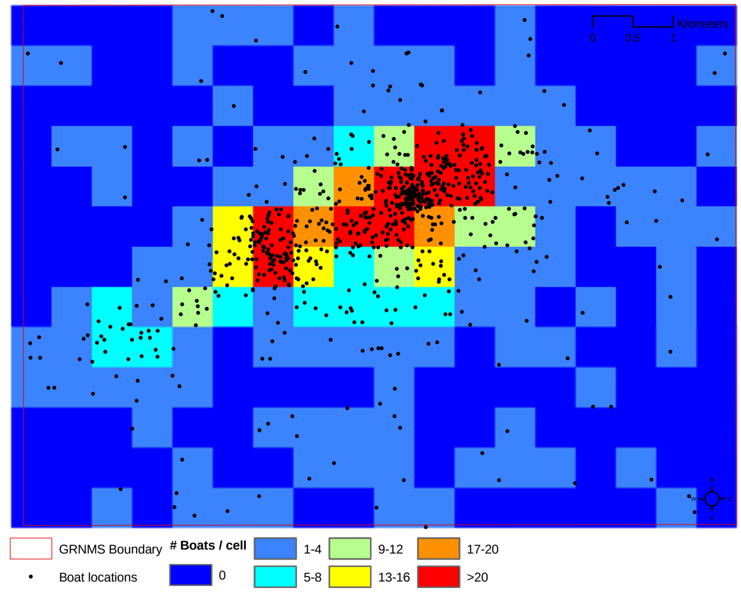

Figure 3.8. Locations of observed boats and density of boats per 0.25 km^2 cell.

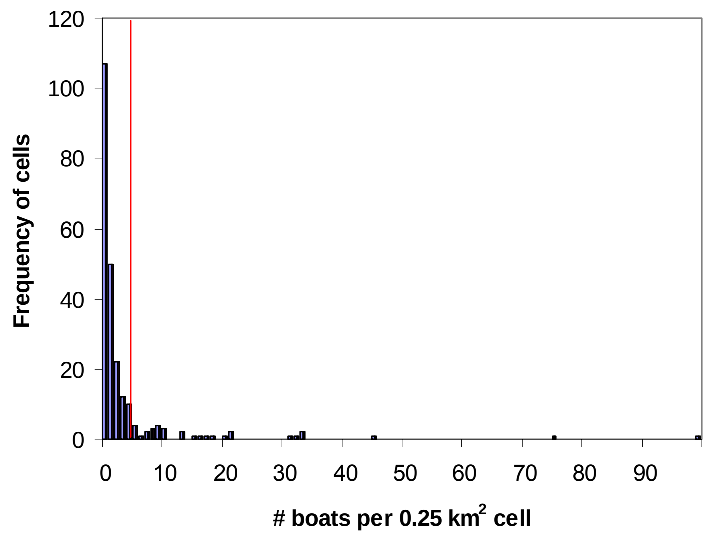

Figure 3.9a. Frequency histogram of the number of boats per cell in GRNMS. The red line represents the selected cutoff between low and high boat density.

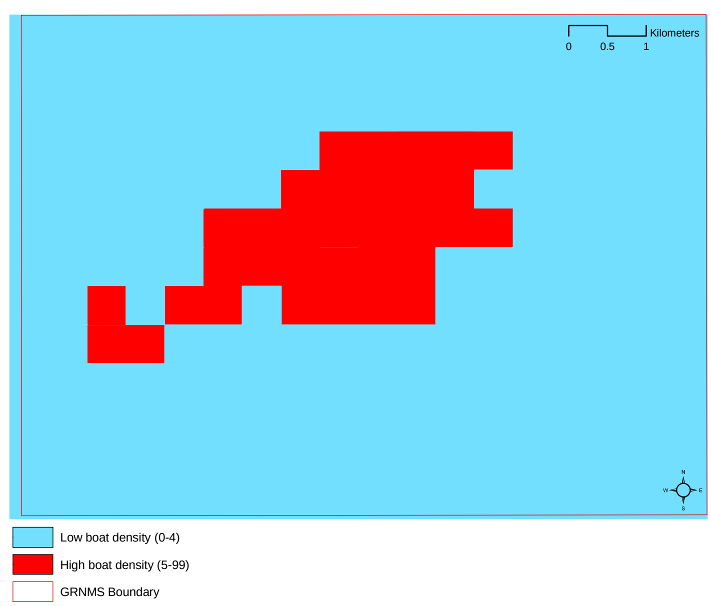

Figure 3.9b. Regions of low (0-4 boats/ 0.25 km^2 cell) and high (5-99 boats/ 0.25 km^2 cell) boat density.

Of all tested variables, boat density had the strongest association with both presence and abundance of debris at ledges. Boat density is highest in the center of the sanctuary on a SW-NE axis, with the largest concentration occurring in the vicinity of the data buoy (NOAA station 41008); 99 boats were observed in the cell that included the buoy. The high density of boats in this region is likely attributed to several factors. Recreational fishermen noted that the buoy is a popular location to catch bait and troll for king mackerel, and a nearby ledge attracts bottom fishers (Captain Judy Helmey and William H. "Bing" Phillips, personal communication). Slightly further away from the buoy, boat activity is less dense but still high. Fewer boats were observed in the southern portion of the sanctuary, despite the presence of numerous ledges, which indicates less fishing occurs here compared to areas of high boat density. This is further supported by the difference in debris types between the two areas. Three-quarters of the debris items found in the region of high boat density were fishing gear, while debris items observed in the low density region were primarily non-fishing related.

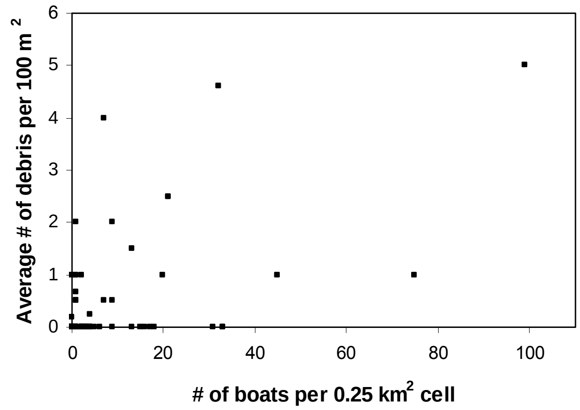

Figure 3.10. For each 0.25 km^2 cell, the relationship of average number of debris items (per 100 m^2) with the number of observed boats.

In addition to the strong link with boat density, patterns of debris occurrence were also related to physiographic features of ledges. The presence of debris significantly increased with increasing area and percent cover of ledges; and given presence, the abundance of debris was positively related to ledge height. It is not surprising that ledge area is a significant predictor of presence of debris because extensive ledges are more likely to be targeted by recreational fishermen who closely monitor their depth sounder (John Duren, personal communication). Once good fishing spots have been located, fishermen often return to those locations. Thus, high boat density in the center of the sanctuary, where many large ledges, including the five with the largest area, are located, may be indicative of preferred fishing spots. Fishing charts that include the GPS location of bottom features and fishing "hot spots" can be purchased in marina stores. Several of the features on such fishing charts (www.sstcharts.com, accessed June 4, 2006) are in close proximity to areas where both a large number of boats were observed and fishing debris was found.

There are a couple of reasons that ledge height may not have been significant in the first stage of the analysis. First, numerous tall ledges occur in the southern portion of the sanctuary, and they may experience lower fishing pressure based on boat sighting data. Such ledges may not be well known or have not been "discovered" at all, which may partially explain why little debris was found on them (Captain Judy Helmey and William H. "Bing" Phillips, personal communication). The importance of ledge height is confirmed in the second stage of the model; among ledges with debris, taller ledges have greater concentrations.

Interpolation (ordinary kriging) of observed debris data was used to predict debris density at ledges throughout GRNMS. Highest densities were predicted in the central region where the most debris was found, whereas little to no debris would be expected in the southern region. Although this method appears to be an effective way to estimate spatial density patterns, additional independent samples would be necessary to perform cross-validation analysis. Potential future work could refine the predictive model to include information on boat density and bottom feature characteristics, since these were significantly related to debris presence

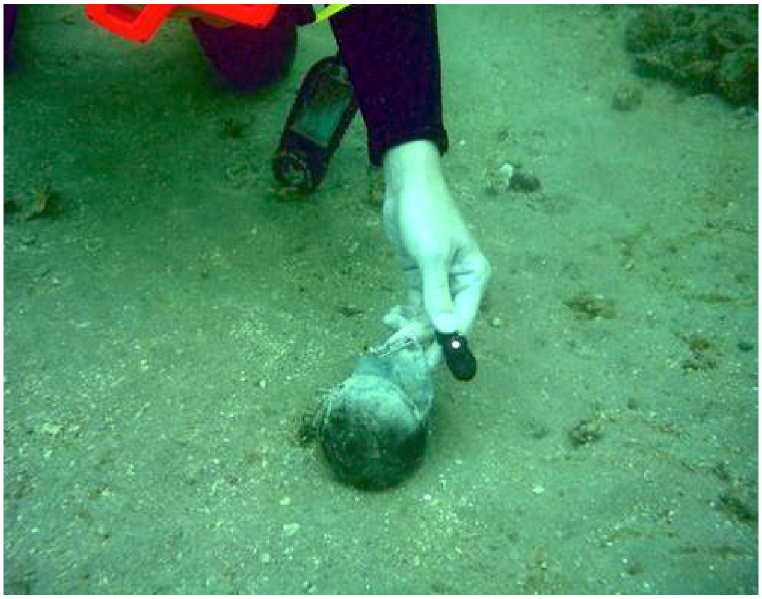

Image 18. Lead weight used for fishing.

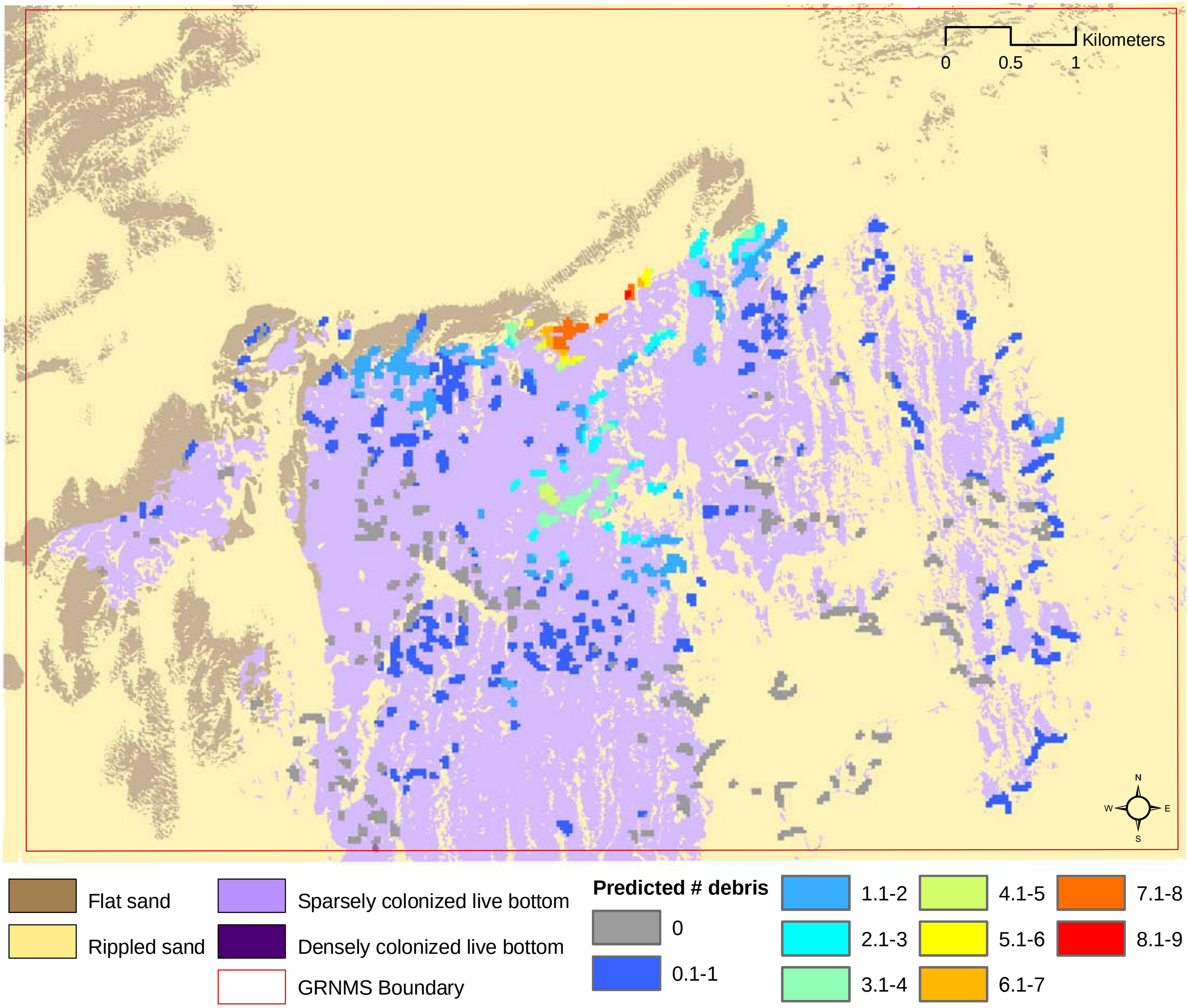

Figure 3.11. Interpolated debris density (per 100 m^2) in GRNMS from ordinary kriging.

and abundance. As stated previously, this was not carried out here as estimates of some variables (e.g., percent cover) are not available for all ledges.

The potential for outside sources of debris to enter the sanctuary was a subject of concern in the recent draft management plan (GRNMS 2006). Although there is no way to verify the origin of debris items found within GRNMS, we examined ocean current data to evaluate the potential for debris from outside the sanctuary to contribute to debris accumulation in GRNMS. Currents in GRNMS are primarily tidal, as indicated by the bimodal frequency in direction of currents recorded by the NOAA data buoy. The directions of the dominant currents, 305º and 125º, suggest that debris originating in the north-central part of the sanctuary could roll easily over featureless sand areas during a tidal cycle until it encounters the line of ledges where highest debris densities were observed. This is also the portion of the sanctuary nearest land, further suggesting that currents could bring in land-based debris items from outside the sanctuary. However, the highest densities of debris were not distributed evenly along this line of ledges, as would have been expected were tidal currents depositing marine debris from outside the sanctuary. It is likely that most fishing-related debris originates from boats inside the sanctuary. All observed fishing gear consisted of permitted gear types that are known to be used in the sanctuary. The prevalence of gear that is not used locally is often an indication that it has traveled from elsewhere, as has been observed in the NWHI (Donohue et al. 2001). The net movement of water could not be evaluated from available data; however,

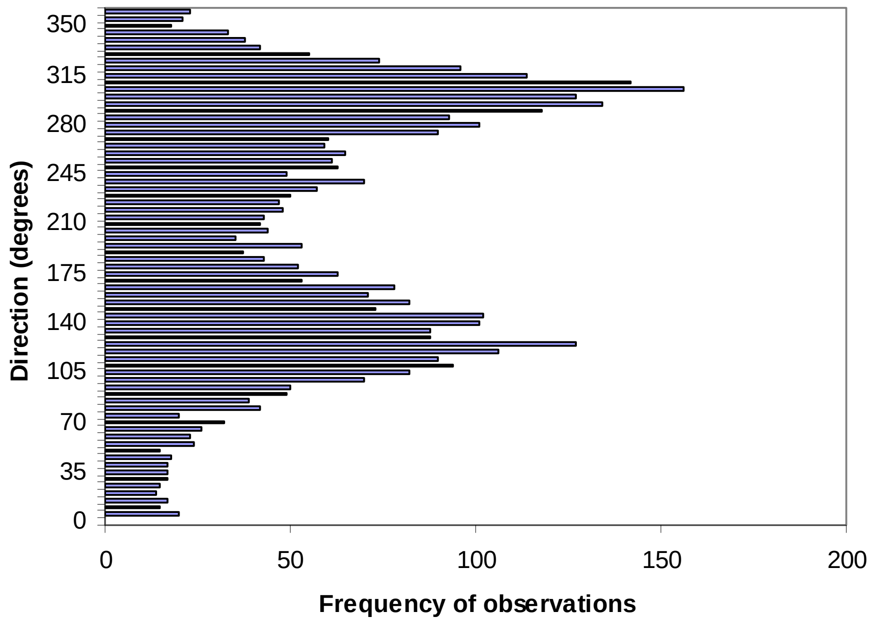

Figure 3.12a. Frequency of current direction observations at 15m depth at the NOAA buoy located in GRNMS. Observations were taken at hourly intervals from 9/1/05 to 2/28/06.

Seim and Edwards (Seim and Edwards in press) demonstrated that the NOAA buoy-mounted ADCP in GRNMS underestimated current velocity at depth.

The influence of ocean currents on debris accumulation in GRNMS warrants further study, particularly in relation to items that may more easily transported. For example, many of the non-fishing related debris items found in GRNMS consisted of beer and soda cans/bottles. While the highest concentration of non-fishing debris was also located in the center of the sanctuary, these items were often present at sites with no fishing debris and in the area of lower boat density. Marking debris items and tracking their movement over time is one possible way to assess

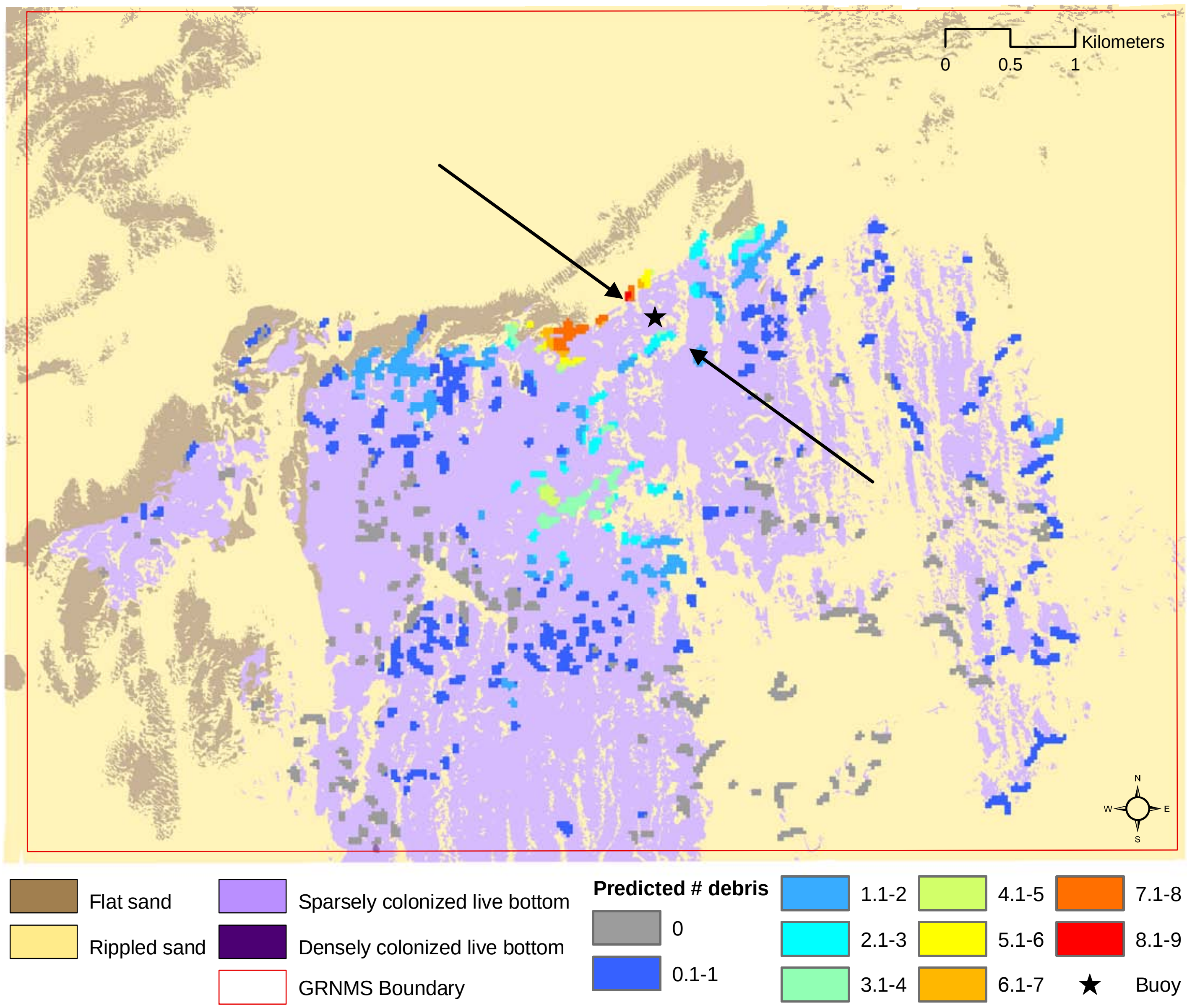

Figure 3.12b. Tidal current direction overlaid on map of GRNMS. The arrows represent the bimodal peaks from the frequency distribution (125º and 305º). 360º is due north.

the influence of currents on debris movement and accumulation.

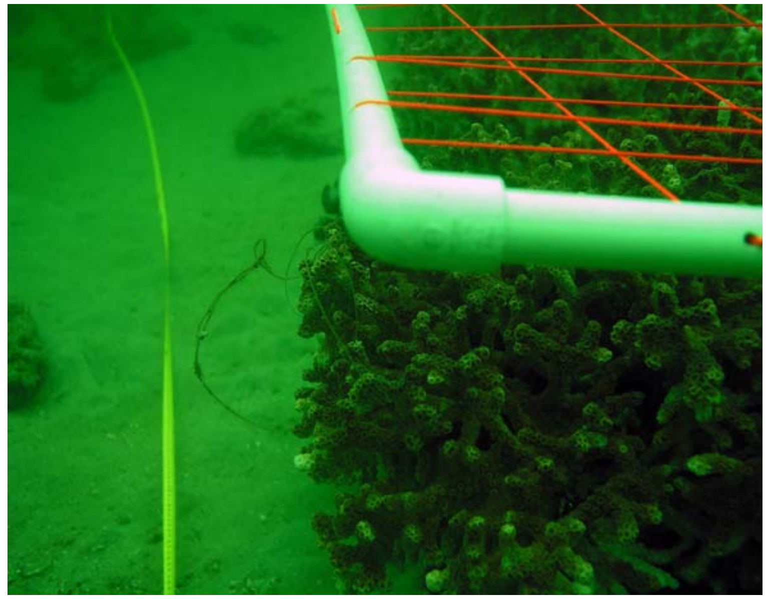

Image 19. Fishing line entangled in coral.

Debris density at GRNMS can be compared to estimated densities in the Florida Keys National Marine Sanctuary (FKNMS) found during a study using similar methodology (Chiappone et al. 2004). Total marine debris in the high relief spur and groove and low relief bottom types in FKNMS were estimated as 1.15 (±0.14 SE) and 1.22 (±0.20 SE) per 100 m^2, respectively (Chiappone et al. 2004), which is slightly higher than the mean density observed on ledge bottom type (0.97) and twice as high as overall mean density (0.52) in GRNMS. Furthermore, the distribution of debris in FKNMS appears to be more widespread; debris was recorded at 92% of sites sampled in FKNMS (Chiappone et al. 2004). The differences between the two sanctuaries may be a reflection of the disparities in accessibility; GRNMS is further from shore and likely receives fewer fishing trips than FKNMS. However, due to the differences in the bottom types that were sampled, it is difficult to directly compare our results to those in the Florida Keys. Chiappone et al. (2004) also compared hook and line density between regions of varying fishing pressure (no fishing, fished, and catch and release zones) but surprisingly found no significant differences between the three areas. The authors hypothesized that this may be due to noncompliance with regulations and/or the deposition of debris prior to enactment of regulations in protected zones in 1997. Similarly, it is unknown when debris that we observed in GRNMS was deposited. Periodic monitoring and removal of debris at designated sites would greatly improve our understanding of debris accumulation rates in GRNMS.

3.6 RECOMMENDATIONS FOR MANAGEMENT AND MONITORING

Information gleaned from the current analysis was used to devise a strategy for prioritizing cleanup efforts (Figure 3.13). Because the overwhelming majority of debris was located in densely colonized ledge habitat, ledges should be considered a higher priority for debris mitigation and removal. Second, due to the significant difference in presence and abundance of debris between regions of high versus low boat density, ledges positioned within the area of more intense fishing pressure are more likely to have debris. Of the 436 mapped ledges in GRNMS, 156 are located within the region of high boat density. The number of ledges receiving top priority for cleanup can be reduced further by accounting for ledge height and area, since the results of this study demonstrated that presence and abundance of debris are positively correlated with these variables. As described in the methods section, all of the ledges in GRNMS were classified as short, medium, or tall in height and small, medium or large in area. Within the region of high boat density, 34 ledges are clas-

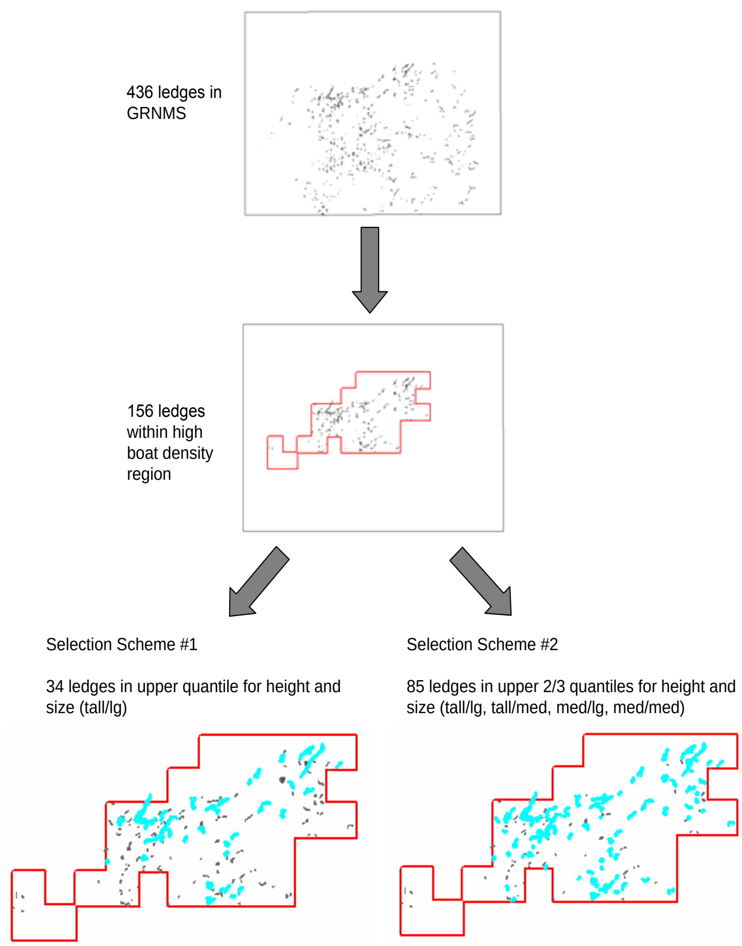

Figure 3.13. Recommended strategy to prioritize ledge sites within GRNMS for debris removal.

sified as both “tall” and “large” and would be recommended as the first sites to target. During the recent “Sweep the Reef, Sweep the Beach” World Ocean Day Cleanup 2006, divers removed numerous debris items, including fishing gear and beverage cans/bottles, from several sites within this category (Gail Krueger, personal communication).

If sufficient resources are available, an additional 54 ledges that fall into both the upper two quantiles for height and area (tall/medium, medium/large, medium/medium) are additional recommended sites for debris removal, bringing the total to 85 ledges. After debris is removed, sites should be monitored periodically to measure rates of new debris accumulation. In addition, we would recommend expanding long-term monitoring efforts to include several ledges that are located in the areas of lower observed boat densities to compare accumulation rates. Periodic updates of boat sighting data will allow managers to detect any changes in recreational boating patterns in GRNMS.

Image 20. Example of fouled fishing line (out of water).

Marine debris may inflict both direct and indirect damage to biota in GRNMS. Although impacts on biota were not quantified as part of our study, in several instances fishing line was observed to be entangled with benthic organisms, particularly the branching corals in the family Oculinidae. Fishing line, wire, hooks, and leaders can cause tissue abrasion when they snag on reef organisms. Chiappone et al. (2005) documented significant relationships between the density of lost hook-and-line gear with the density of damaged sponges, gorgonians, and milleporid hydrocorals, and found a positive correlation between length of fishing line and densities of damaged gorgonians. Once entangled, fishing line may become incorporated into the reef matrix if it is overgrown by individual organisms (Chiappone et al. 2005). In our study, fishing line was often fouled by algae. In time, progressive algal fouling of fishing line entangled in coral may lead to coral death (Schleyer and Tomalin 2000; Asoh et al. 2004; Yoshikawa and Asoh 2004). In GRNMS, taller ledges in particular may be most susceptible to damage because they tend to be most densely colonized with benthic organisms (this document). The impacts of hook-and-line fishing gear and other debris on benthic organisms in GRNMS and elsewhere need further study because negative effects are likely to become more severe as use of the sanctuary increases.

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CHAPTER 4: CHARACTERIZATION OF THE BOTTOM FISH

4.1 INTRODUCTION

Image 21. Various species of fish.

A comprehensive characterization of the density and size distribution of bottom fish and their associated habitats has not yet been conducted for Gray's Reef National Marine Sanctuary (GRNMS). Not long after the sanctuary was designated in 1981, Gilligan (1989) began compiling a list of 91 fish species that were characteristic of the area and noted the general habitats of each species such as hardbottom, sand, or in the pelagic environment. Video and scuba surveys over selected ledges and other bottom types in recent years have greatly expanded this species list and have also estimated the relative abundance of some taxa (Parker et al. 1994, Reef Environmental Education Foundation). Other studies have had sites on ledges or hardbottom within GRNMS and have further characterized fish communities, general bottom associations, fish densities, and some seasonal differences among fish assemblages (Sedberry and Van Dolah 1984, Parker et al. 1994, Barkoukis 2006). Many additional studies have been conducted elsewhere in the South Atlantic Bight on fish communities over live bottom (Struhsacker 1969, Huntsman 1976, Miller and Richards 1980, Powles and Barans 1980, Grimes et al. 1982, Wenner 1983, Chester et al. 1984, Sedberry and Van Dolah 1984), sand bottom (Struhsacker 1969, Wenner et al. 1979a, 1979b), and shelf edge environments (Struhsacker 1969, Grimes et al. 1982, Barans and Henry 1984, Parker and Ross 1986, Gilmore and Jones 1992, Parker and Mays 1998, Sedberry et al. 2004, Quattrini and Ross 2006). Most of these studies were conducted at broad scales covering much of the South Atlantic Bight and examined differences in assemblage structure between inshore and offshore communities or latitudinal changes in biogeography.

Despite this abundance of studies in the South Atlantic Bight, very little quantitative analysis has been done on mid-shelf fish and their specific habitat associations (but see Parker et al. 1994). Hardbottom and limestone ledges are known to be key habitats for bottom fish in the region; however, the factors that make them attractive to various components of the fish community have not been quantified. Even studies that have focused on individual species of bottom fish often do not quantify their fine-scale habitat preferences (Matheson et al. 1986, Mercer 1989, Gilmore and Jones 1992, Harris et al. 2002, McGovern et al. 2005, Barkoukis, 2006). At best, gross ledge height has been categorized as small, medium, and large or sparsely, moderately, or densely colonized by sessile invertebrates and then related to fish assemblages (Parker et al. 1994, Riggs et al. 1996, Quattrini and Ross 2006). Although all of these studies have provided a wealth of biogeographic information on the South Atlantic Bight and an understanding of the general habitat associations of bottom fish, the more detailed structural attributes of benthic habitat that control the variability in the fish community at locations like GRNMS have remained unknown.

In contrast to the lack of detailed studies on hardbottom habitats in the South Atlantic Bight, much research has been focused on defining fine-scale habitat associations of fish in coral reef environments although often with conflicting results (Risk 1972, Luckhurst and Luckhurst 1978, Molles 1978, Roberts and Ormond 1987, Chabanet et al. 1997, Öhman and Rajasuriya 1998, Friedlander and Parrish 1998, Gratwicke and Speight 2005). In these studies, the total abundance, species richness, diversity, and trophic structure of reef fish have variously been correlated with benthic characteristics such as rugosity, vertical relief, coral cover, and other variables. Various reef types and regions have been shown to have quite different relationships between fish community parameters and benthic characteristics and have demonstrated the need to identify the factors that drive community structure of fish that are specific to each reef type and locale.

Bottom type at GRNMS has been coarsely defined as sand, flat live bottom, and ledges. A key precursor to the present study was conducted by Parker et al. (1994) who examined the fish communities associated with these general bottom types as mapped by Hunt (1974), and further categorized live bottom as covered with sparse (<25%), moderate (25-50%), or dense (>50%) cover of sessile benthic invertebrates. An important next step is analysis of how fish community structure varies with habitat features measured on continuous rather than categorical scales. For example, how ledge height, area, undercut, percent cover of hard or soft substrate, and percent cover of sessile biota relate to resident fish communities at GRNMS has not been quantified.

With the recent availability of much more detailed benthic maps of GRNMS (Kendall et al. 2005), a spatially comprehensive inventory of fish and their associated bottom features is now possible. Necessary improvements to the existing inventory include comprehensive surveys of fish associated with all bottom types, estimation of the size structure of fish communities, analysis of the fine-scale benthic features that are associated with the fish community, and detailed analysis of the spatial distribution of key species.

In addition to a detailed characterization of fish and their associated bottom types, the impact of other forces that shape fish communities remain largely unknown. For example, recreational fishing is a key user activity to understand and sustain at GRNMS. Fishing effort has presumably been on the rise at GRNMS in recent decades given increasing human populations for coastal Georgia, higher numbers of recreational anglers and days spent fishing (Ehler and Leeworthy 2002), and increasing boat density observed within the sanctuary (NOAA 2006). Recreational fishing with hook and line is the dominant approach at GRNMS although some spear fishing occurs as well. Both methods selectively target fish such as black sea bass (*Centropristis striata*), gag (*Mycteroperca microlepis*), and scamp (*M. phenax*) (Huntsman 1976, Mercer 1989). Trap fishing and bottom trawling are not allowed in the sanctuary (NOAA 2006). Direct and indirect effects on fish communities of several forms of fishing (e.g. commercial, recreational, artisanal) have been demonstrated in many parts of the world (Russ and Alcala 1989, McClanahan 1994, Watson and Ormond 1994, Grigg 1994, Jennings et al. 1995, Jennings and Polunin 1996, Jennings and Polunin 1997, Wantiez et al. 1997, Chiappone et al. 2000, Westera et al. 2003, Dulvy et al. 2004). Despite an abundance of studies elsewhere, little is known about the effects of recreational fishing on the overall species richness, diversity, and abundance of benthic fish communities in the South Atlantic Bight. The impact of recreational fishing directly on target species has been considered at broader scales but less is known about impacts at discrete localities such as GRNMS. Similarly, indirect effects of such activities on fish resources are not well understood. The spatial distribution of fishing effort is not uniform throughout the sanctuary. Patterns of boat use and marine debris such as fishing line and lures indicate that the central area of the sanctuary receives more fishing pressure than surrounding areas (Chapter 3). This offers the potential to look for differences in the fish community between the heavily used and less used areas.

The objectives of this component of the study were to: 1) conduct comprehensive surveys of bottom fish associated with all bottom types in the sanctuary using a random stratified sampling approach and the best available bottom maps; 2) describe the size structure of fish communities and key species of interest to the recreational fishery; 3) identify the fine-scale benthic features that are associated with the fish community and key species; 4) compare fish communities and key species in heavily fished versus less intensively fished areas of the sanctuary; 5) map the spatial distribution of key species; and 6) offer suggestions for future monitoring of bottom fish at GRNMS.

4.2 METHODS FOR FISH SURVEYS

Visual fish surveys occurred along a 100 m^2 transect at randomly selected sites as outlined in Chapter 1. Once at a site, the fish surveyor attached a tape measure to the substrate or weighted line that

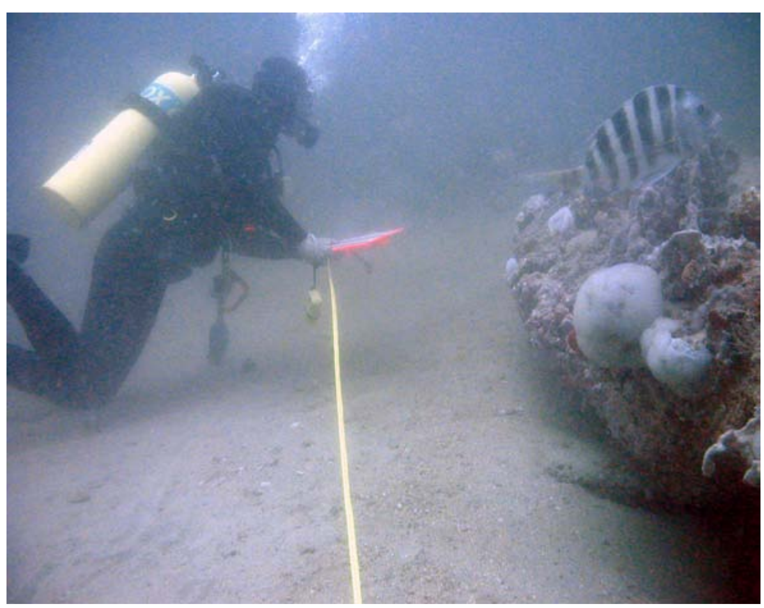


Image 22. Diver conducting fish survey.

was used to mark the site from the surface and began the survey. Recall that surveys were conducted in a random direction on all bottom types except for ledges. On dives over ledge habitat, the survey was conducted along the ledge face or lip if undercut. This allowed fish on the underside, face, and top of the ledge to be surveyed. As the tape rolled out, the diver looked forward toward the end of the transect and recorded all fish species to the lowest taxonomic level possible within the survey area. To maximize time spent observing fish and minimize the time spent writing the data, four letter codes were used that consisted of the first two letters of the genus name followed by the first two letters of the species name. In the rare case that two species had the same four-letter code, letters were added to the species name until a difference occurred. If the fish could only be identified to the family or genus level then this was all that was recorded. The number of individuals per species was tallied in 10 cm size class increments up to 70 cm using visual estimation of fork length. If an individual fish was greater than 70 cm, then a visual estimate of the actual fork length was recorded. Although the benthos was not altered by lifting or moving rocks or other objects, the fish surveyor moved off the center line of the transect temporarily to identify, enumerate, or observe fish in holes and under ledges.


Image 23. Triggerfish and tomtates.

Several similar looking pairs or groups of species that were observed often moved too quickly, kept a distance from divers, or remained far under recesses of ledges to allow consistent identification to the species level and were therefore identified only to the genus level. Those species were *Seriola dumerili* and *S. rivoliana, Pareques umbrosus* and *P. acuminatus*, and *Decapterus maculatus* and *D. punctatus.*

4.3 METHODS FOR DATA ANALYSIS

A summary of all species observed in this characterization was created in tabular format. The probability of encounter, mean abundance (+/- standard error), and biomass (+/- standard error) within a 100 m^2 transect were provided for each species within the four bottom types surveyed. Probability of encounter is the proportion of surveys in a given habitat type on which a species was observed. For species that had zero values for probability of encounter, abundance and biomass were left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass were calculated. Mean values are rounded to the nearest whole number and SE is rounded to tenths. Biomass was calculated using the length-weight relationship $W = aL^b$, where L is length in centimeters and weight is in grams. The mid point of each size class was used as the value of L. For example, if a fish were in the 10-20 cm size class its length (L) for biomass estimation was assumed to be 15 cm. Values of the terms (a) and (b) were obtained from FishBase (Froese and Pauly 2005) for each species. For species with more than one length-weight relationship defined, values for the study nearest GRNMS were used. For species with no length-weight relationship published, terms for a morphologically similar species were used. Analysis of seasonal differences in the fish community is limited to noting presence/absence by sampling month (i.e., May, August, or both).

General differences in the fish communities among bottom types were evaluated by comparing species richness (number of species), diversity (Shannon Index), abundance, and biomass for each bottom type. Data were grouped by bottom type: flat sand, rippled sand, sparse live bottom, or ledge as identified by divers at each site. All data were log transformed to meet normality and homogeneity of variance assumptions. ANOVA was used to determine if multiple means comparisons were warranted followed by Tukey tests to identify which bottom types differed for each variable.

Differences in the size distribution of fish among bottom types were examined with size frequency histograms. For these, fish abundance was averaged across all species within each 10 cm size class.

To further evaluate the differences in community structure among bottom types, the differences in the particular fish species that were present at each site were examined using cluster analysis. Sites were hierarchically clustered based on presence/absence of the 78 species found in the study using Ward's Minimum Variance technique. Presence/absence was used to focus the analysis on simple community membership. Patterns were checked for stability using other clustering procedures and by clustering based on abundances of species at each site with extreme outliers removed.

The fish communities at ledges were examined in greater detail through regression, cluster analyses, multiple means comparisons, and GIS plots. Relationships between community structure of fish and ledge characteristics were investigated with multiple regression of the 92 ledge sites. Response variables were species richness, abundance, and diversity of fish. Explanatory variables included mean percent cover of sessile invertebrates, total height, undercut height, undercut width, and total area of ledges from benthic maps (Kendall et al. 2005). In the event that percent cover was significant in explaining fish community variables, abiotic cover (hardbottom, sand, etc.) and biotic cover groups (coral, sponges, etc.) were examined further in a separate analysis. In addition, to evaluate any differences in fish community structure due to fishing pressure, fish data associated with ledges located in areas of high boat density were compared with low boat density areas (see Chapter 3). Preliminary analysis of boat count data likely to be engaged in bottom fishing and marine debris data revealed that the high and low boat density areas used in Chapter 3 were good surrogates for areas receiving relatively higher versus lower bottom fishing pressure respectively. Backwards selection in regression models was used to ensure that only the most influential variables were retained in the model. Analyses were performed on untransformed data except for fish abundance which was log transformed to meet statistical assumptions for multiple linear regression.

The 92 ledge sites were further examined for differences in their fish communities through cluster analysis. These 92 sites were hierarchically clustered based on presence/absence of the 72 species found on ledges in the study using Ward's minimum variance technique. Patterns were checked for stability using other clustering procedures and clustering based on abundance with removal of extreme values (e.g. school of 40,000 *Haemulon aurolineatum*). The 92 ledge sites were also clustered based on ledge characteristics including percent cover, total height, undercut height, and undercut width.

The association between fish communities and ledge characteristics was examined further by considering the types of ledges with which each fish community was found. This was done by comparing the results of the cluster analysis for sites based on their fish community with the clusters based on ledge measurements. To facilitate this comparison, a scatter plot was created in which the sites clustered based on the fish data were placed on the X axis and the sites clustered based on the ledge data were placed on the Y axis. The intersection of each site was then plotted in chart space. The results from earlier analyses indicated four clusters based on the fish community analysis and four based on the ledge measurement analysis respectively. These clusters were used to separate the chart space into sixteen intersecting regions. This enabled both the fish community, hereafter called fish clusters, and the corresponding physical characteristics of ledge sites, hereafter called ledge clusters, to be described relative to each other. To check the stability of the resulting coincidence of fish clusters and ledge clusters, an additional clustering procedure was conducted wherein ledge sites were clustered based on both their ledge characteristics and fish species present in the same analysis.

Image 24. Sea robin on sparsely colonized live bottom.

An additional summary of all species observed on ledges was created in tabular format. The probability of encounter, mean abundance (+/- standard error), and biomass (+/- standard error) within each 100 m^2 transect are provided for each species within the four ledge types identified by the cluster analysis.

Simple plots of species richness, abundance, biomass, diversity, and ledge clusters were produced in a GIS using each survey location's latitude and longitude. Sites were overlaid on benthic maps of the sanctuary and visually assessed for spatial patterns.

Finally, selected fish species were examined further due to their importance to the recreational fishery including black sea bass (*Centropristis striata*), gag (*Mycteroperca microlepis*), and scamp (*M. phenax*) (Huntsman 1976). Only those surveys conducted on ledges (n=92) were used in the analyses for these species since that is their preferred bottom type and is where fishermen most often target them (Duren and Helmey, pers. comm.). In particular, *Mycteroperca* species are rarely seen apart from ledges. Size frequency histograms were created for each species with sightings designated as either in more intensively fished or less fished areas according to boat density (Chapter 3). Average number of fish in each size class +/- SE was calculated. The size bin containing the size limit of the recreational fishery (South Atlantic Fishery Management Council 2006) is noted on these plots and the proportion of fish above and below this value was calculated for high versus low boat density areas of the sanctuary respectively. Where size limits fell within our size classes, the number of fish in that class was split proportionally above and below the value. For example, the size limit for gag is 61 cm (24 inches total length) and our size bin ranged from 60 to 70 cm. Therefore, 10% of the fish observed within that bin were assumed to be below and 90% were assumed to be above the size limit. In addition, size frequency histograms of these three species were plotted for each survey site and overlaid onto the benthic map of GRNMS to examine the spatial distribution of the various size classes.

In addition, these three fish species of interest were examined further for relevant relationships to ledge characteristics and other variables using data from the 92 ledge sites. The abundance and mean body length of *C. striata* was examined for relationships with ledge and other relevant variables through multiple regression. Variables tested were total percent cover of sessile biota, total ledge height, ledge area, and location (high or low boat density region). In addition, all possible two-way interactions with boat density (high versus low) were examined. Undercut variables were not considered in this analysis since *C. striata* is not observed to utilize ledge undercuts. Abundance was log transformed to meet statistical assumptions.

Probability of occurrence for the two *Mycteroperca* species respectively, as related to ledge variables, was examined through logistic regression. Abundances were too low to enable analysis beyond simple presence/absence. Observations of these species made while diving indicate that these species utilize undercut ledges. Therefore, relationships between the presence/absence of these species and undercut height, undercut width, ledge area, and location (high or low boat density region) were considered along with all possible two-way interactions with boat density. Mean size of these species was also examined through multiple regression with these same variables.

The relationship between occurrences of the two grouper species and *Centropristis striata* relative to each other was also evaluated with multiple regression. For this analysis the presence/absence of both *Mycteroperca* species was combined because they often occur together. The abundance of *C. striata* was analyzed as a response variable with presence/absence of *Mycteroperca* species and the significant variables predicting *C.striata* abundance and *Mycteroperca* species occurrence as independent variables (ledge area, percent cover, and undercut height).

4.4 RESULTS

Visual censuses recorded 78 fish species (or species groups) from 61 genera (Appendix A). Of the 78 species, 45 were observed in both May (68 total surveys) and August (111 total surveys) sampling periods, 8 were only observed in May, and 25 were only observed in August.

On ledge habitat, 72 of the 78 species observed in the study were found with *Centropristis striata* (seen on 98% of ledge surveys), *Halichoeres bivittatus* (89%), *Serranus subligarius* (88%), and *Stenotomus species* (80%) encountered most frequently (Appendix A). The most numerically abundant species on ledges were schooling juvenile fish such as *Haemulon aurolineatum* (mean abundance/100 m^2 transect 931 +/- 495 SE) and *De-*

capterus species (195 +/- 119 SE) which were seen in great abundance during August surveys in particular. Also quite abundant at all times were *Pareques* species (55 +/- 23 SE), *C. striata* (28 +/- 2 SE), and *Stenotomus* species (24 +/- 3 SE). Pelagic schooling fish such as *Caranx crysos* had by far the highest biomass (mean biomass (g)/100 m^2 14278 +/- 9082 SE). Bottom associated fish with high biomass were *Pareques* species (6013 +/- 3411 SE), *C. straita* (4111 +/- 524 SE), *Archosargus probatocephalus* (3041 +/- 840 SE), *Mycteroperca phenax* (3035 +/- 884 SE), and *M. microlepis* (2586 +/- 1073 SE).

Image 25. Black seabass.

Thirty-five out of the 78 fish species were observed over sparse live bottom (Appendix A). The species most commonly encountered were *C. striata* (seen on 98% of surveys over sparse live bottom) and *Stenotomus* species (90%). These were also the most numerically abundant and had the highest biomass of bottom associated species on this habitat type although *Caranx crysos*, considered a pelagic fish, had the highest biomass (3026 +/- 1560 SE) among all species.

Seventeen of the 78 species observed in the study were seen over flat sand habitat (Appendix A). The most commonly encountered species was *Xyrichtys novacula* (seen on 75% of surveys over flat sand). Pelagic schooling fish such as *Decapterus* species, *Caranx crysos*, and *Scomberomorus maculatus* were the most numerically abundant and had the highest biomass. Eighteen fish species were seen over rippled sand, with *Xyrichtys novacula* again being the most frequently encountered (seen on 88% of the surveys over rippled sand) (Appendix A). Flat and rippled sand shared 13 species comprised mostly of pelagics and those specializing in sand habitat such as flatfish and razorfish. The most numerically abundant bottom species on rippled sand were *X. novacula* (9 +/- 6.8 SE) and also *Stenotomus* species (69 +/- 62.4 SE) due to a large number of juveniles observed at some sites during the May sampling period. *Stenotomus* species also had high biomass on rippled sand (257 g +/- 161.6 SE), second only to *Decapterus* species (628 +/- 524.8 SE), a pelagic schooling species.

Significant differences occurred in fish species richness, diversity, abundance, and biomass among bottom types (Figure 4.1). Flat and rippled sand sites had lowest values for all four variables. Ledge sites had significantly higher species richness, abundance, and biomass than all other bottom types. Fish diversity at sparse live bottom habitat was not significantly different from that at ledge sites. The spatial distribution of species richness, abundance, biomass, diversity, and ledge clusters based on the fish species present at each site all showed no clear clumping or other non-random pattern when plotted and visually examined within the sanctuary boundaries.

Size frequency of all fish by bottom type revealed large differences in abundance and size structure of fish communities among the four bottom types (Figure 4.2). Flat and rippled sand were populated exclusively with the smaller size classes of fish with virtually all benthic associated fish in the 0-20 cm size classes. Fish in the 20-40 cm size classes that were observed over sand habitats were almost exclusively pelagic schooling species such as *Caranx crysos, Decapterus* species, and *Scomberomorus maculatus*. Also of note, rippled sand had a large but highly variable occurrence of fish in the smallest size class. This was due to large schools of *Stenotomus* species observed at some sites in May 2005. Sparse live bottom sites were also dominated by the smaller size classes of fish although occasional observations of individual longer fish, up to 70 cm FL, such as *Gymnothorax saxicola* were made. Ledges had much higher abundance of fish in all size classes. Of note were immense schools of fish in the smallest size class, primarily juvenile *Haemulon aurolineatum*, and highest abundances of the very largest fish such as serranids and *Lutjanus campechanus* in the 60-90 cm size classes as well as *Ginglymostoma cirratum* up to 160 cm.

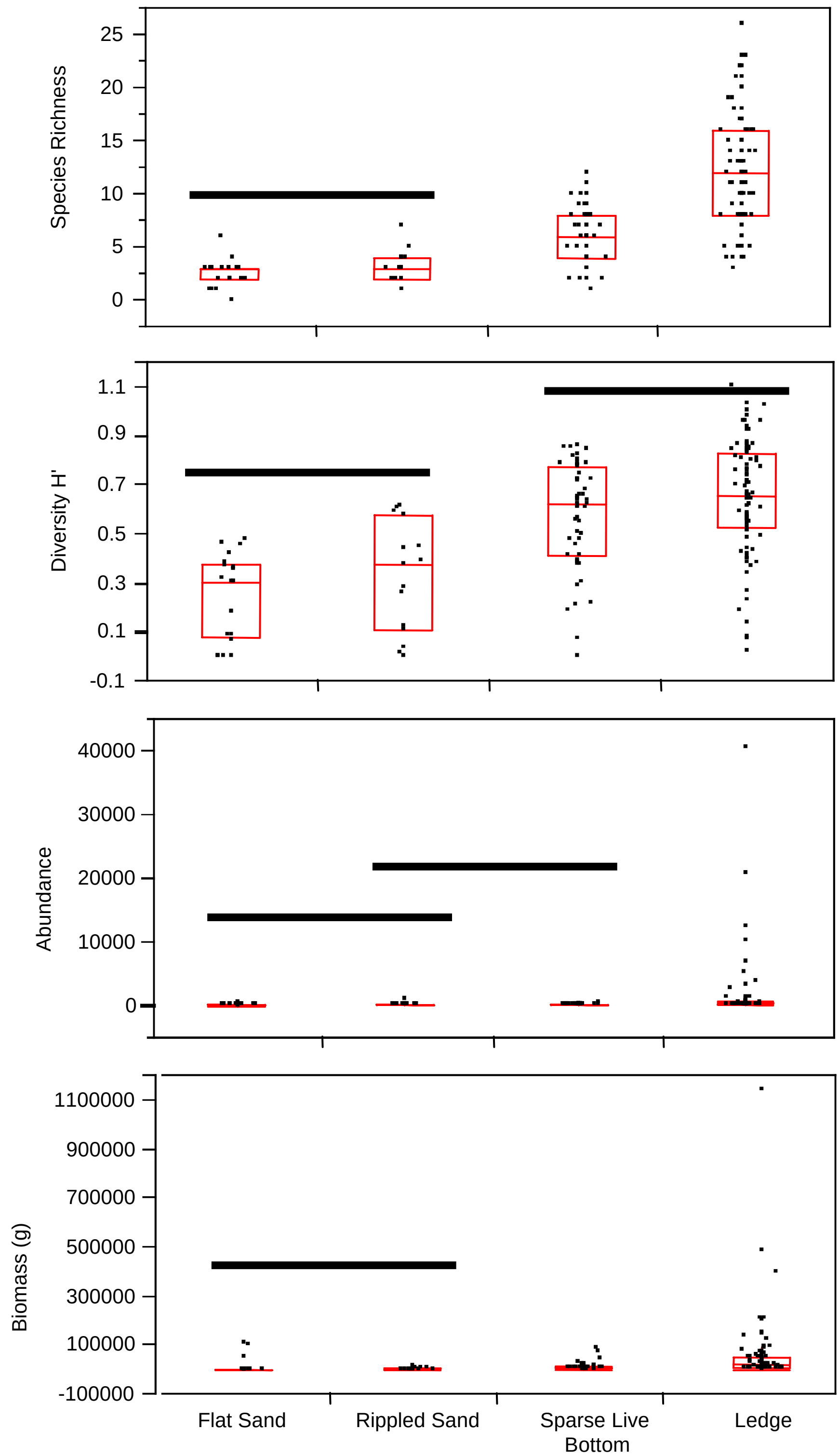


Figure 4.1. Species richness, Shannon Diversity (H'), abundance, and biomass of fish on 100 m² surveys within each bottom type. Box plots denote median and interquartile range. Bars denote groups that are not significantly different from each other based on Tukey multiple means comparisons.

The clustering procedure on all 179 of the fish survey sites identified groups of sites with similar species composition (Figure 4.3). The inflection point on the scree plot at the bottom of the clustering dendrogram indicated the presence of 4 well separated clusters. Two clusters included only ledge sites with 26 and 20 sites respectively. Sites in these two clusters typically had a similarly high number of species (16-17) (although obviously with different membership). One large cluster consisted primarily of sparse live bottom sites (49 of 94) although a large number of low relief ledges were also included. These sites had fewer species with an average of only 8.8 per site. The final cluster consisted primarily of flat and rippled sand which together accounted for 32 of its 39 sites.

An average of only 3.4 species was present at these sites. Resulting patterns were similar whether based on fish abundance or other clustering techniques, adding confidence that the groupings are reliable. Plots of site clusters overlaid on the benthic maps revealed no spatial patterns.

The regression of ledge variables on fish community metrics indicated that only a few ledge characteristics influenced the overall fish assemblage. Species richness and abundance of fish had significant positive relationships

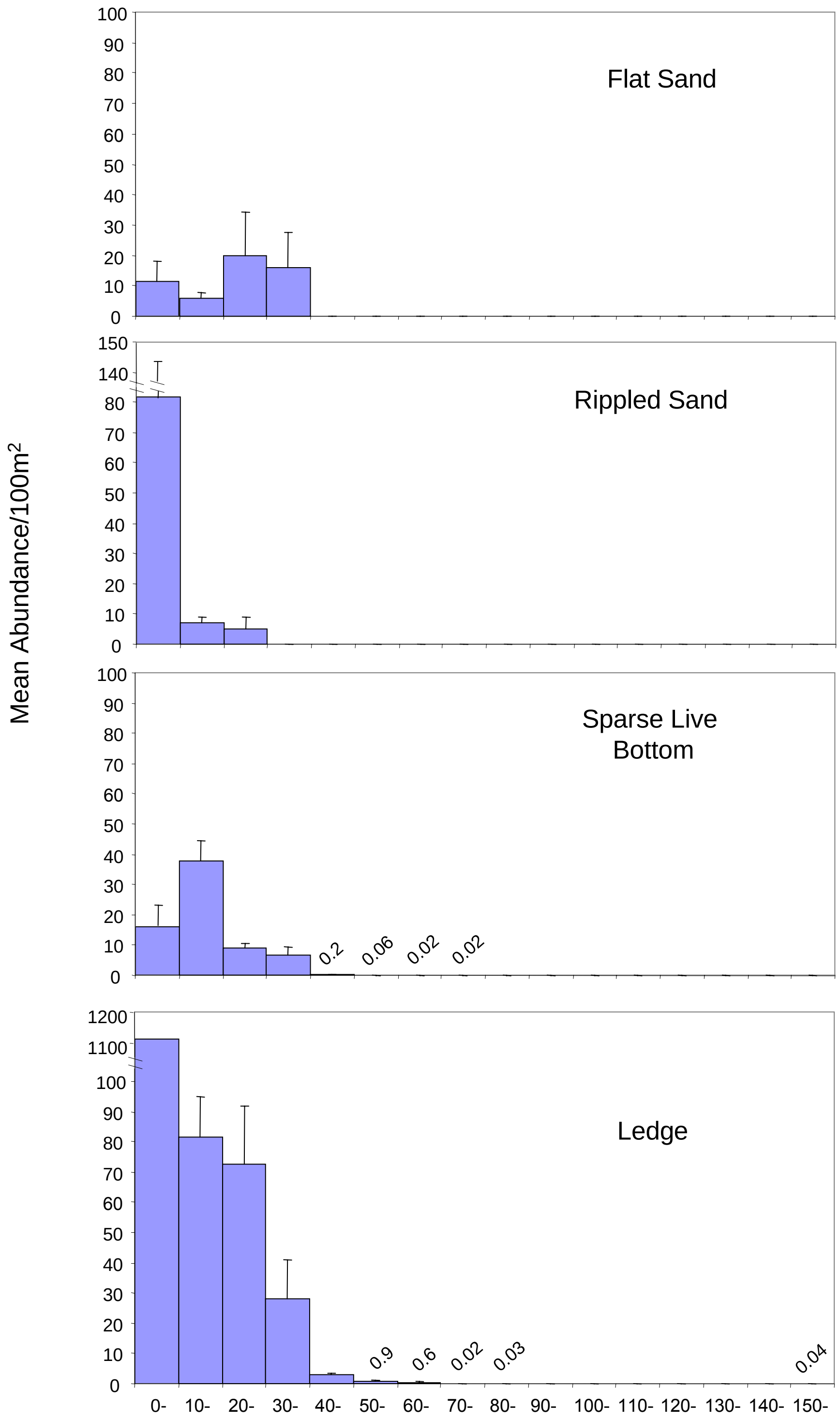


Figure 4.2. Size frequency histograms of fish by bottom type. Columns denote average number of fish (+/- SE) within each size class. Numbers within the sparse live bottom and ledge plots denote low mean occurrence values which were not discernable at this scale.

to both average percent cover and total height (Figures 4.4-4.5). These two-variable models for fish richness and abundance explained 65% and 70% of the variability in the data. Analysis of abiotic and biotic cover groups indicated a significant relationship for these two measures of the fish community occurred with only macroalgae and other (mostly tunicates) cover types, the two most dominant colonizers on ledges. Fish diversity (H') had a significant, positive, and linear relationship with ledge area and a significant negative relationship with average undercut height (Figure 4.6), however, these variables explained only 12% of the variability in the data. Undercut width was not a significant variable in predicting values for any fish community metric. Ledges under high boat

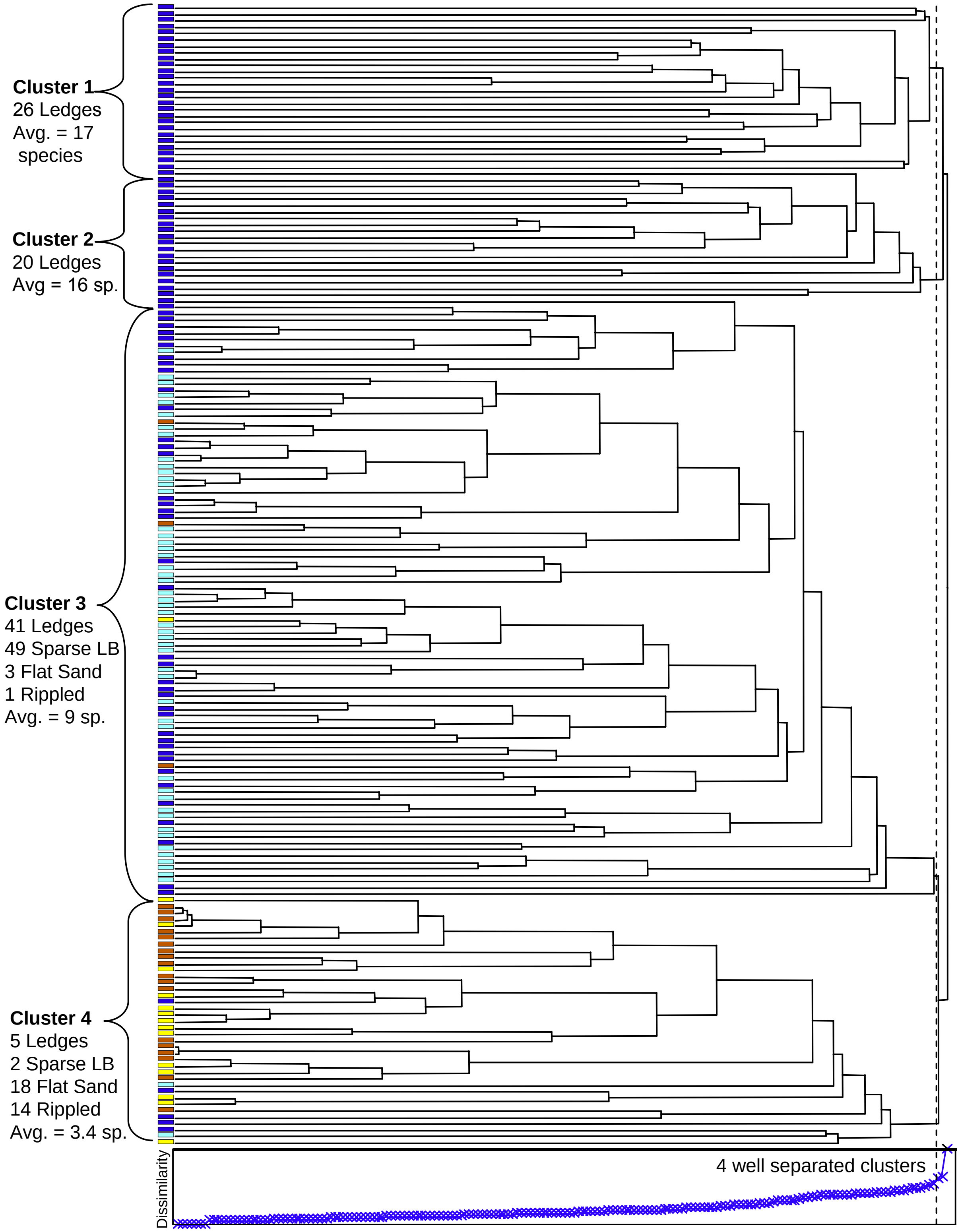


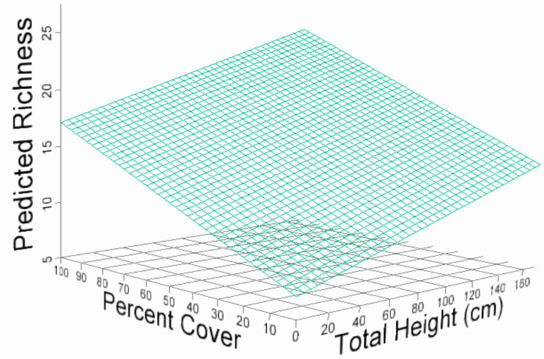
Figure 4.3. Dendrogram for cluster analysis of all 179 sites based on species composition. The scree plot at bottom indicates that there are four well separated clusters. Dark blue denotes ledge, light blue denotes sparse live bottom, flat sand is represented by brown, and rippled sand is yellow.

density (presumed to be more intensively fished) versus low boat density areas did not have a significant relationship with fish community structure when added to the final models except for overall fish abundance. Even then, while the relationship was significant with less fished ledges having higher fish abundance it only explained an additional 1.7% of the variability in the data (Adjusted R^2=0.713 relative to 0.696 for the two variable model).

The clustering procedure on the 92 ledge sites based on occurrence of fish species identified groups of ledges with similar species composition (Appendix B, Figure 4.7). The inflection point on the scree plot below the cluster dendrogram (Figure 4.7) indicated the presence of four clusters. Several clustering procedures were tested and yielded similar patterns as did clustering based on abundance. Clusters 1 and 3 were typically made up of sites with a higher number of species (average species richness 17 and 16 respectively). Cluster 2 typically had sites with a lower number of species (average 8.5). Cluster 4 was made up of a single site with nine species and had the only observations of a couple of rare species, *Pomacanthus paru* and *Ogcocephalus nasutus*. This lone site/cluster was not considered further. Unlike the other clusters, sites in Cluster 1 appeared separated from others by virtue of never having a record of *Lagodon rhomboides* but often having observations of other species such as *Chaetodipterus faber, Haemulon plumieri, Holacanthus bermudensis, Mycteroperca microlepis*, and *Mycteroperca phenax.* Sites in Cluster 2 were separated from others by typically having no occurrence of *Apogon pseudomaculatus, Archosargus probatocephalus, Balistes capriscus, Haemulon aurolineatum, Pareques* sp., and *Rypticus maculatus* but often with occurrence of *Diplectrum formosum*. Cluster 3 often had *Apogon pseudomaculatus, Centropristus ocyurus*, and *Haemulon aurolineatum*.

The clustering procedure on the 92 ledge sites based on ledge measurements identified groups of ledges with similar physical characteristics (Figure 4.8). Ledge sites in Cluster 1 were tall and heavily colonized but had little or no undercut. Ledges in Cluster 2 were tall, heavily colonized, and had deep undercuts. Ledges in Cluster 3 were short, sparsely colonized, and had little or no undercut. Ledges in Cluster 4 were also short and had little undercut but were heavily colonized.

Species occurrence was markedly interrelated with ledge type (Figure 4.9). The chart of ledge sites



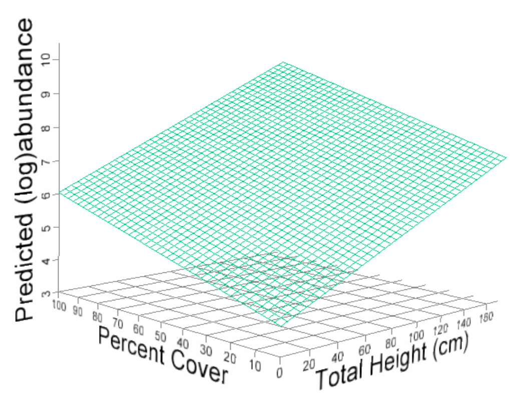
Predicted Richness = 6.77 + 0.104(Percent Cover) + 0.044(Total Height (cm))

R^2 = 0.66

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	6.77	0.55	12.29	<.0001
Mean Percent Cover	0.10	0.01	7.88	<.0001
Mean Total Height (cm)	0.04	0.01	3.07	0.0028

Figure 4.4. Multiple regression model of species richness of fish at ledge sites.



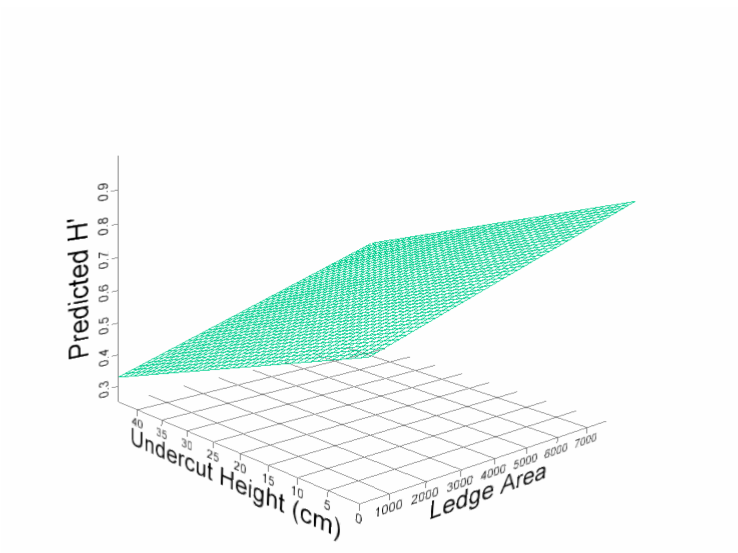
Predicted (log)abundance = 3.80 + 0.022(Mean Percent Cover) +0.021(Mean Total Height (cm))

R^2 = 0.70

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	3.80	0.14	26.84	<.0001
Mean Percent Cover	0.02	0.003	6.61	<.0001
Mean Total Height (cm)	0.02	0.004	5.76	<.0001

Figure 4.5. Multiple regression model of (log) abundance of fish at ledge sites.



Predicted H' = 0.64 + -0.007 (Mean Undercut Height (cm)) + 0.000(Ledge Area)

$R^2 = 0.12$

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.64	0.04	17.75	<.0001
Mean Undercut Height (cm))	-0.007	0.002	-3.31	0.0013
Area (m^2)	0.00004	0.00002	2.26	0.0261

Figure 4.6. Multiple regression model of diversity of fish at ledge sites.

plotted using fish clusters versus ledge clusters revealed only 5 distinct combinations of fish community and ledge characteristics (Areas A-E in Figure 4.9) out of a possible total of 16 (recall there were four clusters of sites based on fish community and four based on ledge measurements). The largest of these, Area A, represented the intersection of sites in Cluster 2 based on the fish community and Cluster 3 based on the ledge characteristics. Of the 48 sites in fish Cluster 2, all but 3 were within Ledge Cluster 3. Similarly, of the 51 sites in Ledge Cluster 3, all but 6 were within fish Cluster 2. Sites in this area had short ledges with little or no undercut and consequently lacked many of the undercut associated species such as *Apogon pseudomaculatus, Pareques* sp., and *Rypticus maculatus*. This area had high occurrence and/or biomass of *Stenotomus* sp. and *Urophycis earlli* but is perhaps better described by those species that were seldom present in contrast to other ledge clusters. In addition to those undercut associated species mentioned, *Archosargus probatocephalus* and *Balistes capriscus* also had low occurrence. Area B represented all of the sites from Ledge Cluster 2 and 6 of the 26 sites in Fish Cluster 1. The tall, heavily colonized, and deeply undercut ledges of this area were characterized by some of the largest fish species. Typically *Archosargus probatocephalus, Calamus bajonado, Caranx crysos, Chaetodipterus faber, Diplodus holbrookii, Haemulon aurolineatum, Haemulon plumieri, Holacanthus bermudensis, Mycteroperca microlepis, M. phenax, Pareques* sp., and *Rypticus maculatus* had high occurrence and/or biomass. Area C included all but 4 of the remaining 20 sites in Fish Cluster 1. The tall, heavily colonized, but less undercut ledges of Cluster 1 typically had high occurrence and/or biomass of *Archosargus probatocephalus, Lagodon rhomboides, Balistes capriscus, Caranx crysos, Pareques* sp., and *Seriola* sp.. Area D included half of the sites in fish Cluster 3 and two thirds of the sites in ledge Cluster 4. Sites in this area were characterized by short ledges with low or no undercut, low or moderate height, and high cover of sessile biota. The short but heavily colonized ledges of this area typically had high occurrence and/or biomass of *Centropristus ocyurus, Halichoeres caudalis, Microgobius carri*, and *Stenotomus* sp.. Last, area E included many sites in Fish Cluster 3 and Ledge Cluster 1. The tall, heavily colonized, but less undercut ledges of Cluster 1 typically had high occurrence and/or biomass of *Archosargus probatocephalus, Lagodon rhomboides, Balistes capriscus, Caranx crysos, Pareques* sp., and *Seriola* sp. The stability of these groups was checked by clustering sites based on both species present and ledge variables at the same time. The scree plot from this indicated the presence of five well separated clusters that corresponded well to areas A, B, C, D and E combined, plus one outlier site.

Size-frequency histograms of the key species targeted by bottom fishermen, (*Centropristis striata, Mycteroperca microlepis*, and *M. phenax*) revealed that many fewer fish were observed in size classes above the size limit of the fishery (Figure 4.10).

Image 26. School of *Pareques* sp.

This was evident in both the high and low boat density portions of the sanctuary although the differences were markedly smaller in the low boat density areas for *M. microlepis* and *M. phenax*. The modal size for *C. striatus* was ~20 cm for fish in both areas. In contrast, *M. microlepis* had a mode size of ~40 cm in areas with high boat density and a higher mode size of ~60-70 cm in areas with lower boat density. Similarly, *M. phenax* had a mode size of ~40 cm in areas with high boat density and a larger mode of ~50 cm in areas with low boat density although the distribution was much flatter with fewer fish in the low boat density areas.

The size frequency plots of *C. striata* for each ledge site indicated no clear clumping of this species (Figure 4.11). In contrast, *M. phenax* and *M. microlepis* were seen at only a few sites in two main areas of the sanctuary (Figures 4.12-4.13). Many were observed on the tall ledges in the north/central part of the sanctuary. Another

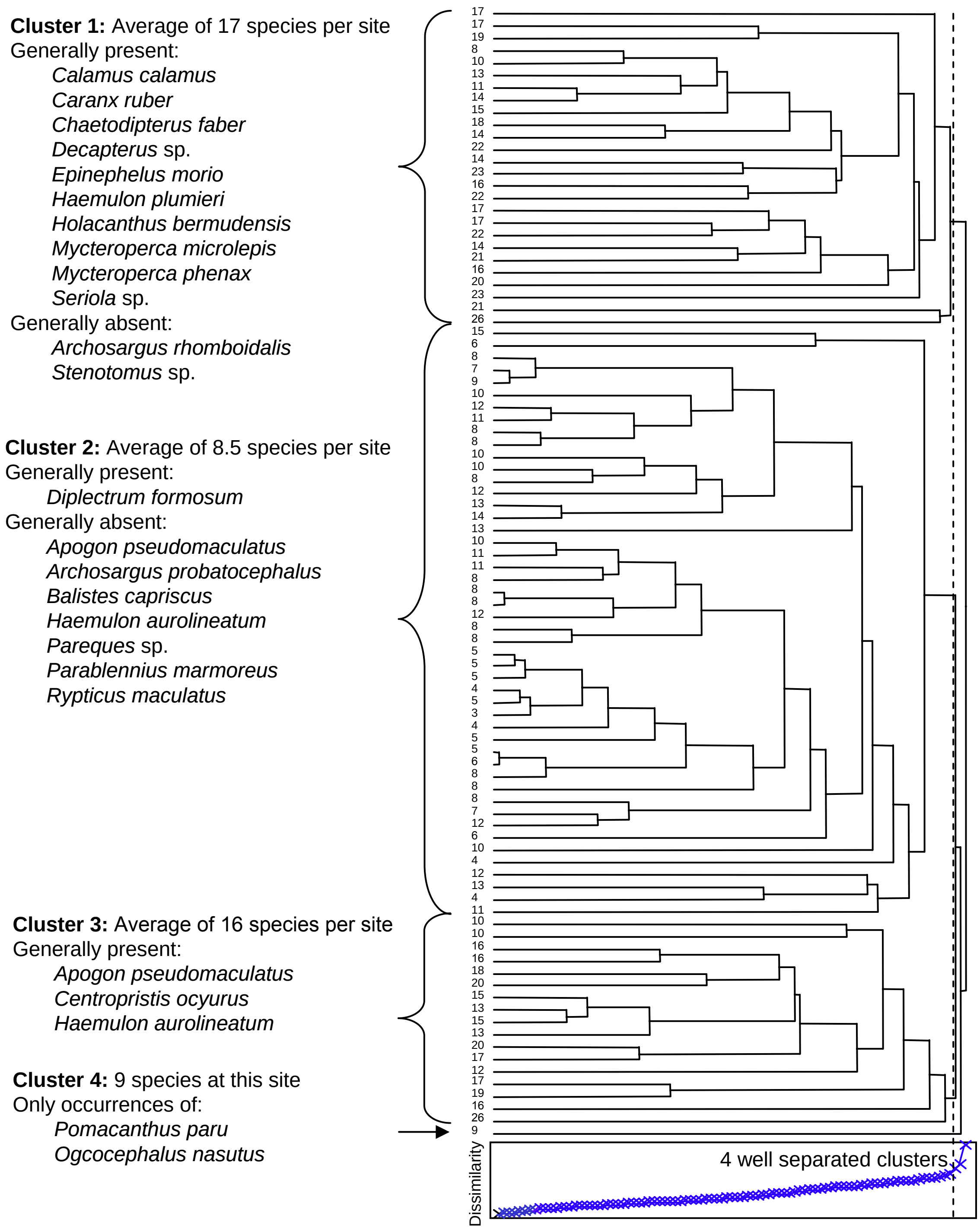


Figure 4.7. Dendrogram for cluster analysis of the 92 ledge sites based on species composition. The scree plot at the bottom indicates that there are four well separated clusters. The numbers representing each site denote species richness. Species typically present or absent that separate each cluster from the others are noted at left.

concentration was found on the tall ledges along or near the south/central boundary of the sanctuary. *C. striata* was much more abundant than the *Mycteroperca* species. The abundance of *C. striata* was significantly related to only percent cover and ledge area. Abundance was positively related to percent cover and negatively related to ledge area (Figure 4.14) although these two variables accounted for only 15% of the variability in the data. None of the variables tested was a significant predictor of mean *C. striata* size.

The presence/absence of *M. microlepis* was significantly related only to the undercut height of ledges (Figure 4.15). Presence/absence of the other grouper species, *M. phenax*, was significantly related to undercut height of ledges and ledge area although comparisons with a reduced model indicated that ledge area explained only

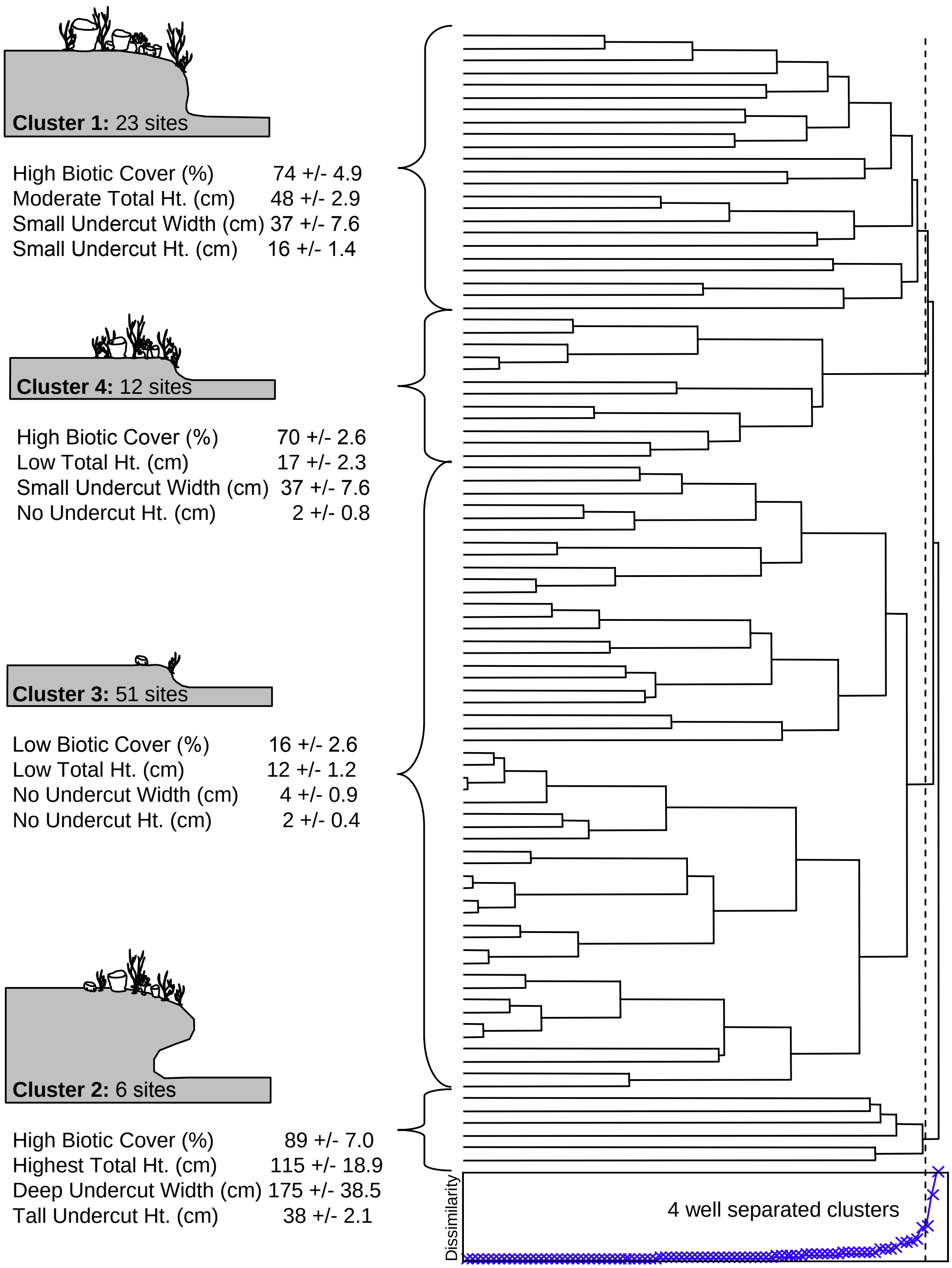


Figure 4.8. At right is the dendrogram for cluster analysis of the 92 ledge sites based on ledge measurements. The scree plot at the bottom indicates that there are four well separated clusters. Descriptive and quantitative characteristics (mean +/- SE) typical of ledges within each cluster along with a cross-sectional cartoon are noted at left.

8% of the variability in the data (Figure 4.15). No other variables or interactions were significantly related to the presence/absence of either species including heavily/less fished areas. None of the variables tested were significantly related to mean size of either species. The abundance of *C. straita* was significantly related to the presence/absence of the two grouper species (Figure 4.16). When *Mycteroperca* species are present, the abundance of *C.straita* is significantly lower although only 17% of the variability in abundance was explained by the model.

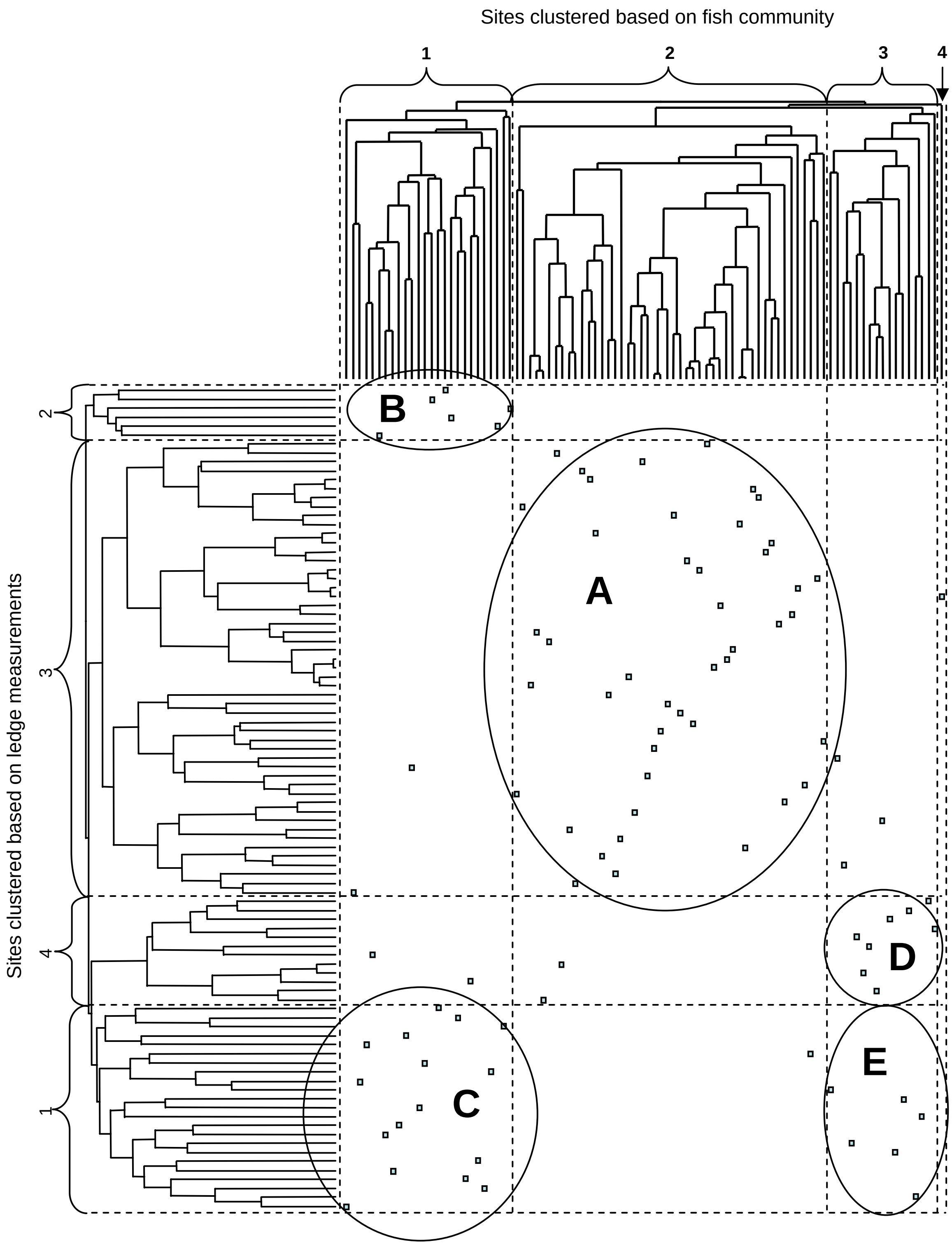


Figure 4.9. Intersection of sites clustered based on ledge measurements and fish communities. Groups of sites have both the same ledge characteristics and species composition.

4.5 DISCUSSION

This study provides a comprehensive baseline assessment of the fish communities and their associated bottom types at GRNMS. Prior to this, knowledge of the fish community was based on a handful of sites within the sanctuary, a limited diversity of bottom types, and with marginal quantification of associations with fine scale benthic features. This baseline characterization provides the foundation for future monitoring to track the trajectory of fish communities in the sanctuary.

Fish communities at GRNMS are closely linked to the benthic structure within it (Gilligan 1989, Parker et al. 1994). Species richness, diversity, composition, abundance, and biomass of fish all showed striking differences

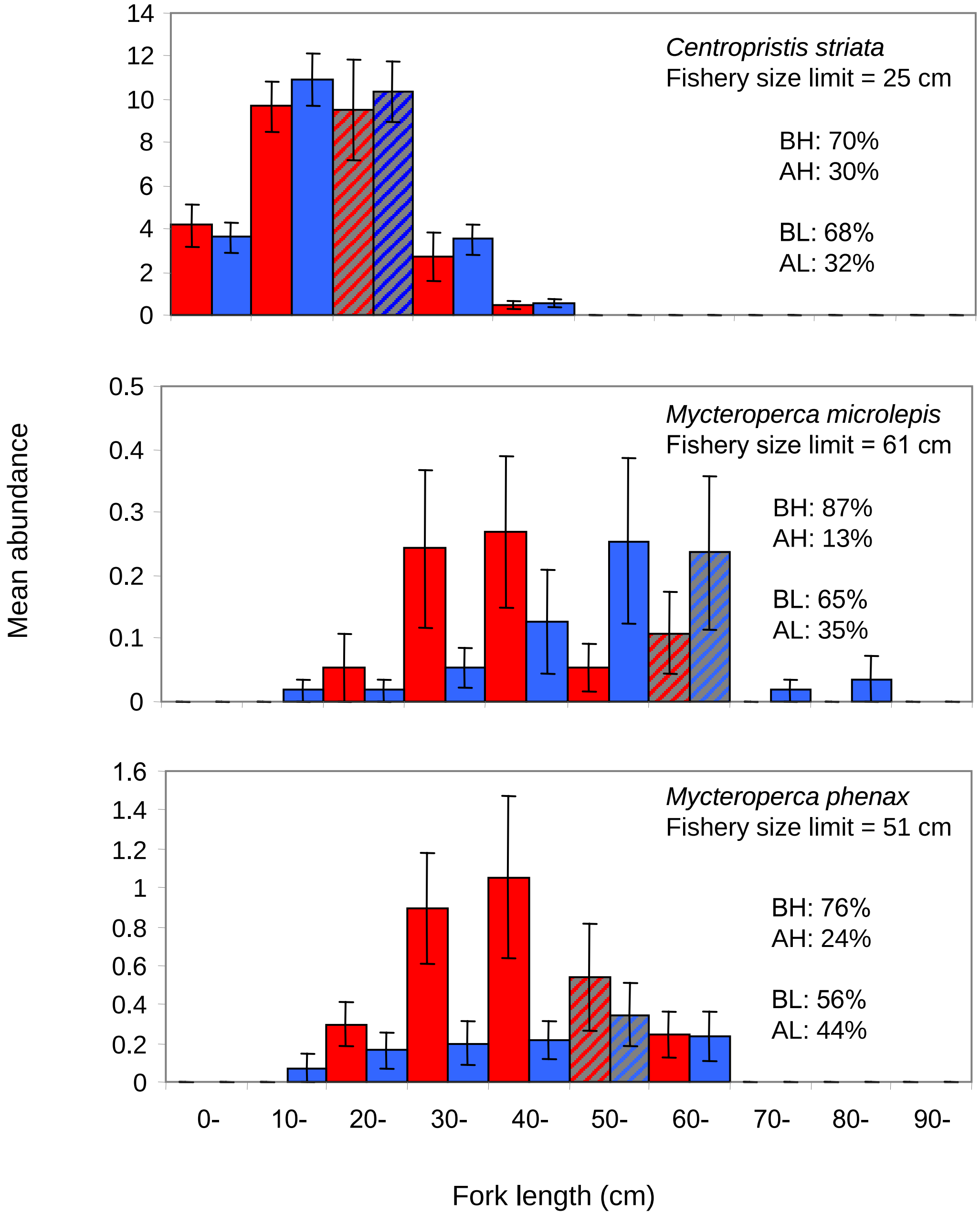


Figure 4.10. Size frequency histograms for selected bottom fish targeted by the recreational fishery for regions of low (blue) and high (red) boat density. Only ledge sites are included in the figure. Columns denote mean number of fish (per 100m^2) within each size class. Error bars represent standard error. The recreational fishery size limit for each species is noted and the shaded bars represent the size class in which the size limit occurs. The proportion of fish above and below the size limit of the fishery within the areas of high and low boat density respectively are noted; BH=fish below size limit within the area of high boat density, AH= fish above size limit within the area of high boat density, BL= fish below size limit within the area of low boat density, and AL= fish above the size limit within the area of low boat density. Note the differences in abundance scale.

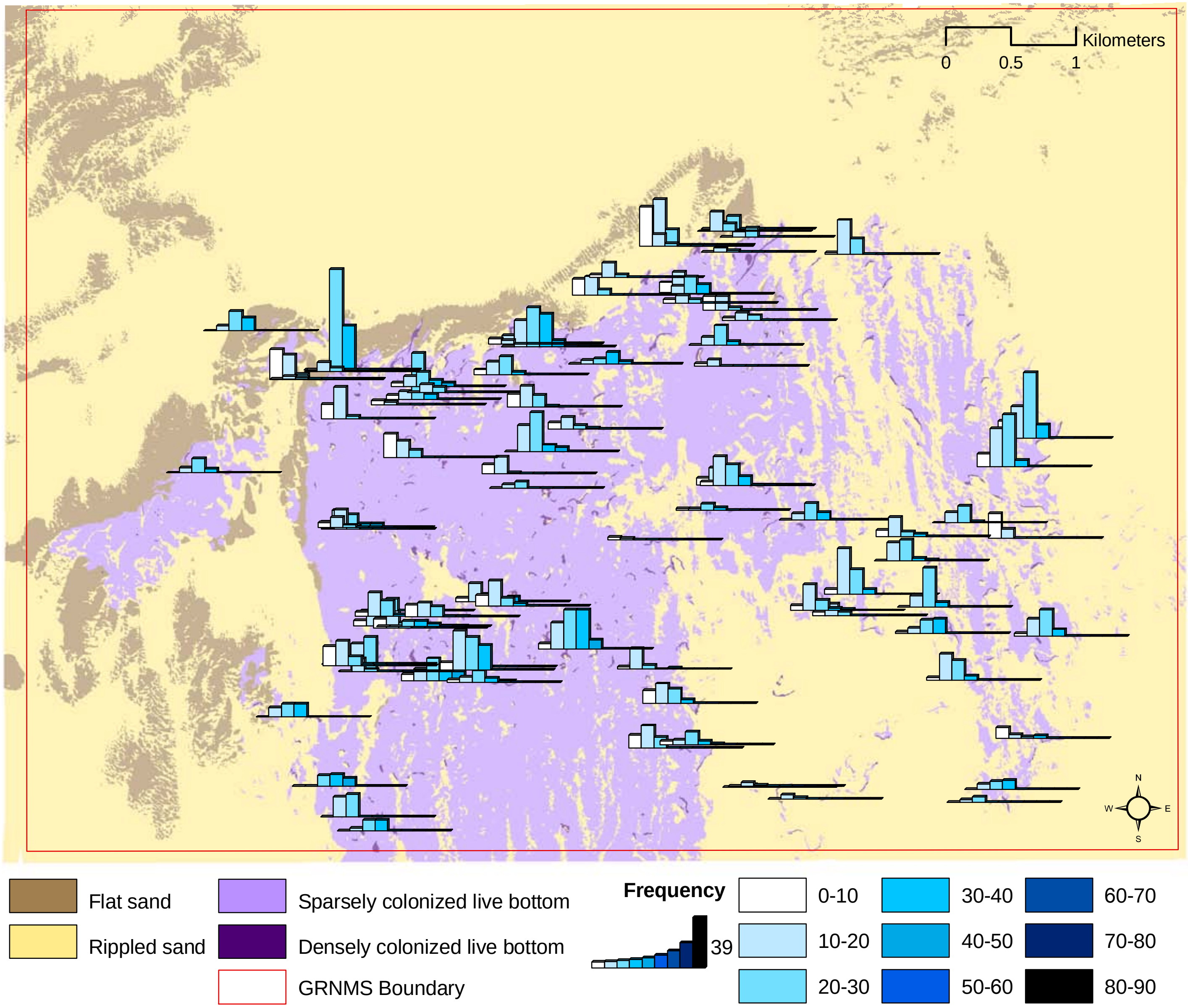


Figure 4.11. Size-frequency plots of *Centropristis striata* observed at ledge sites. The tallest bar in the legend represents 39 individuals.

depending on bottom type. As expected, flat and rippled sand had the lowest values for these aspects of the fish community relative to sparse live bottom and ledge habitats. There were no differences in species richness, diversity, biomass, abundance, or species composition between fish over flat and rippled sand in any analysis. In contrast, a recent study of benthic infauna at GRNMS did not find such equality between sand types. Rippled sand had significantly higher diversity, species richness, and density of infauna in grab samples (Hyland et al. 2006). It was hypothesized that differing hydrologic and disturbance regimes between these bottom types could result in differing infaunal assemblages. Why this would not translate to fish communities as well is not clear. Perhaps the greater mobility of fish relative to infauna results in a more even distribution between sand types. The largest difference between sand types was observed in May sampling when large schools of juvenile *Stenotomus* species were observed at some rippled sand sites. Ledges, which have higher structural complexity, showed the highest values of nearly all metrics (except diversity which was the same for both ledges and sparse live bottom).

Values of some fish community variables were comparable among studies. For example, Parker et al. (1994) recently conducted video surveys of fish within GRNMS. Their sampling design was similar to the present study in that survey sites were randomly placed and stratified by bottom type including ledge, three categories of live

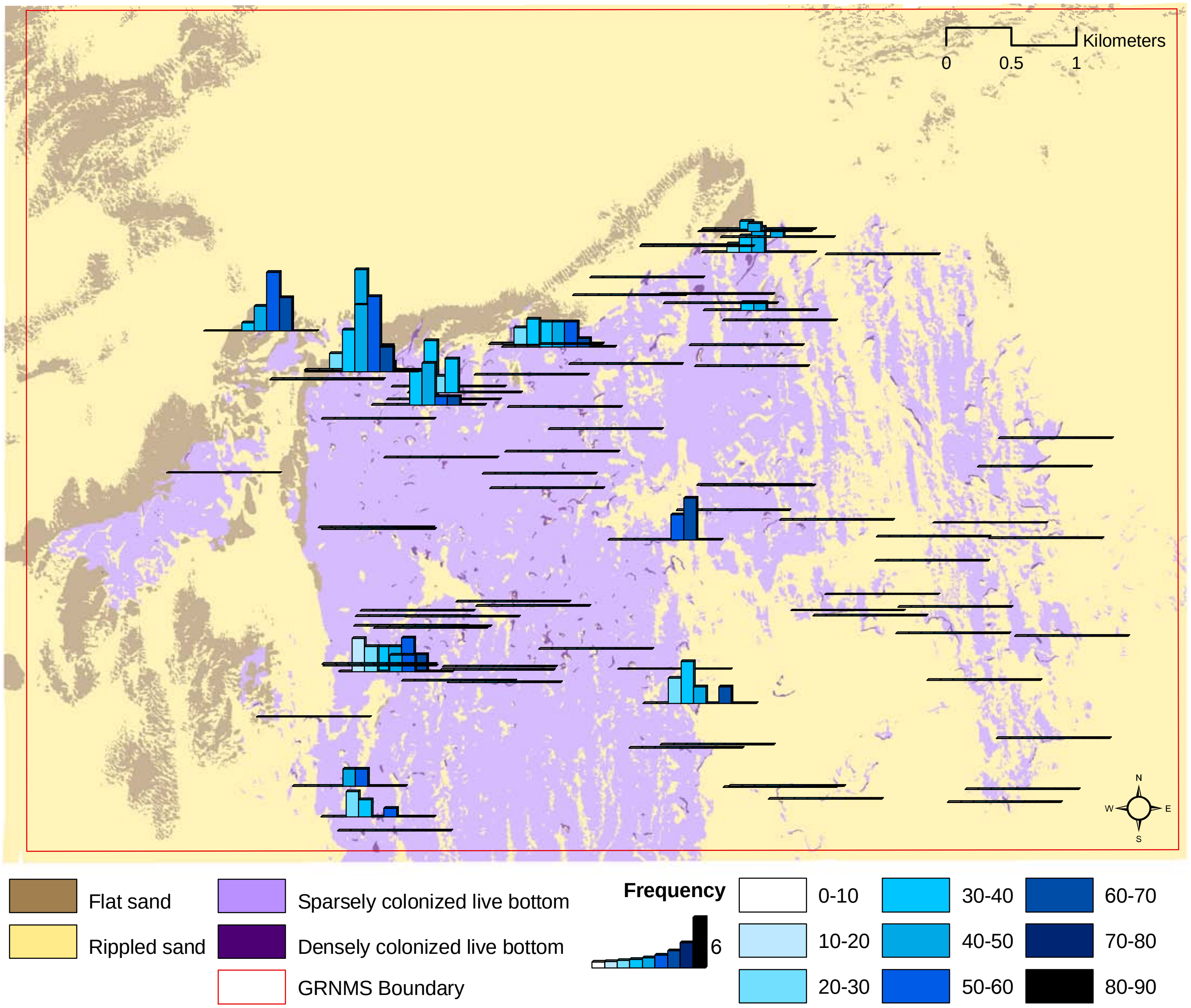


Figure 4.12. Size-frequency plots of *Mycteroperca phenax* observed at ledge sites. The tallest bar in the legend represents 6 individuals.

bottom based on colonization density, and sand (no distinction between rippled and flat). Site selection was guided by the best bottom map of GRNMS available at the time (Hunt 1974). Surveys were conducted in August 1985, November 1985, May 1986, and August 1986. Apart from the November survey, this seasonal distribution of samples allowed excellent comparison to the present study which was conducted in August 2004, May 2005, and August 2005. Species richness, density, and community structure of fish were compared between the studies with November 1985 data excluded where possible.

Overall fish density on ledges observed by Parker et al. (1994) was 8-20 fish/m^2 based on video surveys in August 1985 and 1986. The same month in the present study fell at the high end of this range with an average of 21 fish/m^2 on ledges. This average included observations of very large schools of fish such as *Haemulon aurolineatum* juveniles and many pelagics. Similarly, 55 species were observed by Parker et al. (1994) and the present study identified 59. Despite a similar density and overall number of species on ledges that were seen by the two studies, the lists of particular species seen were quite different. Over 1/3 of the species identified in each survey technique were not seen by the other (these comparisons generously assumed probable matches for fish identified to species level in one study but only genus or family in the other). Specifically, visual surveys included 22 species not encountered in the video approach, and conversely, the video surveys included 18 species not encountered in visual surveys. These discrepancies included not only rarely seen species, which is not surprising,

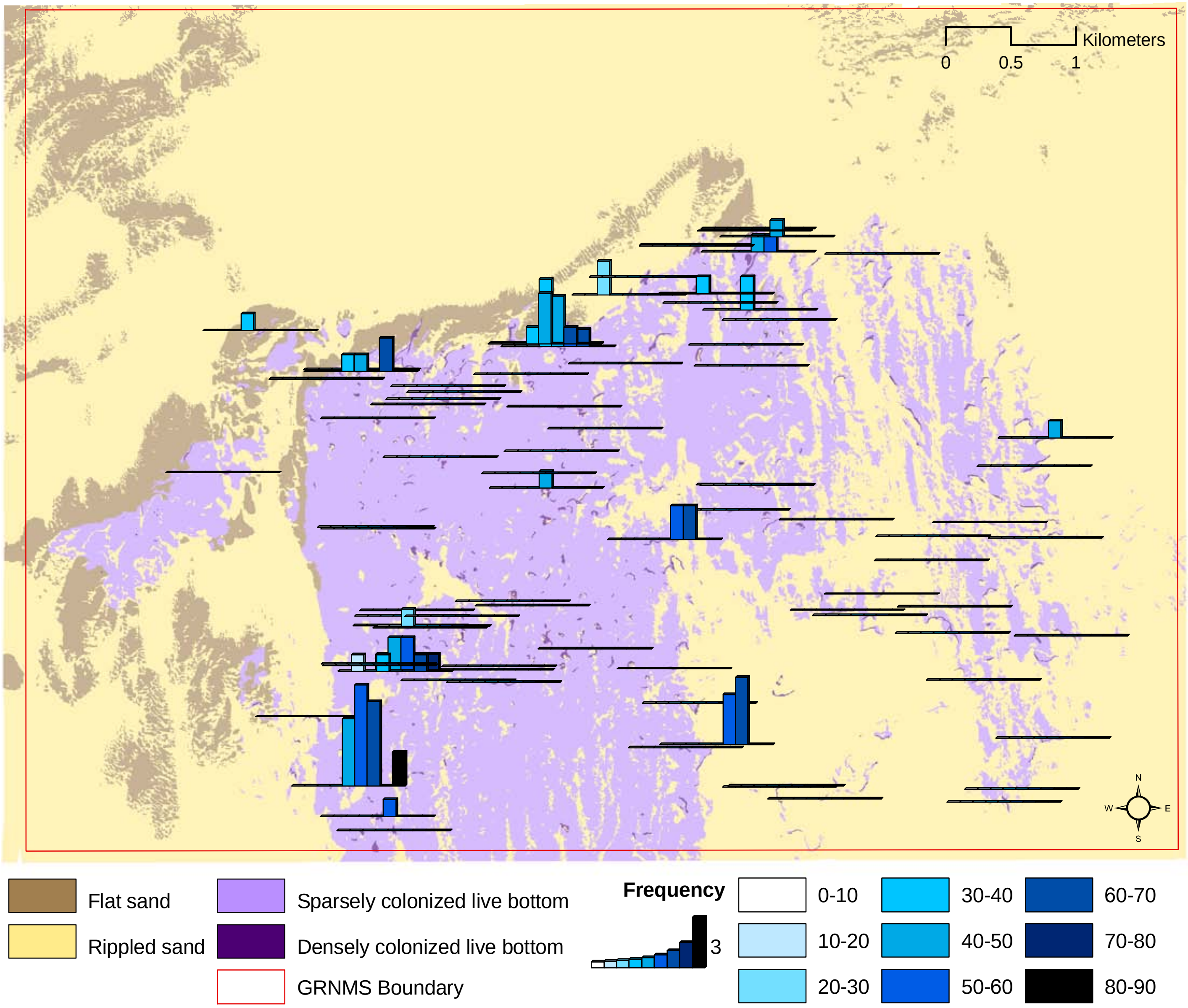
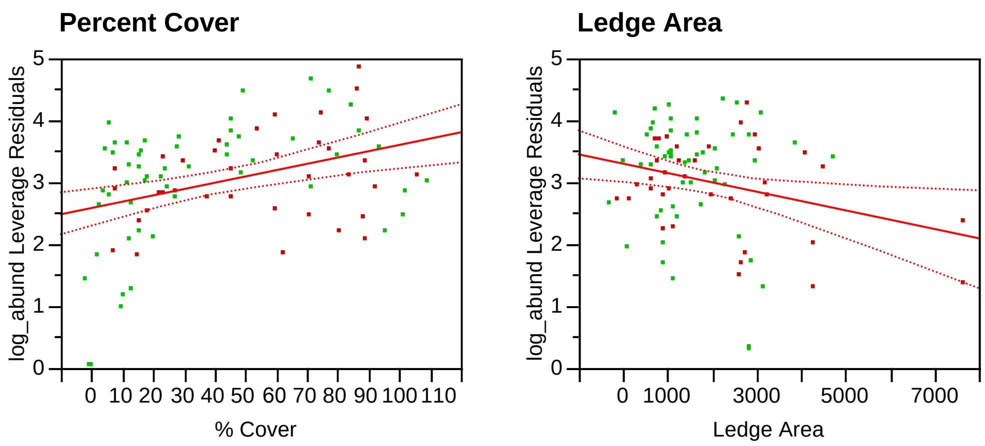


Figure 4.13. Size-frequency plots of *Mycteroperca microlepis* observed at ledge sites. The tallest bar in the legend represents 3 individuals.

but also quite common ones. For example, two species of *Acanthurids* were routinely recorded on the video surveys but were never seen on visual transects. Similarly, on visual surveys, two very different species, the bottom dwelling *Urophysis earlii* and the pelagic *Caranx crysos*, were among the most common and abundant species encountered respectively. Differences in the bias of video versus visual survey techniques alone cannot account for these striking differences. The additional video survey in November may account for some of the 18 species seen in that study that were not encountered in the August and May visual surveys of the present assessment, however, this does not explain the 22 species seen with visual assessment but not video. Also of note, on flat bottom, 54 species were encountered in the video surveys but only 28 were found using visual assessments. This may be due to the more detailed stratification over flat live bottom that was used by Parker et al. (1994) in the video assessments. They surveyed sparse, moderate, and densely colonized (flat) live bottom whereas in the present study only sparsely colonized (flat) live bottom was sampled. It is also probable that the older, more general maps used to guide initial site selection by Parker et al. (1994) led to the sampling of somewhat different habitats and fish communities on ledges than the much more detailed maps used in the present study in which specific ledges were randomly chosen from the entire group within the sanctuary (Kendall et al. 2005). Despite these influences, the differences in species composition between these studies are striking. Rather than explained by the differences in survey technique, seasonal effort, or sampling design, some considerable change in community structure between the two studies appears present. Unlike a trend toward more tropical species

Leverage Plots



Summary of Fit

RSquare	0.15
RSquare Adj	0.13
Root Mean Square Error	0.85

Analysis of Variance Whole Model

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Model	2	10.801182	5.40059	7.5328	0.0010
Error	87	62.373963	0.71694		
C. Total	89	73.175145			

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.881797	0.165383	17.42	<.0001
Percent Cover	0.0100302	0.002774	3.62	0.0005
Ledge Area	-0.000151	0.000063	-2.40	0.0184

Figure 4.14. Regression model of *Centropristis striata* abundance at ledge sites.

found on deeper live bottom off North Carolina (Parker and Dixon, 1998), neither study had differing proportions of tropical versus temperate species nor pelagic versus benthic species, the assemblages were simply different. This could be due to some long term gradual changes between the 1985-1986 study and the present one which was based on 2004-2005 data. It could also be as a result of more random variation in recruitment success prior to the two studies, which may have resulted in different community composition at GRNMS on the scale of decades. Without quantitative observations during the interval between these studies and additional monitoring in the future, the variability and stability of fish community patterns at GRNMS cannot be known.

Another study that provided data for possible comparisons with the present study was conducted by Sedberry and Van Dolah (1984) using trawl surveys. They evaluated the influence of shelf position and season on fish assemblages in the South Atlantic Bight in 1980. One site fell within GRNMS and three others were within the same shelf zone. During summer they found 48 species over live bottom, a value similar to the present findings and those of Parker et al. (1994). In contrast, to these studies however, the trawls in GRNMS revealed much lower fish density of 0.1132/m^2. Differences in these values and those of other studies must be cautiously interpreted due to vastly different biases in trawl, trap, and visual assessment techniques.

In addition to evaluating species composition by bottom type as others had done previously, the present study quantified the size structure of fish assemblages, a metric not recorded by other studies at GRNMS. Not surprisingly, ledges harbored the greatest abundance of fish in all size classes. Like structurally complex habitats

Mycteroperca microlepis

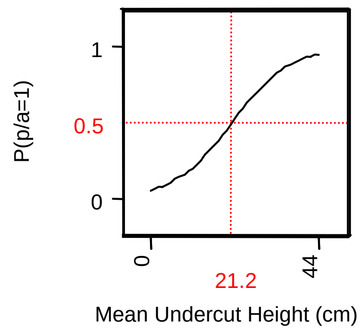
Whole Model Test

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	14.425299	1	28.8506	<.0001

RSquare (U) 0.32

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Mean Undercut Height (cm)	1	1	17.7609622	0.0000



Mycteroperca phenax

Whole Model Test

Mean Undercut Height (cm)

Model	-LogLikelihood	DF	ChiSquare	Prob>ChiSq
Difference	30.829540	2	61.65908	<.0001

RSquare (U) 0.61

Effect Wald Tests

Source	Nparm	DF	Wald ChiSquare	Prob>ChiSq
Ledge Area	1	1	5.97305373	0.0145
Mean Undercut Height (cm)	1	1	14.0116536	0.0002

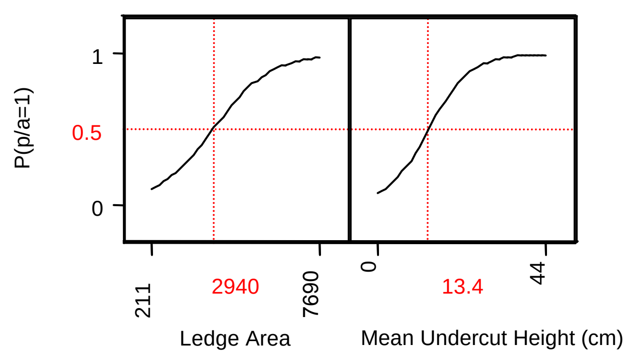


Figure 4.15. Logistic regression model of presence(1)/absence(0) of grouper species at ledge sites. Values at 50% probability of occurrence are highlighted.

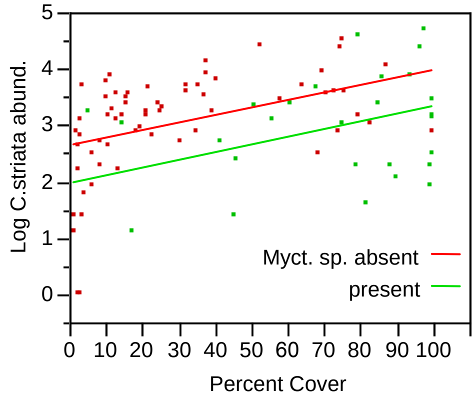
elsewhere, ledges offer by far the greatest diversity of niche space to support a variety of fish sizes and species. Sparse live bottom and both sand types offer virtually no change in substrate relief which could be used as structural refugia. Sparse live bottom offers only modest additional protection with its low density of gorgonians, sponges, and other sessile biota.

The species composition of fish communities was quite distinct for ledges, sparse live bottom, and sand sites as indicated by cluster analysis. This finding was similar to that of Parker et al. (1994) who also used cluster analysis of the overall fish communities in the area based on video data. A possible exception to this separation of fish community by bottom type was in Cluster 3 which was composed of a majority of sparse live bottom sites but also had a large number of ledge sites. Closer inspection indicated that these ledges were quite short (average height = 5 cm) with little or no undercut and relatively sparse colonization of sessile invertebrates. In fact, many of these sites when viewed underwater appeared more as sparse live bottom abutting sandy areas than true ledges.

Many studies outside of the South Atlantic Bight have examined the relationship between structure of fish communities and benthic variables although with conflicting results. The relationships between fish abundance, species richness, diversity, and benthic characteristics appear to be highly localized phenomena. Different reef types among regions have been shown to have unique correlations between fish community parameters and benthic characteristics with few rules common to all systems (Roberts and Ormond 1987, Chabanet et al. 1997, Öhman and Rajasuriya 1998). Working in a variety of reef types and regions worldwide, many have found species richness of fish to be positively correlated with rugosity or vertical relief of the substrate (Luckhurst and Luckhurst 1978, Molles 1978, Öhman and Rajasuriya 1998, Gratwicke and Speight 2005) although not in all systems (Roberts and Ormond 1987, Öhman and Rajasuriya 1998). At GRNMS, species richness was positively correlated with ledge height and explained 66% of the variability in the data. This highlights the importance of vertical relief in adding niche space at GRNMS. The ledges are essentially the only hard vertical structure in the otherwise flat landscape of GRNMS. In other studies, species richness of fish has also been found related to diversity of benthic cover (Roberts and Ormond 1987, Gratwicke and Speight 2005) or particular bottom types such as hard bottom and live coral (Parker et al. 1994, Öhman and Rajasuriya 1998, Gratwicke and Speight 2005) although, again results were inconsistent among regions (Luckhurst and Luckhurst 1978, Roberts and Ormond 1987). At GRNMS, species richness was also positively correlated with percent cover of sessile biota, namely macroalgae and 'other', the two dominant cover types. The three dimensional planar plot of this relationship indicates that either high percent cover or total height (or both) of ledges can be related to high richness values. Possible mechanisms are higher food resources for fish afforded by greater cover and enhanced structural refuge options and niche space offered by taller ledges.

Fish abundance at GRNMS was also significantly correlated with percent cover and ledge height, which together explained 70% of the variability in the data. Links between fish abundance and

Regression Plot



Summary of Fit

RSquare	0.17
RSquare Adj	0.15
Root Mean Square Error	0.84

Analysis of Variance Whole Model

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	2	12.206558	6.10328	8.7092
Error	87	60.968587	0.70079	Prob > F
C. Total	89	73.175145		0.0004

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.3311367	0.190883	12.21	<.0001
p/a Myct.sp,	0.3320177	0.118075	2.81	0.0061
Percent Cover	0.0133319	0.003218	4.14	<.0001

Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
absent	3.2326824	0.11316164	3.06279
present	2.5686469	0.18738277	2.96506

Figure 4.16. Logistic regression model of presence(1)/absence(0) of grouper species at ledge sites. Values at 50% probability of occurrence are highlighted.

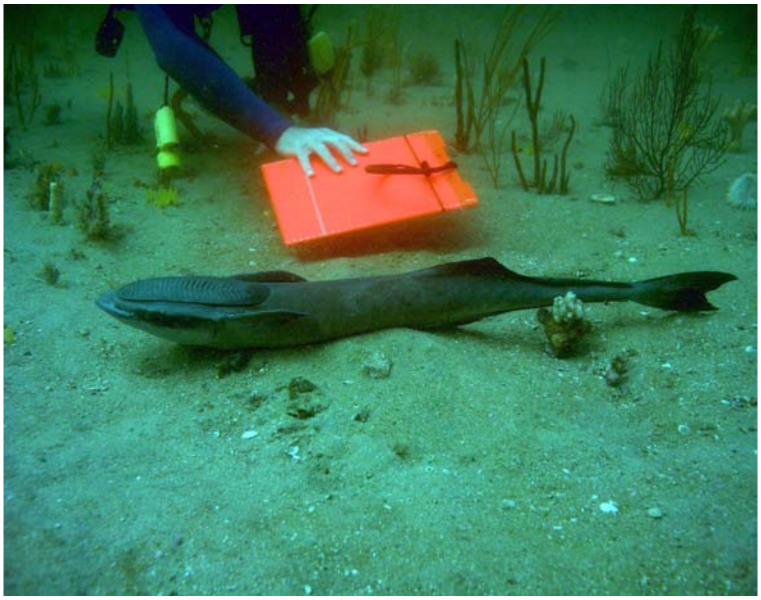


Image 27. Sharksucker.

benthic characteristics have been more difficult to identify in other studies with only weak or no correlation found with rugosity (Risk 1972, Luckhurst and Luckhurst 1978, Öhman and Rajasuriya 1998, Gratwicke and Speight 2005), cover of particular bottom types (Roberts and Ormond 1987, Öhman and Rajasuriya 1998), or other benthic variables (Risk 1972, Luckhurst and Luckhurst 1978, Roberts and Ormond 1987). Similar to the findings for species richness of fish at GRNMS, high abundance can be related to either high percent cover or total ledge height, both are not necessary.


Image 28. School of spadefish.

Diversity (H') of fish has also been elusive to link with benthic characteristics. Fish diversity has been positively correlated with benthic variables such as rugosity or reef height (Risk 1972, Molles 1978, Öhman and Rajasuriya 1998) and live coral cover (Öhman and Rajasuriya 1998) but not with substrate diversity (Risk 1972) and not in all studies or reef types investigated (Luckhurst and Luckhurst 1978, Öhman and Rajasuriya 1998). Unlike fish abundance and species richness, fish diversity at GRNMS was not significantly related to ledge height and percent cover. Instead, ledge area had a positive relationship and undercut height had, counter to expectations, a negative relationship with fish diversity. A large undercut would presumably allow greater niche space, number of species, and equitable distribution of community membership and therefore higher diversity but this was not the case. More detailed evaluation of the data indicated that larger undercuts coincided with the presence of large schools of a few species such as *Pareques* sp., which are regularly observed utilizing undercut ledges, and *Haemulon* sp. Such large monotypic schools actually lowered the overall values of fish diversity at undercut ledges even in the presence of a larger number of species.

Many studies have found fishing intensity to affect species richness, diversity, and abundance of fish communities in many parts of the world (Russ and Alcala 1989, McClanahan 1994, Watson and Ormond 1994, Grigg 1994, Jennings et al. 1995, Jennings and Polunin 1996, Wantiez et al. 1997). At GRNMS, more intensively fished versus less fished (based on high versus low boat density) ledges did not have a significant relationship with fish community structure when added to the final models except for overall fish abundance. Even then, while the relationship was significant with less fished ledges having higher fish abundance it only explained an additional 1.7% of the variability in the data (Adjusted R^2=0.713 relative to 0.696 for the two variable model). While significant in a predictable direction, the influence is quite small and does not appear to be an important variable structuring fish abundance in this area. Based on the present findings, the relationships between fish abundance, species richness, diversity, and benthic characteristics can be predicted from just a few easily quantifiable variables: ledge height, undercut height, percent cover, and ledge area.

Characterizations of the particular fish species associated with ledges revealed five distinct combinations of ledge characteristics and fish assemblages. The four ledge types and four fish community types identified in the cluster analysis could have resulted in sixteen unique combinations of ledge characteristics and fish community. However, only five accounted for nearly 90% of the survey sites over ledges indicating a strong relationship between fish community membership and ledge type. Merely knowing the basic characteristics of a ledge such as total height, undercut width, and percent cover would allow good prediction of not only species richness and abundance of fish, but also which particular fish species are likely to occur there.

4.6 TARGETED SPECIES

This study provides a comprehensive assessment for species of interest to recreational fishermen such as *C. striata, M. microlepis*, and *M. phenax* at GRNMS. Densities of these species were 0.52, 0.04, and 0.02/m^2 respectively on ledges as reported by Parker et al. (1994). Densities found on ledges in the present study were half as high at 0.28 for *C.striata* and 0.01 and 0.02/m^2 respectively for the *Mycteroperca* species. Again, differences in these estimates may be due to several factors including the respective biases of the sampling methods, the inclusion of November sampling by Parker et al. (1994), and the different base maps upon which sampling strategies were designed. However, if both of these assessments are considered to have adequately quantified fish at GRNMS, some real differences appear likely.

The presence of both *Mycteroperca* species was most related to undercut height of ledges rather than any other variables such as total ledge height or biotic cover. Indeed. More *M. phenax* were observed in the fished area of the sanctuary which had better habitat for this species than the less fished area (Chapter 2). Fishing pressure also did not have a significant relationship with the simple presence/absence of these two species, however, it did appear to influence their size distributions. For example, modal size of *M. microlepis* was skewed by ~25 cm toward smaller individuals in the heavily fished area. Similarly, the mode size of *M. phenax* was ~15 cm smaller in the heavily fished area although the size distribution was flattened in the less fished area. This pattern emerged despite the apparent presence of better habitat in the form of more deeply undercut ledges at survey sites in the fished area (Chapter 2). In fact, many fewer *M. microlepis*, and *M. phenax* were observed in size classes above the size limit of the fishery in all areas of the sanctuary. This could be the result of selective removal of largest fish due to fishing, as has been observed in other areas (Chiappone et al. 2000, Westera et al. 2003), as well as ontogenetic migration out of the area by large fish (McGovern et al. 2005). Also of note, the proportion of fish larger than the size limit was higher in low boat density areas than in high boat density areas for both *Mycteroperca* species. This suggests that, despite better habitat in fished areas, fish size in heavily fished areas of GRNMS appear to be lower than in unfished areas.

The spatial distribution of both *Mycteroperca* species was quite clumped on ledges in the north central and south central regions of the sanctuary. Of the 92 ledges surveyed, only 20 had occurrences of these species with the majority only occurring on 10 ledges. Both species were often observed together at the same ledge and were rarely observed as lone individuals.

In contrast, *Centropristis striata* occurred at 98% of the ledges surveyed and appeared evenly distributed throughout the sanctuary. Abundance was best explained by percent cover of sessile biota rather than ledge height or undercut variables. Indeed this species was never observed utilizing the undercut of a ledge. Interestingly, lower abundance of *C. striata* occurred when either of the large grouper (*Mycteroperca*) species were present. Lower abundance of *C. striata* at such sites could be due to predation by the large grouper (Matheson et al. 1986), avoidance of sites with large grouper, or some other mechanism correlated with these two variables. As with the grouper species, many fewer *C. striata* were observed in size classes above the size limit of the fishery. Emigration is not thought to reduce the abundance of *C. striata* which are thought to stay in the same specific area for much of their adult life (Mercer 1989, Parker 1990, Barkoukis 2006,).

There are several important caveats to consider in the present characterization. Surveys were conducted during the day. Some ledge associated species such as those in the family Haemulidae are known to undergo migrations away from ledges into surrounding sand habitats each night to feed. This will have the effect of inflating the biomass and species richness of sand areas each night to levels higher than those observed in the daytime surveys. Also, only visual surveys were used in this assessment and some fish species avoid divers. For example, *Lutjanus campechanus* and *Lagodon rhomboides* are often only seen at the limit of diver visibility, negatively biasing their counts, and other species probably move away prior to diver detection at all. Other sampling gear or survey techniques will evaluate such species better/differently (but not without their own set of biases). Only bottom fish or those pelagics that approached the bottom were surveyed. Among the most abundant species over all bottom types were pelagic species. However, the transect survey technique is not designed to sample pelagic fish effectively. Alternative techniques should be used to sample these species such as sonar, nets, and hook and line. Finally, the seasonal changes known to occur in the fish assemblage of this area (Sedberry and Van Dolah 1984, Parker et al. 1994) are not addressed in detail by this study. The higher number of species unique to August (25 on 111 surveys) relative to May (8 on 68 surveys) is not totally accounted for in the proportionally greater number of August surveys. Changes in proportional abundance are known to occur seasonally as well (Sedberry and Van Dolah 1984) but were not investigated here and should be evaluated with seasonally stratified sampling effort.

4.7 RECOMMENDATIONS FOR MANAGEMENT AND MONITORING

A long term strategy for quantitatively monitoring fish at GRNMS should be devised based on the present findings. A stratified-random sampling design can maximize inference to the entire sanctuary and optimize effort to allow key comparisons among regions within it. At a minimum, sampling should be focused on randomly selected ledges stratified by the four ledge types identified here, as well as in the heavily fished versus less fished areas of the sanctuary. With limited monitoring resources the sampling should be conducted annually within the same season. Given greater monitoring resources, additional sampling could be undertaken to quantify seasonal effects and other strata. Additional strata of interest may include the four major bottom types used here, or perhaps comparison areas outside the sanctuary to place the sanctuary in a regional context.

Image 29. Frogfish.

The same assessment technique must be used each sampling period to simplify analysis and reliably detect changes in community structure in response to fishing pressure or other influences such as range changes due to global warming (Parker and Dixon 1998). For assessment and monitoring of bottom fish at GRNMS, visual transects should be used. No other survey technique provides as effective an approach given the visibility, bottom features, data needs, and logistical constraints. The most robust approach to monitoring of bottom fishes requires quantitative data. Species, size, and number of fish per unit area are needed for monitoring. Roving diver and trap surveys can provide relative per unit area measures at best. Trawl surveys, while spatially quantitative, are ill suited to sampling ledges, the most important bottom type at GRNMS. Trawling can be done from the high to low side of a ledge, but is harmful to the encrusting benthic organisms, and fails to sample the substantial component of the fish community that utilizes the undercut of many ledges. Visual point surveys require 7.5 m visibility (Bohnsack and Bannerot 1986), conditions that rarely occur at GRNMS. Point surveys also do not survey ledges efficiently, nor do findings extrapolate appropriately (see Parker et al. 1994). The ledge is essentially a linear feature that is best evaluated with a linear survey technique. In contrast, visual transects conducted along the axis of ledges meet the data requirements and logistical constraints imposed by the benthic features at GRNMS. Spatially quantitative, requiring only 2 m visibility, and simultaneous survey of fish above and below undercut ledges make transects ideally suited to assessing bottom fish communities in this area. Although not without their own biases as mentioned earlier, transects offer the best approach for assessment and monitoring of fish at GRNMS. While the rationale provided here suggests that visual transects should play the dominant role in quantitative monitoring of bottom fish, other techniques should be used to accomplish other objectives. For example, pelagic fish should be evaluated with alternative approaches such sonar, nets, or hook and line sampling. In addition, long term datasets such as Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) trap sampling must continue. Despite difficulties of comparing these data to other studies, such long term, consistently collected datasets continued in the future will provide comparative information on increases and decreases in fish community variables relative to their data collected previously.

The densities and size structure of selected fish species can be monitored through time with effort optimized to test particular hypotheses of interest. For example, power analysis based on the variability of the density data for a species of interest (or other variable) can be performed. Specifically, the sample size needed to detect a particular change in the fish community can be calculated and field work prioritized to meet that goal. Many variations on monitoring and sampling design are possible. A reference describing monitoring options was recently completed for reef fish and provides a good place to begin such considerations (Menza et al. 2006).

Another assessment option to consider in addition to stratified random sampling is a more complete comprehensive survey of all ledges. There are 436 ledges in GRNMS of various height and dimension. It is possible to visit every one over the course of a year or in a couple of field seasons. Ledges could all reasonably be surveyed without replacement (in the statistical sense) to obtain an understanding of the entire population of ledges. This would not necessarily need to include all of the variables and approaches here, but could instead focus on a subset of fish species or ledge variables such as those deemed significant in the present study. For example, evaluating a ledge's percent cover, total height, undercut width, and undercut height would establish its characteristics relative to the four ledge types identified in this study (Figure 4.8). Based on those characteristics it is possible to infer the species richness (Figure 4.4), fish abundance (Figure 4.5), diversity (Figure 4.6), and even species composition (Figure 4.7 and 4.9) of every ledge in the sanctuary. Based on this it would even be possible to estimate population sizes of ledge associated species.

Additional activities should also be initiated to quantify fishing effort in different parts of the sanctuary. At present only relative levels of fishing effort can be inferred from the boat count data. The central area has higher fishing effort than the rest of the sanctuary, however, exactly what that level of effort and impact to the resource or CPUE may be is not quantifiable given present monitoring activities.

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Appendix A. Fish species observed on all bottom types. Within each of the major bottom types at GRNMS, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. Presence during the May and/or August survey periods is denoted by an X. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zeros.

Genus species **common name**	**May**	**Aug**	**Variable**	**Flat sand Value**	**Flat sand SE**	**Rippled sand Value**	**Rippled sand SE**	**Sparse live bottom Value**	**Sparse live bottom SE**	**Ledge Value**	**Ledge SE**
Abudefduf saxatilis		X	percent of surveys	0		0		0		1	
sergeant major			mean abundance							0	
			mean biomass (g)							0	
Acanthostracion quadricornis	X		percent of surveys	0		0		0		1	
scrawled cowfish			mean abundance							0	
			mean biomass (g)							3	
Antennarius sp.		X	percent of surveys	0		0		0		2	
frogfish			mean abundance							0	
			mean biomass (g)							0	
Apogon pseudomaculatus	X	X	percent of surveys	0		0		0		49	
twospot cardinalfish			mean abundance							3	0.5
			mean biomass (g)							6	1.1
Archosargus probatocephalus	X	X	percent of surveys	0		0		0		33	
sheepshead			mean abundance							2	0.7
			mean biomass (g)							3041	839.7
Archosargus rhomboidalis	X	X	percent of surveys	5		6		25		20	
sea bream			mean abundance	1		0		2	0.5	1	0.3
			mean biomass (g)	138		10		139	47.8	652	507.7
Balistes capriscus	X	X	percent of surveys	0		0		0		26	
gray triggerfish			mean abundance							1	0.3
			mean biomass (g)							846	290.6
Bothus ocellatus	X		percent of surveys	20		13		0		0	
eyed flounder			mean abundance	0	0.1	0					
			mean biomass (g)	0	0.2	0					
Calamus bajonado	X	X	percent of surveys	0		0		0		3	
jolthead porgy			mean abundance							0	0.0
			mean biomass (g)							176	120.5
Calamus calamus	X	X	percent of surveys	0		0		0		10	
saucereye porgy			mean abundance							0	0.1
			mean biomass (g)							229	98.5
Calamus penna	X	X	percent of surveys	0		0		0		5	
sheepshead porgy			mean abundance							0	0.1
			mean biomass (g)							49	33.0
Caranx bartholomaei		X	percent of surveys	0		0		8		3	
yellow jack			mean abundance					0	0.1	0	0.0
			mean biomass (g)					13	6.9	15	13.2
Caranx crysos	X	X	percent of surveys	15		6		22		24	
blue runner			mean abundance	14	10.2	0		5	2.4	21	13.4
			mean biomass (g)	7114	5322.2	5		3026	1560.2	14278	9082.1
Caranx ruber		X	percent of surveys	0		0		0		7	
bar jack			mean abundance							1	0.6
			mean biomass (g)							290	200.5
Centropristis ocyurus	X	X	percent of surveys	5		6		33		41	
bank sea bass			mean abundance	0		0		1	0.5	1	0.3
			mean biomass (g)	1		0		65	34.4	106	29.5
Centropristis striata	X	X	percent of surveys	5		6		98		98	
black sea bass			mean abundance	0		0		13	1.5	28	2.3
			mean biomass (g)	9		38		1327	193.3	4111	524.0
Chaetodipterus faber	X	X	percent of surveys	0		0		2		12	
Atlantic spadefish			mean abundance					1		7	3.4
			mean biomass (g)					182		3070	1572.9
Chaetodon ocellatus		X	percent of surveys	0		0		0		2	
spotfin butterflyfish			mean abundance							0	
			mean biomass (g)							0	
Chilomycterus schoepfi	X		percent of surveys	0		0		0		1	
stripped burrfish			mean abundance							0	
			mean biomass (g)							1	
Chloroscombrus chrysurus		X	percent of surveys	11		13		12		12	
Atlantic bumper			mean abundance	2		0		8	4.5	24	12.4
			mean biomass (g)	146		8		578	289.2	5176	3023.0

Appendix A. Continued. Fish species observed on all bottom types. Within each of the major bottom types at GRNMS, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. Presence during the May and/or August survey periods is denoted by an X. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zeros.

Genus species / common name	May	Aug	Variable	Flat sand Value	Flat sand SE	Rippled sand Value	Rippled sand SE	Sparse live bottom Value	Sparse live bottom SE	Ledge Value	Ledge SE
Conger sp.		X	percent of surveys	0		0		0		1	
conger eel			mean abundance							0	
			mean biomass (g)							3	
Coryphopterus glaucofraenum		X	percent of surveys	0		0		0		5	
bridled goby			mean abundance							0	0.0
			mean biomass (g)							0	0.1
Decapterus sp.	X	X	percent of surveys	20		38		6		10	
scad			mean abundance	14	12.6	8	3.9	1	0.5	195	118.7
			mean biomass (g)	1814	1776.6	628	524.8	240	205.4	908	540.5
Diodon hystrix		X	percent of surveys	0		0		0		1.00	
porcupinefish			mean abundance							0	
			mean biomass (g)							19	
Diplectrum formosum	X	X	percent of surveys	11		38		43		33	
sand perch			mean abundance	0		1	0.3	4	0.9	1	0.4
			mean biomass (g)	0		47	42.8	71	21.4	57	22.3
Diplodus holbrookii	X	X	percent of surveys	0		0		6.00		34.00	
spottail pinfish			mean abundance					0	0.4	4	1.0
			mean biomass (g)					30	26.7	483	112.4
Echeneis naucrates	X		percent of surveys	0		0		2		0	
sharksucker			mean abundance					0			
			mean biomass (g)					23			
Epinephelus morio	X	X	percent of surveys	0		0		0		7.00	
red grouper			mean abundance							0	0.0
			mean biomass (g)							102	43.7
Equetus lanceolatus	X	X	percent of surveys	0		0		6		16	
jackknife fish			mean abundance					0	0.1	0	0.1
			mean biomass (g)					22	15.3	26	10.9
Ginglymostoma cirratum		X	percent of surveys	0		0		0		3	
nurse shark			mean abundance							0	0.0
			mean biomass (g)							1006	776.9
Gymnachirus melas		X	percent of surveys	0		6		0		0	
naked sole			mean abundance			0					
			mean biomass (g)			0					
Gymnothorax saxicola	X	X	percent of surveys	0		0		8		1	
honeycomb moray			mean abundance					0	0.0	0	
			mean biomass (g)					25	14.6	0	
Haemulon aurolineatum	X	X	percent of surveys	0		0		4		48	
tomtate			mean abundance					0		931	494.5
			mean biomass (g)					4		1897	644.2
Haemulon plumierii	X	X	percent of surveys	0		0		0		11	
white grunt			mean abundance							0	0.2
			mean biomass (g)							240	153.8
Haemulon sp.		X	percent of surveys	0		0		2		1	
grunt			mean abundance					0		0	
			mean biomass (g)					0		0	
Halichoeres bivittatus	X	X	percent of surveys	0		0		61		89	
slippery dick			mean abundance					6	1.1	15	1.6
			mean biomass (g)					194	48.0	290	37.0
Halichoeres caudalis	X	X	percent of surveys	0		6		51		45	
painted wrasse			mean abundance			1		3	0.8	1	0.2
			mean biomass (g)			55		115	30.8	57	12.6
Holacanthus bermudensis	X	X	percent of surveys	0		0		0		20	
blue angelfish			mean abundance							1	0.2
			mean biomass (g)							603	180.5
Hypleurochilus geminatus	X	X	percent of surveys	0		0		0		17	
crested blenny			mean abundance							0	0.1
			mean biomass (g)							0	0.1
Lutjanus analis		X	percent of surveys	0		0		0		1	
mutton snapper			mean abundance							0	
			mean biomass (g)							12	

Appendix A. Continued. Fish species observed on all bottom types. Within each of the major bottom types at GRNMS, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. Presence during the May and/or August survey periods is denoted by an X. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zeros.

Genus species / **common name**	**May**	**Aug**	**Variable**	**Flat sand**		**Rippled sand**		**Sparse live bottom**		**Ledge**	
				Value	**SE**	**Value**	**SE**	**Value**	**SE**	**Value**	**SE**
Lutjanus campechanus	X	X	percent of surveys	0		0		2		9	
red snapper			mean abundance					0		0	0.1
			mean biomass (g)					29		473	256.9
Microgobius carri	X	X	percent of surveys	20		31		12		12	
seminole goby			mean abundance	0	0.2	1	0.3	0	0.1	0	0.1
			mean biomass (g)	0	0.2	1	0.3	0	0.1	1	0.6
Micropogonias undulatus		X	percent of surveys	0		0		0		1	
Atlantic croaker			mean abundance							0	
			mean biomass (g)							2	
Muraena retifera	X	X	percent of surveys	0		0		0		11	
reticulate moray			mean abundance							0	0.0
			mean biomass (g)							43	15.9
Mycteroperca microlepis	X	X	percent of surveys	0		0		0		20	
gag grouper			mean abundance							1	0.2
			mean biomass (g)							2586	1073.1
Mycteroperca phenax	X	X	percent of surveys	0		0		0		24	
scamp			mean abundance							2	0.5
			mean biomass (g)							3035	883.7
Nicholsina usta		X	percent of surveys	0		0		8		0	
emerald parrotfish			mean abundance					0	0.1		
			mean biomass (g)					2	1.5		
Ogcocephalus nasutus		X	percent of surveys	0		0		0		1	
shortnose batfish			mean abundance							0	
			mean biomass (g)							1	
Ogcocephalus radiatus	X	X	percent of surveys	0		6		0		1	
polka-dot batfish			mean abundance			0				0	
			mean biomass (g)			0				3	
Opsanus tau	X	X	percent of surveys	0		0		25		61	
oyster toadfish			mean abundance					0	0.1	1	0.1
			mean biomass (g)					56	17.7	188	27.1
Pagrus pagrus	X	X	percent of surveys	0		0		0		2	
red porgy			mean abundance							0	
			mean biomass (g)							45	
Parablennius marmoreus	X	X	percent of surveys	0		0		0		28	
seaweed blenny			mean abundance							1	0.2
			mean biomass (g)							1	0.3
Paralichthys albigutta	X	X	percent of surveys	10		6		8		16	
gulf flounder			mean abundance	0		0		0	0.0	0	0.2
			mean biomass (g)	9		2		31	21.0	309	150.3
Pareques sp.	X	X	percent of surveys	0		0		2		55	
cubbyu/high hat			mean abundance					0		55	22.8
			mean biomass (g)					0		6013	3411.1
Pomacanthus paru		X	percent of surveys	0		0		0		1	
French angelfish			mean abundance							0	
			mean biomass (g)							0	
Pomacanthus sp.		X	percent of surveys	0		0		0		1	
angelfish			mean abundance							0	
			mean biomass (g)							0	
Prionotus ophryas	X		percent of surveys	0		0		2		0	
bandtail searobin			mean abundance					0			
			mean biomass (g)					4			
Prionotus scitulus	X	X	percent of surveys	5		0		0		4	
leopard searobin			mean abundance	0						0	0.0
			mean biomass (g)	2						6	3.0
Prionotus sp.	X	X	percent of surveys	25		6		12		11	
searobin			mean abundance	0	0.1	0		0	0.0	0	0.0
			mean biomass (g)	3	2.2	2		22	10.8	8	3.3
Ptereleotris calliurus	X	X	percent of surveys	0		0		10		5	
blue goby			mean abundance					0	0.1	0	0.1
			mean biomass (g)					1	1.0	0	0.3

Appendix A. Continued. Fish species observed on all bottom types. Within each of the major bottom types at GRNMS, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. Presence during the May and/or August survey periods is denoted by an X. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zeros.

Genus species **common name**	**May**	**Aug**	**Variable**	**Flat sand Value**	**Flat sand SE**	**Rippled sand Value**	**Rippled sand SE**	**Sparse live bottom Value**	**Sparse live bottom SE**	**Ledge Value**	**Ledge SE**
Ptereleotris helenae		X	percent of surveys	0		0		0		1	
hovering goby			mean abundance							0	
			mean biomass (g)							0	
Raja eglanteria	X		percent of surveys	0		0		2		0	
clearnose skate			mean abundance					0			
			mean biomass (g)					48			
Rhinobatos lentiginosus	X		percent of surveys	0		0		0		1	
Atlantic guitarfish			mean abundance							0	
			mean biomass (g)							11	
Rypticus maculatus	X	X	percent of surveys	0		0		2		39	
whitespotted soapfish			mean abundance					0		1	0.4
			mean biomass (g)					1		167	71.8
Scomberomorus maculatus		X	percent of surveys	5		0		4		7	
Spanish mackerel			mean abundance	10				2		3	1.7
			mean biomass (g)	3539				537		970	599.0
Scorpaena sp.		X	percent of surveys	0		0		0		1	
scorpionfish			mean abundance							0	
			mean biomass (g)							1	
Seriola sp.		X	percent of surveys	5		0		4		9	
almaco/amberjack			mean abundance	0				0		0	0.2
			mean biomass (g)	35				149		276	198.7
Serraniculus pumilio		X	percent of surveys	0		0		0		1	
pygmy sea bass			mean abundance							0	
			mean biomass (g)							0	
Serranus subligarius	X	X	percent of surveys	0		0		47		88	
belted sandfish			mean abundance					2	0.6	13	1.4
			mean biomass (g)					6	3.4	25	2.8
Sphyraena barracuda	X	X	percent of surveys	0		0		0		7	
great barracuda			mean abundance							0	0.1
			mean biomass (g)							162	81.5
Sphyraena sp.		X	percent of surveys	0		0		0		1	
barracuda			mean abundance							0	
			mean biomass (g)							0	
Stegastes variabilis		X	percent of surveys	0		0		0		10	
cocoa variabilis			mean abundance							0	0.2
			mean biomass (g)							1	0.6
Stenotomus sp.	X	X	percent of surveys	15		31		90		80	
scup/longspine porgy			mean abundance	8	7.5	69	62.4	20	4.1	24	2.8
			mean biomass (g)	26	18.5	257	161.6	1677	313.0	3007	430.0
Stephanolepis hispidus	X	X	percent of surveys	0		0		0		8.00	
planehead filefish			mean abundance							0	0.0
			mean biomass (g)							14	5.5
Syngnathidae sp.	X		percent of surveys	0		13		0		1	
pipefish			mean abundance			0				0	
			mean biomass (g)			0				0	
Synodus sp.	X	X	percent of surveys	15.00		6.00		12.00		2.00	
lizardfish			mean abundance	0	0.1	0		0	0.1	0	
			mean biomass (g)	23	17.9	24		71	54.4	9	
Urophycis earlli	X	X	percent of surveys	0		0		4.00		26.00	
Carolina hake			mean abundance					0		1	0.4
			mean biomass (g)					2		283	79.4
Xyrichtys novacula	X	X	percent of surveys	75		88		2		1	
pearly razorfish			mean abundance	3	0.7	9	6.8	0		0	
			mean biomass (g)	44	12.2	68	19.5	1		0	

Appendix B. Fish species observed on ledges. Within each of the four ledge types based on cluster analysis, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zero's.

Genus species **common name**	**Variable**	**Cluster 1 Value**	**Cluster 1 SE**	**Cluster 2 Value**	**Cluster 2 SE**	**Cluster 3 Value**	**Cluster 3 SE**	**Cluster 4 Value**	**Cluster 4 SE**
Abudefduf saxatilis	percent of surveys	0		17		0		0	
sergeant major	mean abundance			0					
	mean biomass (g)			1					
Acanthostracion quadricornis	percent of surveys	4		0		0		0	
scrawled cowfish	mean abundance	0							
	mean biomass (g)	11							
Antennarius sp.	percent of surveys	9		0		0		0	
frogfish	mean abundance	0							
	mean biomass (g)	1							
Apogon pseudomaculatus	percent of surveys	74		67		31		67	
twospot cardinalfish	mean abundance	4	0.7	5	1.7	1	0.7	3	1.1
	mean biomass (g)	10	1.6	11	3.9	3	1.5	7	2.6
Archosargus probatocephalus	percent of surveys	70		83		8		42	
sheepshead	mean abundance	6	2.4	6	2.1	0	0.3	1	0.4
	mean biomass (g)	8745	2823.4	7117	3380.8	593	333.7	473	282.1
Archosargus rhomboidalis	percent of surveys	17		0		20		33	
sea bream	mean abundance	2	1.1			1	0.3	2	1.0
	mean biomass (g)	2293	2017.7			123	77.5	76	46.8
Balistes capriscus	percent of surveys	61		67		6		25	
gray triggerfish	mean abundance	3	1.1	2	0.7	0	0.1	0	
	mean biomass (g)	2809	1052.3	952	385.6	123	87.6	104	
Bothus ocellatus	percent of surveys	0		0		0		0	
eyed flounder	mean abundance								
	mean biomass (g)								
Calamus bajonado	percent of surveys	4		33		0		0	
jolthead porgy	mean abundance	0		1	0.5				
	mean biomass (g)	43		2527	1684.6				
Calamus calamus	percent of surveys	17		33		2		17	
saucereye porgy	mean abundance	0	0.1	1	0.8	0		0	
	mean biomass (g)	313	180.2	1794	1221.7	25		151	
Calamus penna	percent of surveys	9		17		4		0	
sheepshead porgy	mean abundance	0		0		0	0.1		
	mean biomass (g)	35		492		14	10.1		
Caranx bartholomaei	percent of surveys	4		0		2		8	
yellow jack	mean abundance	0	0.2			0		0	
	mean biomass (g)	52	52.3			3		6	
Caranx crysos	percent of surveys	26		50		22		17	
blue runner	mean abundance	58	52.0	62	48.2	5	1.9	2	1.7
	mean biomass (g)	39360	34944.5	41552	36637.3	2824	1335.5	1250	1243.2
Caranx ruber	percent of surveys	22		17		0		0	
bar jack	mean abundance	4	2.5	1					
	mean biomass (g)	1152	787.5	24					
Centropristis ocyurus	percent of surveys	39		33		33		83	
bank sea bass	mean abundance	1	0.4	1	0.6	2	0.4	2	0.6
	mean biomass (g)	107	58.2	145	141.9	96	40.5	123	75.7
Centropristis striata	percent of surveys	96		100		98		100	
black sea bass	mean abundance	35	6.8	30	11.7	23	1.9	35	5.2
	mean biomass (g)	6702	1620.6	5368	3228.7	2879	320.0	3747	1077.3
Chaetodipterus faber	percent of surveys	17		83		4		0	
Atlantic spadefish	mean abundance	12	8.6	56	34.0	2	1.4		
	mean biomass (g)	4667	3593.2	26331	18472.4	337	236.5		
Chaetodon ocellatus	percent of surveys	4		0		0		8	
spotfin butterflyfish	mean abundance	0						0	
	mean biomass (g)	0						0	
Chilomycterus schoepfi	percent of surveys	0		0		2		0	
stripped burrfish	mean abundance					0			
	mean biomass (g)					2			
Chloroscombrus chrysurus	percent of surveys	9		17		12		17	
Atlantic bumper	mean abundance	44	43.4	83	83.3	11	5.2	7	4.5
	mean biomass (g)	10923	10700.9	20525	20524.7	1756	1059.6	1024	827.5

Appendix B. Continued. Fish species observed on ledges. Within each of the four ledge types based on cluster analysis, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zero's.

Genus species / **common name**	**Variable**	**Cluster 1** Value	SE	**Cluster 2** Value	SE	**Cluster 3** Value	SE	**Cluster 4** Value	SE
Conger sp.	percent of surveys	0		0		0		8	
conger eel	mean abundance							0	
	mean biomass (g)							26	
Coryphopterus glaucofraenum	percent of surveys	9		0		4		8	
bridled goby	mean abundance	0				0		0	
	mean biomass (g)	0				0		0	
Decapterus sp.	percent of surveys	17		33		6		0	
scad	mean abundance	249	177.5	2000	1633.0	4	3.9		
	mean biomass (g)	1344	1142.0	1663	1358.0	836	819.6		
Diodon hystrix	percent of surveys	4		0		0		0	
porcupinefish	mean abundance	0							
	mean biomass (g)	76							
Diplectrum formosum	percent of surveys	13		0		43		42	
sand perch	mean abundance	0	0.3			2	0.6	1	0.2
	mean biomass (g)	21	14.3			92	39.1	5	3.9
Diplodus holbrookii	percent of surveys	74		83		10		33	
spottail pinfish	mean abundance	10	3.3	11	4.5	1	0.5	3	1.5
	mean biomass (g)	970	270.6	1848	982.5	143	73.3	312	157.6
Echeneis naucrates	percent of surveys	0		0		0		0	
sharksucker	mean abundance								
	mean biomass (g)								
Epinephelus morio	percent of surveys	22		0		0		8	
red grouper	mean abundance	0	0.1					0	
	mean biomass (g)	328	147.6					155	
Equetus lanceolatus	percent of surveys	17		33		12		25	
jackknife fish	mean abundance	0	0.3	1	0.5	0	0.2	0	0.3
	mean biomass (g)	23	15.6	0	0.3	21	14.8	68	46.4
Ginglymostoma cirratum	percent of surveys	9		17		0		0	
nurse shark	mean abundance	0	0.1	0					
	mean biomass (g)	3944	3075.4	306					
Gymnachirus melas	percent of surveys	0		0		0		0	
naked sole	mean abundance								
	mean biomass (g)								
Gymnothorax saxicola	percent of surveys	0		0		2		0	
honeycomb moray	mean abundance					0			
	mean biomass (g)					1			
Haemulon aurolineatum	percent of surveys	87		67		24		67	
tomtate	mean abundance	873	445.4	10675	6645.1	10	6.1	80	50.1
	mean biomass (g)	3068	709.0	14964	8069.3	243	114.1	151	94.6
Haemulon plumierii	percent of surveys	22		83		0		0	
white grunt	mean abundance	1	0.9	1	0.6				
	mean biomass (g)	720	591.1	925	564.0				
Haemulon sp.	percent of surveys	0		0		0		8	
grunt	mean abundance							3	2.5
	mean biomass (g)							3	3.1
Halichoeres bivittatus	percent of surveys	100		100		80		100	
slippery dick	mean abundance	18	3.0	12	4.6	10	1.5	32	6.3
	mean biomass (g)	349	82.0	353	158.8	239	45.4	362	114.4
Halichoeres caudalis	percent of surveys	22		0		49		92	
painted wrasse	mean abundance	0	0.2			2	0.3	3	0.4
	mean biomass (g)	19	11.5			82	21.4	47	10.1
Holacanthus bermudensis	percent of surveys	52		83		2		0	
blue angelfish	mean abundance	2	0.5	4	1.4	0	0.1		
	mean biomass (g)	1221	487.9	3603	1152.6	114	113.7		
Hypleurochilus geminatus	percent of surveys	17		33		12		33	
crested blenny	mean abundance	0	0.1	0		0	0.1	1	0.4
	mean biomass (g)	0	0.2	1		0	0.1	1	0.6
Lutjanus analis	percent of surveys	0		0		2		0	
mutton snapper	mean abundance					0			
	mean biomass (g)					21			

Appendix B. Continued. Fish species observed on ledges. Within each of the four ledge types based on cluster analysis, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zero's.

Genus species / common name	Variable	Cluster 1 Value	Cluster 1 SE	Cluster 2 Value	Cluster 2 SE	Cluster 3 Value	Cluster 3 SE	Cluster 4 Value	Cluster 4 SE
Lutjanus campechanus	percent of surveys	22		33		0		8	
red snapper	mean abundance	0	0.2	2	1.1			0	
	mean biomass (g)	793	432.3	4219	3450.5			0	
Microgobius carri	percent of surveys	4		0		8		50	
seminole goby	mean abundance	0	0.2			0	0.1	1	0.3
	mean biomass (g)	0	0.2			1	1.0	1	0.3
Micropogonias undulatus	percent of surveys	4		0		0		0	
Atlantic croaker	mean abundance	0							
	mean biomass (g)	9							
Muraena retifera	percent of surveys	17		50		2		17	
reticulate moray	mean abundance	0	0.1	1		0		0	
	mean biomass (g)	101	54.2	132		10		28	
Mycteroperca microlepis	percent of surveys	43		83		4		8	
gag grouper	mean abundance	1	0.7	5	1.3	0	0.1	0	
	mean biomass (g)	5283	3700.8	13386	3824.1	689	670.3	79	
Mycteroperca phenax	percent of surveys	61		100		2		8	
scamp	mean abundance	4	1.1	11	3.3	0		1	1.3
	mean biomass (g)	6141	1997.9	16701	6939.8	12		3095	3095.3
Nicholsina usta	percent of surveys	0		0		0		0	
emerald parrotfish	mean abundance								
	mean biomass (g)								
Ogcocephalus nasutus	percent of surveys	0		0		2		0	
shortnose batfish	mean abundance					0			
	mean biomass (g)					1			
Ogcocephalus radiatus	percent of surveys	0		0		2		0	
polka-dot batfish	mean abundance					0			
	mean biomass (g)					6			
Opsanus tau	percent of surveys	61		100		55		67	
oyster toadfish	mean abundance	1	0.3	3	0.8	1	0.1	1	0.3
	mean biomass (g)	215	55.3	504	140.9	141	30.6	178	82.1
Pagrus pagrus	percent of surveys	4		0		2		0	
red porgy	mean abundance	0				0	0.2		
	mean biomass (g)	14				75	75.4		
Parablennius marmoreus	percent of surveys	52		67		14		25	
seaweed blenny	mean abundance	2	0.5	3	1.2	0	0.1	1	0.4
	mean biomass (g)	3	0.8	5	2.0	0	0.2	1	0.7
Paralichthys albigutta	percent of surveys	35		50		4		17	
gulf flounder	mean abundance	1	0.3	4	2.1	0		0	
	mean biomass (g)	518	194.6	2338	2145.3	30		81	
Pareques sp.	percent of surveys	96		100		25		83	
cubbyu/high hat	mean abundance	154	85.3	190	73.8	6	3.1	8	1.7
	mean biomass (g)	19444	13361.6	13366	3123.5	492	359.6	61	50.4
Pomacanthus paru	percent of surveys	0		0		2		0	
French angelfish	mean abundance					0			
	mean biomass (g)					0			
Pomacanthus sp.	percent of surveys	4		0		0		0	
angelfish	mean abundance	0							
	mean biomass (g)	0							
Prionotus ophryas	percent of surveys	0		0		0		0	
bandtail searobin	mean abundance								
	mean biomass (g)								
Prionotus scitulus	percent of surveys	0		0		8		0	
leopard searobin	mean abundance					0	0.0		
	mean biomass (g)					10	5.4		
Prionotus sp.	percent of surveys	4		0		16		8	
searobin	mean abundance	0				0	0.1	0	
	mean biomass (g)	7				11	5.0	0	
Ptereleotris calliurus	percent of surveys	0		0		2		33	
blue goby	mean abundance					0	0.1	0	0.2
	mean biomass (g)					0	0.1	3	2.2

Appendix B. Continued. Fish species observed on ledges. Within each of the four ledge types based on cluster analysis, the percent of surveys on which the species was encountered and the average abundance and biomass (and standard error) are provided. For species which have zero values for probability of encounter, abundance and biomass are left blank. No standard error is given when a species was seen on less than three surveys although mean abundance and biomass are provided. Also note that mean values are rounded to the ones digit and SE is rounded to tenths which results in some low values appearing as zero's.

Genus species **common name**	**Variable**	**Cluster 1**		**Cluster 2**		**Cluster 3**		**Cluster 4**	
		Value	**SE**	**Value**	**SE**	**Value**	**SE**	**Value**	**SE**
Ptereleotris helenae	percent of surveys	0		0		2		0	
hovering goby	mean abundance					0			
	mean biomass (g)					0			
Raja eglanteria	percent of surveys	0		0		0		0	
clearnose skate	mean abundance								
	mean biomass (g)								
Rhinobatos lentiginosus	percent of surveys	0		0		2		0	
Atlantic guitarfish	mean abundance					0			
	mean biomass (g)					19			
Rypticus maculatus	percent of surveys	65		100		16		58	
whitespotted soapfish	mean abundance	2	0.5	10	4.3	0	0.1	1	0.3
	mean biomass (g)	213	63.6	1442	995.1	21	8.8	64	40.1
Scomberomorus maculatus	percent of surveys	9		50		2		0	
Spanish mackerel	mean abundance	5	4.3	22	19.6	0	0.1		
	mean biomass (g)	1693	1539.4	8036	6912.8	42	41.6		
Scorpaena sp.	percent of surveys	0		0		0		8	
scorpionfish	mean abundance							0	
	mean biomass (g)							6	
Seriola sp.	percent of surveys	17		17		2		17	
almaco/amberjack	mean abundance	1	0.7	0		0		0	0.3
	mean biomass (g)	999	785.5	235		5		62	47.0
Serraniculus pumilio	percent of surveys	0		0		2		0	
pygmy sea bass	mean abundance					0			
	mean biomass (g)					0			
Serranus subligarius	percent of surveys	100		100		78		100	
belted sandfish	mean abundance	20	2.8	22	5.0	7	1.2	23	5.7
	mean biomass (g)	35	5.1	37	8.4	15	3.3	39	9.6
Sphyraena barracuda	percent of surveys	13		0		4		8	
great barracuda	mean abundance	0	0.3			0		0	
	mean biomass (g)	320	246.8			61		370	
Sphyraena sp.	percent of surveys	0		17		0		0	
barracuda	mean abundance			1	1.3				
	mean biomass (g)			1	1.0				
Stegastes variabilis	percent of surveys	17		0		8		8	
cocoa variabilis	mean abundance	1	0.4			0	0.1	1	1.2
	mean biomass (g)	2	1.2			0	0.3	4	3.6
Stenotomus sp.	percent of surveys	52		17		98		92	
scup/longspine porgy	mean abundance	10	4.3	0		32	3.8	31	6.6
	mean biomass (g)	2107	1124.7	109		3470	454.4	4218	1465.1
Stephanolepis hispidus	percent of surveys	9		17		6		8	
planehead filefish	mean abundance	0		0		0		0	
	mean biomass (g)	13		38		13		5	
Syngnathidae sp.	percent of surveys	0		0		2		0	
pipefish	mean abundance					0			
	mean biomass (g)					0			
Synodus sp.	percent of surveys	0		0		4		0	
lizardfish	mean abundance					0			
	mean biomass (g)					17			
Urophycis earlii	percent of surveys	26		17		31		8	
Carolina hake	mean abundance	1	0.3	0		2	0.6	0	
	mean biomass (g)	254	123.1	74		383	130.3	19	
Xyrichtys novacula	percent of surveys	0		0		2		0	
pearly razorfish	mean abundance					0			
	mean biomass (g)					0			

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