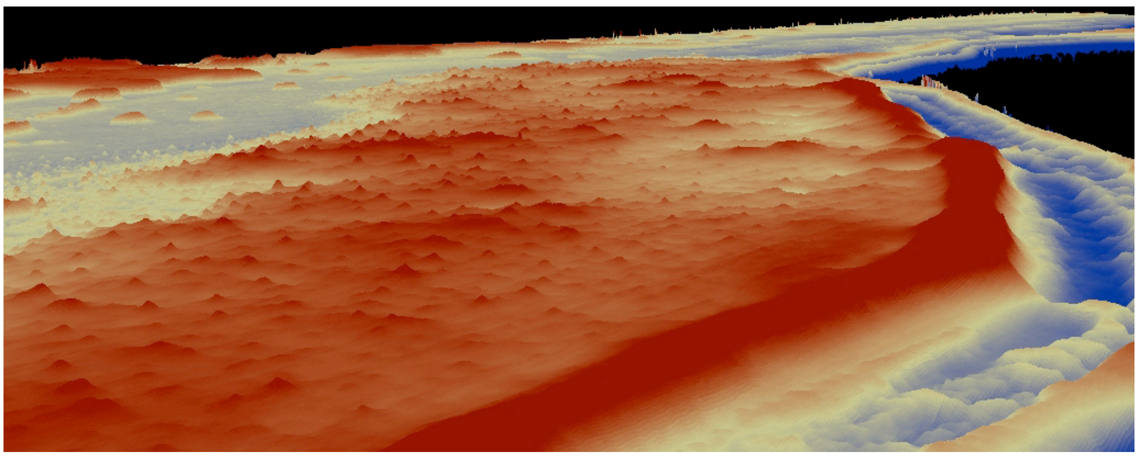
CHARACTERIZATION OF DEEP WATER REEF COMMUNITIES WITHIN THE MARINE CONSERVATION DISTRICT, ST. THOMAS, U.S. VIRGIN ISLANDS

FINAL REPORT



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EXECUTIVE SUMMARY

The University of the Virgin Islands, in collaboration with the Caribbean Fisheries Management Council, completed a survey of the habitat and fisheries resources of the Red Hind Marine Conservation District (MCD), St Thomas, United States Virgin Islands. The purpose of this research was to validate habitat classifications developed for the CFMC and to assess fisheries and non-fisheries resources within this marine protected area. This research provides information that is applicable for the classification and ranking of essential fish habitat (EFH) within the MCD and similar mesophotic reef habitat (30 – 50 m) along the Puerto Rican Shelf.

Benthic habitat assessments revealed extensive and well developed mesophotic coral reefs at depths of 34 – 47 m. Coral reefs were determined to occupy 65% of sites sampled in the MCD (coral cover > 4%, N = 80), with an average coral coverage of 25.3% ± 2.1 SE and maximum coral coverage of 50.1%. Coral species richness was high, with 37 species or genera recorded from the MCD, including the threatened elkhorn coral (*Acropora cervicornis*). Coral coverage was dominated (91.8%) by members of the *Montastraea annularis* species complex.

Benthic habitats were predicted with variable accuracy using classified sonar imagery. Coral reefs were found to occupy almost all sampling strata predicted to contain pavement and sand habitat types. However, algae and coral strata were well predicted.

Coral health assessments revealed an extensive and severe cryptic coral mortality event caused by an unknown disease referred to as unknown necrosis. Disease signs and mortality covered a coherent region comprising over one fifth of the area of the MCD. The mean prevalence (42.4% ± 6.3 SE, N = 27) and severity (32.8% ± 4.6 SE) of unknown necrosis at affected sites suggested that the effects of the disease were intense in these areas, and may have contributed to a loss of over half the coral coverage.

Motile resource surveys of fish and commercially important invertebrates showed a total of 112 fish species. No motile macro invertebrates were seen during our surveys, but previous studies within the MCD have documented spiny lobster (*Panulirus argus*) and channel crabs (*Mithrax spinosissimus*). Species richness and biomass was highest in coral habitats followed by sand and pavement. Species richness was significantly lower in algal habitats than in the three other habitat types. Fish assemblage structure was dominated numerically by herbivorous and planktivorous species. Greatest fish biomass was found among invertivores, herbivores, and piscivores, respectively. Commercially important species were found primarily in coral and hard-bottom habitats. The fact that fish communities in the sand stratum were similar to coral and pavement strata indicates the discrepancy in habitat classification. True sand habitats contained a fish assemblage structure more similar to algal plains. Abundance and distribution of reef

fishes varied throughout the MCD depending upon taxa and presence of habitat types within the MCD. For example, the queen triggerfish (*Balistes vetula*) showed higher biomass near the northern boundary and in the eastern end of the MCD. These portions of the MCD contained large, sandy areas that are the preferred habitat of *B. vetula*.

INTRODUCTION

The Sustainable Fisheries Act of 1996 provided for significant changes in the management of fishery resources. In particular, it created the concept of an essential fish habitat (EFH) and required that scientific research be undertaken to determine habitats that were critically important to maintain fish stocks. Defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity” this amendment to the Magnuson-Stevens Act requires a broader assessment of the habitats and locations that should be afforded protection.

To address threats of over fishing and provide additional protective measures to essential fish habitat, the Caribbean Fishery Management Council (CFMC) initiated a study of one of the most significant marine protected areas within the US Virgin Islands, the Red Hind Bank Marine Conservation District (MCD; Fig. 1, Fig. 2). Established in 1999, regulations within the MCD prohibit anchoring and fishing of any kind, except trolling for pelagic species (Federal Register 64:213). The MCD encompasses 44.5 square kilometers (39.5 square kilometer < 50 m depth) of federal waters at the edge of the Puerto Rican Shelf south of St. Thomas.

Although a number of studies have been conducted within the MCD (Beets and Friedlander 1999, Nemeth 2004, Whiteman et al 2005, Nemeth and Quandt 2005, Herzlieb et al. 2006) there remain significant gaps in knowledge about the fish and benthic resources within its boundaries. For example, little is known about deepwater shelf slope and shelf edge benthic communities nor the status of the fish stocks that utilize these habitats.

Characterization and assessment of benthic habitats and associated communities will provide valuable data to inform the development and/or revision of fishery management plans based on the principles expressed by the EFH concept. This information can be used to understand the necessity of future marine protected areas and guide their designation. The specific objectives of the research presented in this report were to characterize benthic habitat composition across the MCD, provide ground validation to support existing GIS habitat maps of the MCD, assess the health of coral resources, and quantitatively describe the associated fish and fisheries resources. This report fills in gaps of previous research within the MCD and provides baseline characterization data that will allow greater assessment and management of EFH within the MCD and across similar mesophotic reefs within the U.S. Caribbean.

Background

Studies conducted in the MCD have indicated that the area includes numerous deep habitats (30-100+ m) that contain resources important to fisheries dependent economies and regional biodiversity. A detailed bathymetric and habitat characterization of the MCD was conducted in 2003 (Moody 2003; Prada 2003, Rivera) using multibeam sonar and Side Scan Sonar (SSS) imagery. These studies delineated three Meta-communities including corals and gorgonians, submerged aquatic vegetation, and sand. Within these Meta-communities 23 habitat types were classified.

Direct visual surveys of sessile benthic communities within the MCD have suggested the presence of exceptionally rich and extensive mesophotic coral reef communities. Autonomous underwater vehicle (AUV) benthic surveys (Armstrong et al. 2006) and in situ assessments and monitoring (Nemeth et al. 2005, Herzlieb et al. 2006, Smith in review) have revealed coral reef banks and patch reefs dominated by reef forming corals of the *Montastraea annularis* species complex. These surveys also have shown that coral cover is typically higher (10-50%) and coral health greater than on shallow and midshelf reefs in the USVI and wider Caribbean (Gardner et al. 2003). Coral cover and health at two locations within the MCD (Hind Bank and College Shoal East) have been under semi-annual to annual benthic monitoring since 2003 by the USVI Territorial Monitoring Program (Figure 1, lower panel; Nemeth et al. 2006, Smith et al. 2007). These detailed studies of benthic composition and trajectory, and coral health, have shown that reefs within the MCD may be partially buffered from the effects of climate change through mechanisms that include reduced light intensity and moderation of temperature as the result of upwelling along the shelf edge (Smith et al., in prep). Such studies suggest that the MCD may be a regionally important refuge for coral reef biodiversity and fish habitat under scenarios of future seawater warming in the Western Atlantic (Donner et al. 2007).

The MCD is likely to protect a large biomass of resident and transient commercially important fishes. Fish and fisheries resources in the MCD are broadly similar to shallow waters of the Puerto Rican Shelf, but differ from shallow and midshelf coral reefs in relative species composition and the occurrence of more rare deep water associated fishes (Nemeth et al. 2006). An important red hind spawning aggregation site (SPAG) within the MCD is well characterized (Olsen and Laplace 1979, Beets and Friedlander 1999, Nemeth 2005) and was the initial stimulus for establishment of the management area along the shelf edge. Historical SPAGs of the federally protected Nassau grouper (*Epinephelus striatus*) and existing or extant spawning aggregations of other commercially important species are also known from the MCD (Olsen and LaPlace 1979, Nemeth unpub data, Table 1). In addition, the Grammanik Bank, a 1.4 km reef less than 5 km east of the MCD boundary, hosts spawning aggregations of Nassau, yellowfin (*Mycteroperca venenosa*), yellowmouth (*M. interstitialis*) and tiger (*M. tigris*) grouper (Nemeth et al. 2006b). Recent hydro-acoustic data from Nassau and yellowfin grouper tagged on the Grammanik Bank indicate that many move west into the MCD between monthly spawning events in February, March and April, and that the MCD affords protection to those species from fishing during a very critical period of the year (Nemeth, unpub. data).

Table 1. Species known to spawn or form aggregations around the red hind spawning aggregation site (18.202 N, 65.002 W).

Common Name	Scientific Name	Number observed	Timing
Red hind	*Epinephelus guttatus*	80,000	Dec-Feb
Nassau grouper	*E. striatus*	Historic	Dec-Feb
Tiger grouper	*Mycteroperca tigris*	100	Jan-Mar
Mutton snapper	*Lutjanus analis*	200	Mar-May
Schoolmaster snapper	*L. apodus*	100	Mar-May
Horse-eye jack	*Caranx latus*	300	Feb-Apr
Black jack	*Caranx lugubris*	500	April

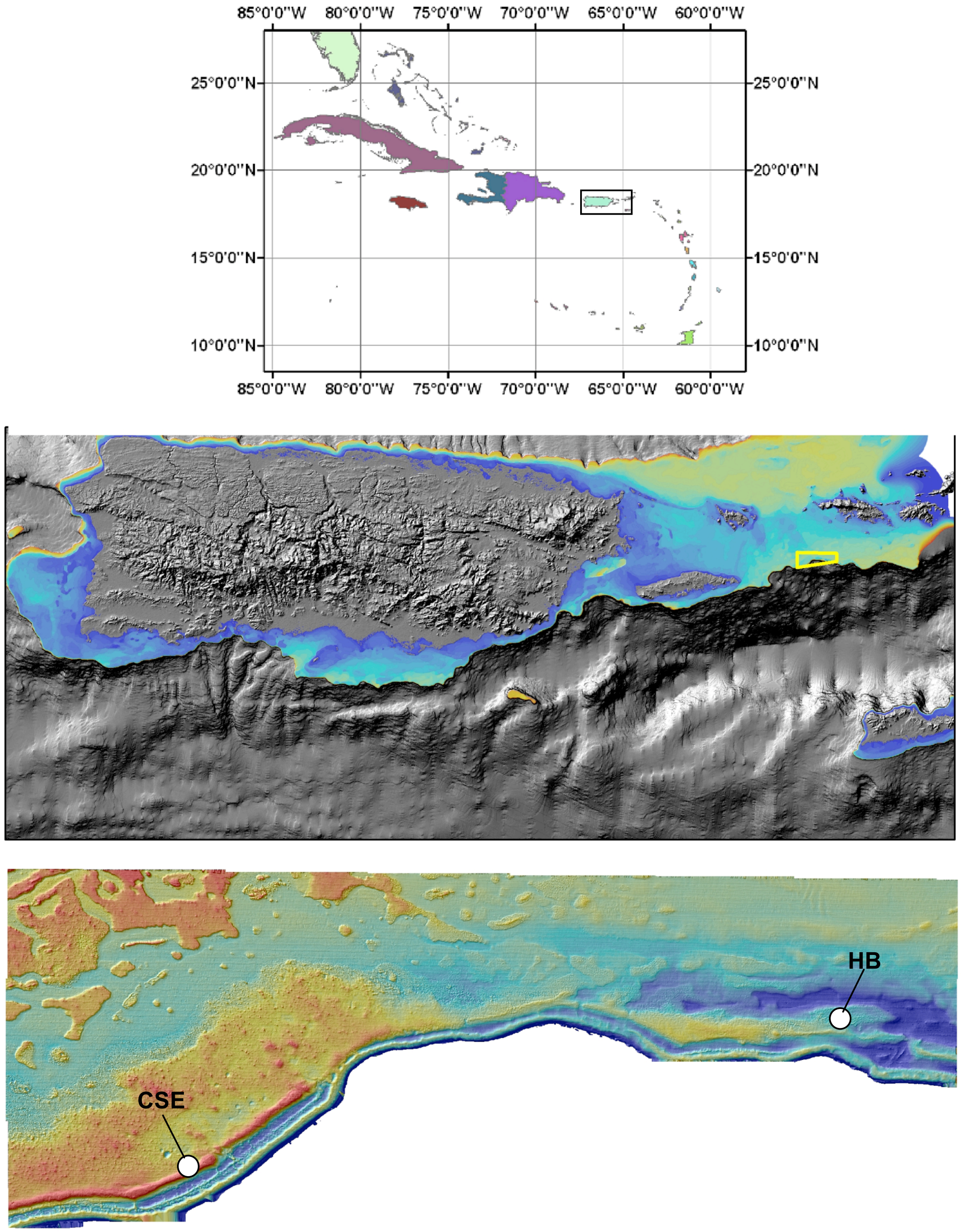

Figure 1. Map of the wider Caribbean (top panel), the shelf area of the Puerto Rican Shelf, U.S. Caribbean, with the Red Hind Marine Conservation District (MCD) indicated (yellow polygon) (middle panel), bathymetry of the MCD (lower panel). Permanent coral reef monitoring locations are College Shoal East (CSE) and Hind Bank (HB).

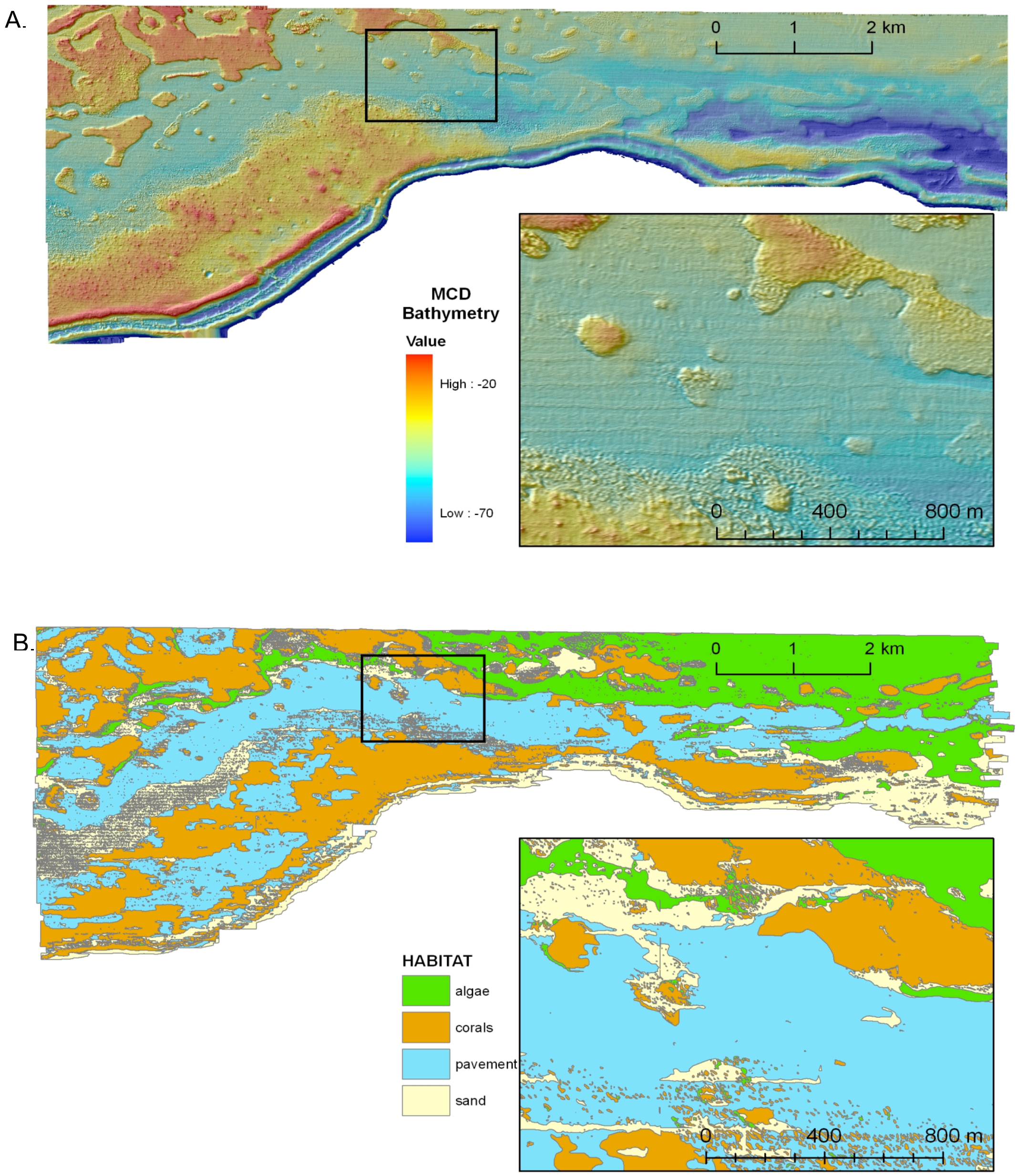

Figure 2. A) MCD multibeam bathymetry data at 1m resolution, inset shows bathymetry detail. B) MCD habitat map indicating the four strata (algae, coral, pavement and sand) used in study design, inset shows habitat detail. Maps created with GIS using data provided by Moody 2003 and Prada 2003.

METHODS

Habitat Stratification and Sampling Design

The ecosystem-based assessment of the Red Hind Marine Conservation District (MCD) presented in this report was based on a stratified random sampling strategy. Stratified random assessments offer a robust appraisal of natural resources with minimized bias (Menza et al. 2006). They allow for statistical assessment of sampling sufficiency for variables of interest because they are minimally biased and are amenable to predictive scaling of data, such as fish biomass and benthic composition, to larger geographic regions. Assignment of sampling sites within the MCD was based on predicted habitat structure defined in GIS products produced by Prada 2003 (Figure 1B). Habitat designations by Prada (2003) were determined using modifications of the scheme produced by NOAA for shallow waters of Puerto Rico and U.S. Virgin Islands (NOAA-NOS 2001). Four predicted habitat designations were chosen for sampling and included: coral, pavement, sand, and algae. These designations encompassed all benthic areas of the MCD less than 50 m. The choice of these four general habitat strata, as opposed to more specific habitat designations that were available from GIS products, was two-fold. First, because of uncertainties in true habitat composition from the assignment algorithms developed for shallow-water Caribbean benthos, it was decided that broad categories offered the greatest possibility of locating in situ assessments within accurately predicted habitats. Second, because of limitations in diver-based sampling effort in deep (30-50 m) benthic areas (i.e., 10 – 25 min. safe repetitive bottom times and the allocated study budget), it was predetermined that diver pairs could accomplish a robust number of surveys per stratum by using only four strata (80 total surveys). With these constraints, and with the lack of a priori information on habitat structure and motile resources, it was predicted that 20 surveys per predicted habitat strata would be required to make reliable assessments.

Allocation of sampling effort within each predicted benthic strata was accomplished by randomized assignment of sampling locations using the Geographic Information System (GIS). Using the four predicted benthic habitat strata supplied in GIS format, gridlines were removed and all adjacent polygons were aggregated using the Dissolve tool in ArcGIS 9.2 (ESRI software) and clipped to remove habitat defined outside the MCD boundary. To exclude benthic sampling units smaller than the size of sampling surveys (25 m linear distance, see below), any polygons in the resulting file that had areas less than 625 m^2 were removed from the shapefile. Hawth's Tools extension for ArcGIS was than used to generate 200 random points, with 50 points allocated for each habitat type. Generated sampling points (locations) were constrained so that points could not lie within 25 meters of any other sampling point. This was done to avoid the possibility of re-sampling. Sampling units were also allocated to a maximum depth of 50 m, which was considered the maximum safe depth for repetitive dives following the sampling protocol. Sampling sites and their general characteristics are presented in Appendix I.

In Situ Sampling Protocols

Randomly determined points were used a survey locations for in situ sampling protocols. Within each of the 50 random sampling points, the first 20 points were used as the drop point for diver pairs. Subsequent sampling points (randomly generated points 21-50) in each habitat strata were sequentially used if ship-board depth sounder measurements or initial diver reconnaissance of the sampling point determined that benthic areas were unsafe for completion of sampling protocols. This resulted in four randomly replaced surveys. Diver pairs utilizing technical NITROX or closed circuit rebreather were launched on the water surface within ten meters of the designated sampling point using ship-board GPS. Divers descended directly downwards on the sampling point. It was estimated that actual benthic sampling areas deviated no further than 25 meters from the predetermined sampling point of each survey.

The sampling protocol was designed to assess benthic composition, coral health, and the abundance of fish and other motile resources. Upon reaching the seafloor diver pairs deployed 30 m transect line along a compass direction randomly determined a priori using the function RAND()*360 in Microsoft Excel. Each diver pair had divided responsibility for resource assessments. Diver 1 deployed the transect tape while assessing fish and other motile resources. Following Diver 1, Diver 2 assessed the health of coral resources along the transect line. After Diver 1 had deployed the transect tape, Diver 1 returned along the transect line and recorded the benthos using digital video. Detailed methods for assessment of benthic composition, coral health, fish, and other motile resources are described below.

Benthic Composition

Benthic composition was recorded along a transect using standardized video monitoring protocols (Aronson et al. 1994, Carleton and Done 1995, Rogers and Miller 2001, Rogers et al. 2001). The video monitoring protocol is used in numerous coral reef benthic sampling programs, including the USVI Territorial Coral Reef Monitoring Program (Nemeth et al. 2006a, Smith et al. 2007). This protocol maximizes assessment times underwater and is particularly useful in time-limited assessments, such as in deep diving conditions. During video sampling, a diver swam at a uniform speed (~5 min. per transect) recording the benthic cover using a Sony TRV-950 digital camcorder in a Light and Motion Stingray II underwater housing. The diver pointed the camera down and perpendicular to the substrata remaining approximately 0.4 m about the substrate at all times. A guide wand attached to the camera housing was used to help the diver maintain the camera at a constant distance as they followed the vertical contour of the substratum. The total length of the transect taped by the diver was variable but ranged between a minimum of 10m to a max of 30m. In habitats that the diver determined were homogenous (e.g., unbroken coral cover, algal plane), the diver recorded the terminal 10 m of the transect. In habitats that were more variable (e.g., reef edge habitats and other mixed bottom habitats), the diver recorded the full 30 m of the transect. This strategy maximized limited bottom time when the habitat could be sufficiently sampled in a short transect, but captured greater variability in heterogeneous sampling locations.

After taping, approximately 40 - 80 non-overlapping images per transect were captured and saved as JPEG files on a computer using a Sony video capture card. Captured images represented a planar area of reef that varied around a true planar area of 0.31 m^2 (0.64 m x 0.48 m), and ultimately depended on the rugosity of the substratum. Microsoft Excel and Adobe Photoshop were used to superimpose ten randomly located dots on each captured image. The benthic cover under each of the points was then identified by experienced observers (TCRMP) to the lowest identifiable taxonomic level or abiotic group. For each transect, the percent cover of benthic categories was calculated by dividing the number of random points falling on the substrata type by the total number of points for the transect. The benthic categories that were assessed included: coral, dead coral with turf algae, macroalgae, sponges, gorgonians, and non-living substrata (sand, sediment, rubble, pavement). A total of 4,403 images were analyzed across the study.

Mean values for percent cover were calculated for each site and values were arcsine transformed prior to analysis. Data were tested for normality and homogeneity of variance. Data that met assumptions were analyzed with one-way ANOVA between benthic strata (algae, coral, pavement, non-living). Data that did not meet assumptions were tested with a non-parametric Wilcoxon test on rank sums. Significantly different means were analyzed post hoc with Tukey's HSD tests.

Coral Health

Scleractinian coral and hydrocoral colonies (all sizes) located directly under the transect lines were assessed in situ for signs of mortality and disease following a modified Atlantic and Gulf Rapid Reef Assessment protocol (AGRRA; Kramer et al. 2005). The line intercept method of coral health assessment provided a total coral sample size of 1,233 colonies for the study. Partial mortality of coral colonies was broken into the categories 'old partial mortality', skeleton eroded and covered with turf or macroalgae, and 'recent partial mortality', skeleton not eroded (fine corallite structure still intact) and bare or with a thin veneer of sheeting or filamentous algae. In the USVI, the transition between recent and old mortality categories usually occurs within three months following tissue death (Smith pers. obs.). In addition, old mortality becomes unrecognizable when the colony erodes into an amorphous form or a coral secretes new skeleton away from the dead surface. At this point it difficult to discern if a new coral has settled on a dead colony and sheeted, or if a surviving portion of a partially dead colony has resheeted. This transition takes place between 1 – 4 years after the initial mortality (Smith pers. obs.; also see http://www.agrra.org/method/methodcor.html). The surface area (%) of the colony that was dead was also estimated for each partial mortality category. Disease lesions and signs were categorized into recognized Caribbean scleractinian diseases and syndromes (e.g., white plague) following Bruckner 2007. In addition to recognized coral diseases, a novel coral disease was encountered across numerous sites and is referred to in this study as Unknown Necrosis. The severity of disease on coral colonies was estimated as the area (percent of colony) of active disease lesion.

Bleaching[1] was assessed as abnormal paling of the colony, and, when present, the severity of the bleaching (paling or total whitening) and the area of the colony affected were assessed. This data was used to ordinate bleaching intensity into one of five categories: 0) unbleached, 1) any degree of paling less than completely white, or 1% - 10% bleached, 2) 10% – 50% bleached, and 4) 50% – 90% bleached, and 4) >90% bleached (after Gleason 1993). For each transect at each location, the prevalence of colonies with mortality, bleaching, and disease was calculated by dividing the number of affected colonies by the total number of colonies assessed.

Fish and Other Commercially Important Motile Resources

Characterization of the fish community and motile invertebrates (primarily lobster) was conducted along 25 x 4 m belt transects used in the benthic habitat surveys. Within this belt transect all fish species and motile invertebrates were identified to species level and total length estimated in 5 cm and 10 cm size categories (i.e. <5, 6-10, 11-20, 21-30, 31-40, >40). Data from fish and motile invertebrate density, diversity and size distribution were analyzed using non-parametric statistics (because of non-normal distribution patterns) to test for differences among habitat strata within the MCD.

Detection of the less abundant and often more commercially valuable species may be limited using standard belt transects. Therefore, a timed swim (i.e. roving diver technique) was conducted at a subset of randomly selected sites in which two divers actively searched for rare, cryptic and highly mobile species as well as invertebrate mega-fauna. Divers remained within a single habitat type but indicated on their data sheet if searches included habitat edges (abrupt change from one habitat type to another) or gradual transitions. The duration of the timed swim was constant throughout the study across all sites and habitats and was determined based on appropriate dive times and safety protocol. During the timed swim the observer recorded to species and enumerated all fish and invertebrate mega-fauna encountered on a logarithmic scale (i.e. 1, 2-10, 11-100, 101-1000). Data for total fish diversity was obtained from roving dives in the MCD at four designated habitat types (algae, coral, pavement, sand) sampled during the MCD survey and at two fixed sites sampled from 2005-2007 (see Table 6). These two sites included the Red Hind Bank (RHB), a coral reef site located in the eastern end of the MCD, and Collage Shoal East (CSE), another coral site located in the western part of the MCD (Figure 1, lower panel).

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[1]Bleaching is presented separately from other disease due to differing assessment of severity.

RESULTS AND RECOMMENDATIONS

Benthic Composition

Benthic sampling revealed a unique array of habitat types ranging from topographically simple algal and sand planes to highly complex coral reef banks. Examples of these habitats are presented as photographs in Fig. 3 (A-D), in captured stills from video transects (Appendix II), as videos (Appendix Video Captures III) and as video mosaics (Appendix III). The benthic composition of sampling locations is presented as percent cover from video assessments in Fig 4 - 7.

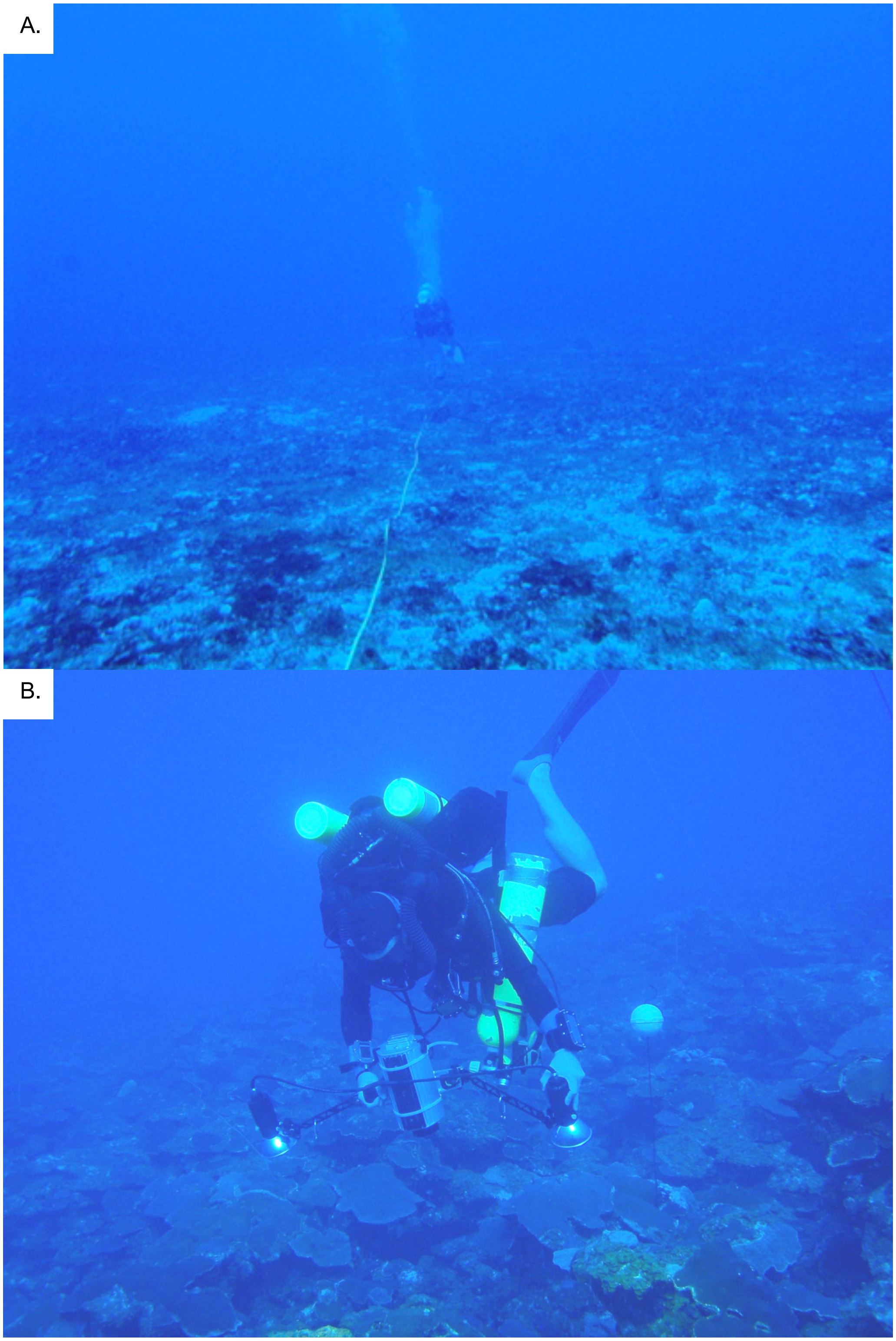

Figure 3. Representative photos of distinct habitat types sampled within the Marine Conservation District and Corresponding to A) Algae, B) Coral, (following page) C) Pavement, and D) Sand.

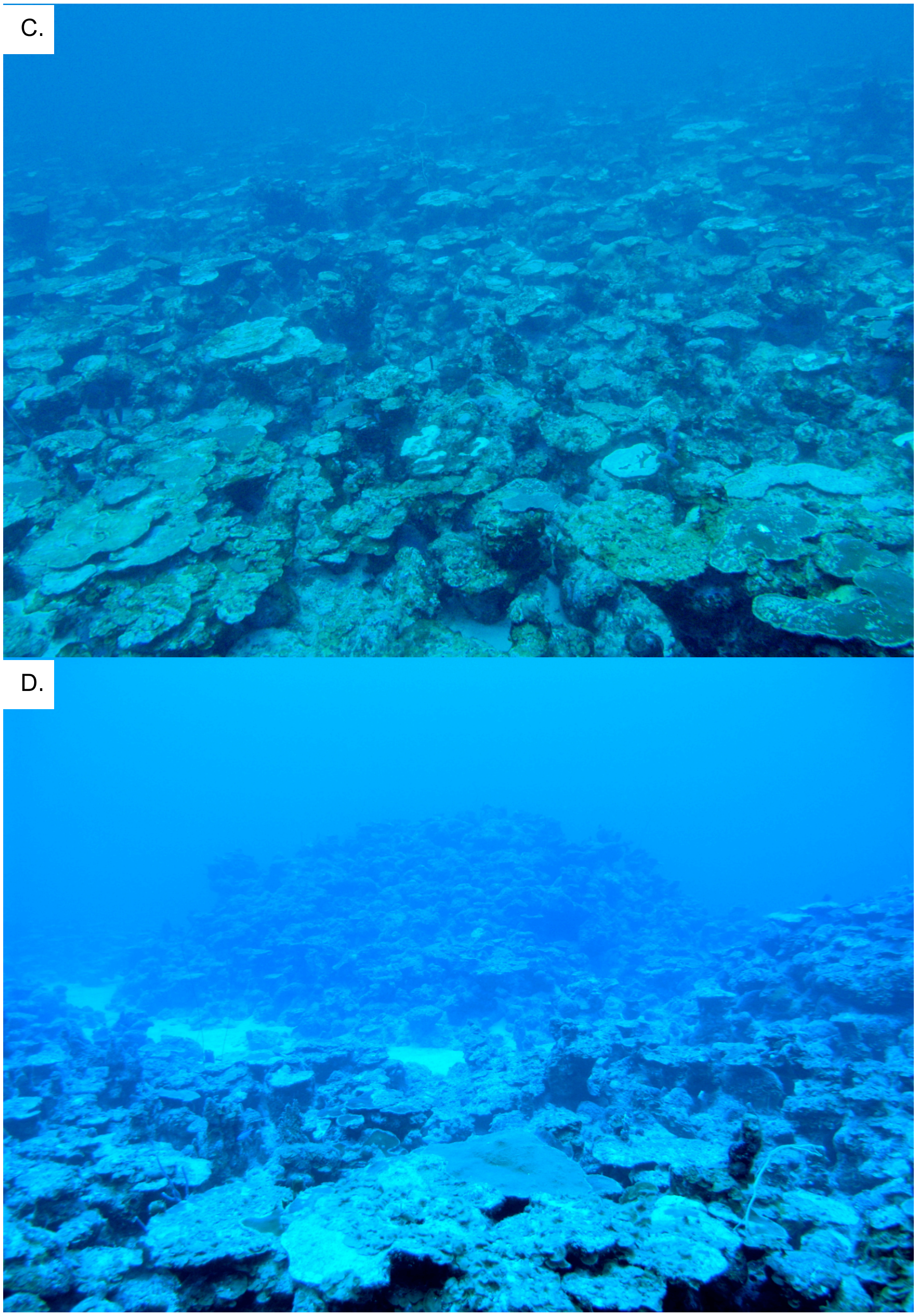

Figure 3. (continued)

Scleractinian Corals and Hydrocorals

Coral cover had a mean of 16.6% ± 1.9 SE and ranged from 0 to 50.1% across the MCD (Fig. 4A). For all locations that had coral cover greater than zero, coral cover had a mean of 20.7% ± 2.1 SE (N = 64). The dominant coral across the MCD were members of the *Montastraea annularis* species complex [*Montastraea annularis* (Ellis & Solander, 1786), *Montastraea faveolata* (Ellis and Solander, 1976), and *Montastraea franksi* Gregory, 1895)] and their coverage largely drove overall coral cover trends (Fig. 4B, Table 2). The cover of the *M. annularis* species complex across the MCD had a mean of 14.9% ± 1.8 SE and ranged from 0 to 48.1%.

In total, 20 scleractinian coral species or genera and one hydrocoral species were identified in video transects (Table 2). This estimate of scleractinian coral species richness was revised upwards to 25 from in situ coral health assessments that tended to include small coral species that were missed in video analysis and permitted a greater ability to separate rare genera into species (Table 3). At present, the number of known scleractinian coral and hydrocoral species for the MCD is 37 (Table 3), including one endangered or threatened species [*Acropora cervicornis* (Lamarck, 1816)].

Table 2. The ranked percent coverage and percent of total coral cover for scleractinian coral and hydrocoral species recorded in video surveys.

Species	**Benthic Coverage**	**Percent of Coral Cover**
Montastraea annularis species complex	14.81%	91.8%
Agaricia spp. (Lamarck, 1801)	0.47%	2.9%
Porites astreoides (Lamarck, 1816)	0.36%	2.3%
Agaricia agaricites (Linnaeus, 1758)	0.28%	1.7%
Montastraea cavernosa (Linnaeus, 1767)	0.21%	1.3%
Siderastrea siderea (Ellis and Solander, 1786)	0.08%	0.5%
Porites porites (Pallas, 1776)	0.05%	0.3%
Stephanocoenia intersepta (Lamarck, 1816)	0.04%	0.2%
Diploria labyrinthiformis (Linnaeus, 1758)	0.02%	0.1%
Mycetophyllia spp. (Milne Edwards and Haime, 1848)	0.02%	0.1%
Madracis formosa (Wells, 1973)	0.01%	0.1%
Colpophyllia natans (Houttyn, 1772)	0.01%	0.1%
Siderastrea radians (Pallas, 1766)	0.01%	0.1%
Diploria strigosa (Dana, 1848)	0.01%	0.1%
Madracis decactis (Lyman, 1859)	0.01%	0.1%
Agaricia undata (Ellis & Solander, 1786)	0.01%	0.04%
Millepora alcicornis (Linnaeus, 1758)	0.01%	0.03%
Mycetophyllia aliciae (Wells, 1973)	0.01%	0.03%
Manicina areolata (Linnaeus, 1758)	0.004%	0.02%
Mycetophyllia ferox (Wells, 1973)	0.003%	0.02%
Eusmilia fastigiata (Pallas, 1766)	0.002%	0.01%

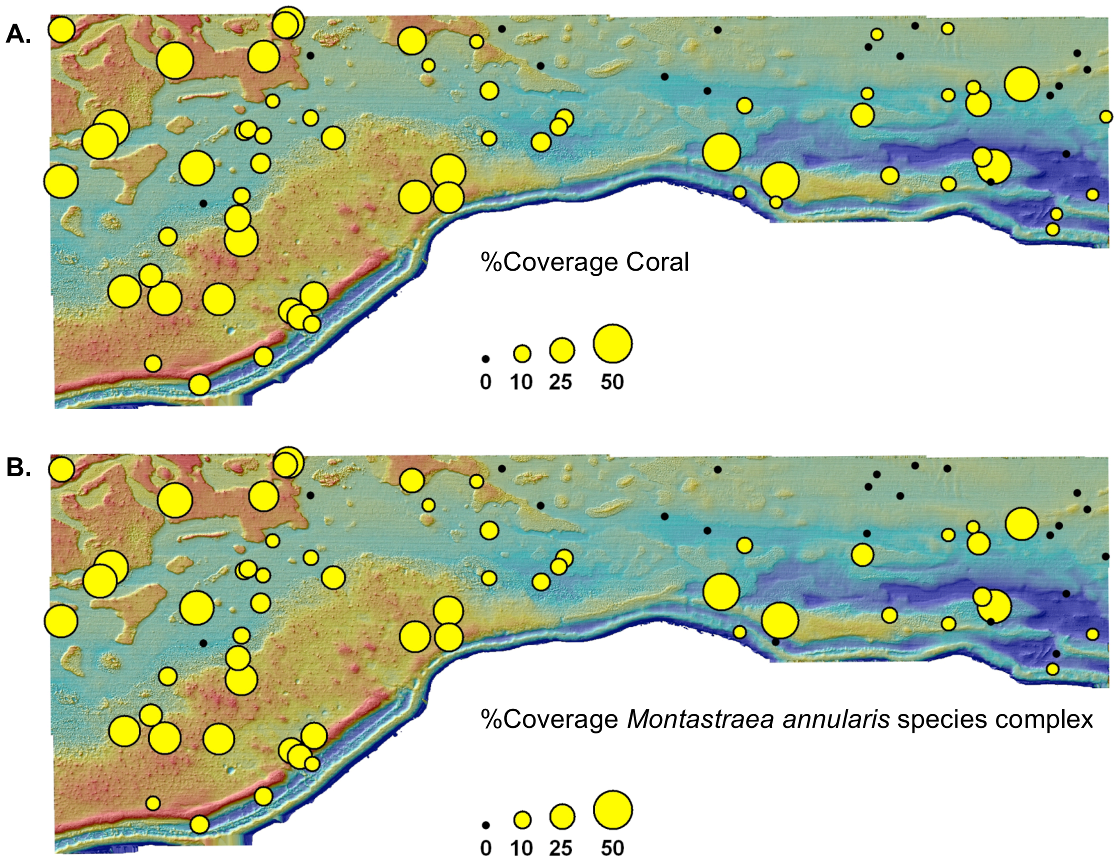

Figure 4. Percent coverage of A) all coral species and B) *Montastraea annularis* species complex in the Marine Conservation District.

Table 3. A list of known scleractinian coral and hydrocoral species found within the Marine Conservation District. "X" indicates that the coral was found in this study and/or in the Territorial Coral Reef Monitoring Program. "o" indicates that these species were likely encountered in this study, but could not be distinguished in the field.

Species	Found in Present Study	Found in TCRMP
Acropora cervicornis		X
Agaricia agaricites	X	X
Agaricia fragilis Dana, 1848		X
Agaricia grahamae Wells, 1973	o	X
Agaricia humilis Verrill, 1901		X
Agaricia lamarcki Milne Edwards and Haime, 1851	o	X
Agaricia undata	X	
Colpophyllia natans	X	X
Dichocoenia stokesii Milne Edwards and Haime, 1851		X
Diploria labyrithiformis	X	X
Diploria strigosa (Dana, 1848)	X	X
Eusmilia fastigiata	X	X
Isophyllia sinuosa (Ellis & Solander, 1786)		X
Helioseris cucullata (Ellis & Solander, 1786)	X	
Madracis decactis	X	X
Madracis formosa	X	X
Madracis mirabilis (Duchassaing & Michelotti, 1860)		X
Mancinia aerolata	X	
Meandrina meandrites (Linnaeus, 1767)		X
Montastraea annularis	X	X
Montastraea cavernosa	X	X
Montastraea faveolata	X	X
Montastraea franksi	X	X
Millepora alcicornis	X	X
Millepora complanata Lamarck, 1816		X
Mycetophyllia ferox	X	
Mycetophyllia aliciae	X	
Mycetophyllia danaana Milne Edwards and Haime, 1848		X
Mycetophyllia lamarckiana Milne Edwards and Haime, 1851		X
Oculina diffusa Lamarck, 1816		X
Porites astreoides	X	X
Porites divaricata Lesueur, 1821	X	
Porites porites	X	X
Scolymia spp. Haime, 1852	X	
Siderestrea siderea	X	X
Siderestrea radians	X	
Stephanocoenia intercepta	X	

Gorgonians and Sponges

Gorgonians and sponges were minor constituents of the benthos of the MCD, and separately averaged less than 1% of benthic coverage (Fig. 5). The coverage of soft corals had a mean of 0.1% ± 0.02 SE and ranged from 0 to 1.1%. The coverage of sponges had a mean of 0.7% ± 0.1 SE and ranged from 0 to 3.9%.

Although species-level discrimination of soft corals and sponges was not attempted from video transects, observations suggested that diversity within these groups was high and included rare and commercially important shallow water types, such as antipatharians (black coral). Soft coral and sponge diversity can be more accurately assessed with surveys that directly target these groups, use methods to determine area-based density, and attempt in situ species level categorization.

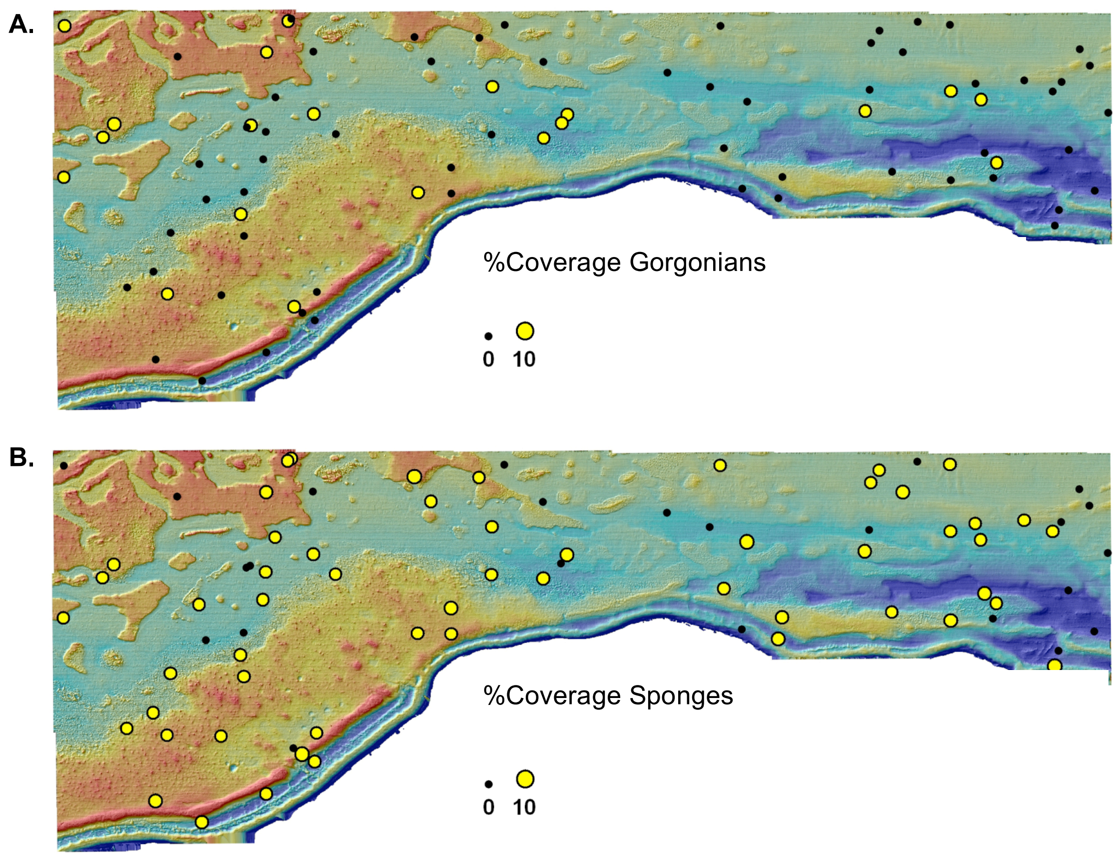

Figure 5. Percent coverage of A) gorgonians and B) sponges in the Marine Conservation District.

Algae

Algae covered the majority of the substrata for most sites in the MCD. Algal cover had a mean of 61.6% ± 1.7 SE and ranged from 0 to 94.8% across the MCD. The majority of algal cover consisted of macroalgae and large filamentous cyanobacteria, and had a mean coverage of 38.6 ± 2.3 SE and ranged from 0 to 93.3% (Fig. 6A). Over half of macroalgae and filamentous cyanobacteria were composed of the filamentous cyanobacteria *Schizothrix* spp. (mean = 11.7% ± 1.9 SE, range: 0 to 70.5%; Fig. 6B) and the phaeophyte *Lobophora variegata* (mean = 9.7% ± 1.0 SE, range: 0 to 30.1%; Fig. 6C). A minor component of macroalgae was composed of *Dictyota* spp., (mean = 0.5% ± 0.1 SE; Fig. 6D). Dead coral covered with turf algae comprised the second most important category of algae and had a mean of 18.9% ± 1.8 SE and ranged from 0 to 64.7% (Fig. 6E). Crustose coralline algae formed a relatively minor component of the benthic algal cover and had a mean of 4.1% ± 0.5 SE and ranged from 0 to 16.7% (Fig 6F).

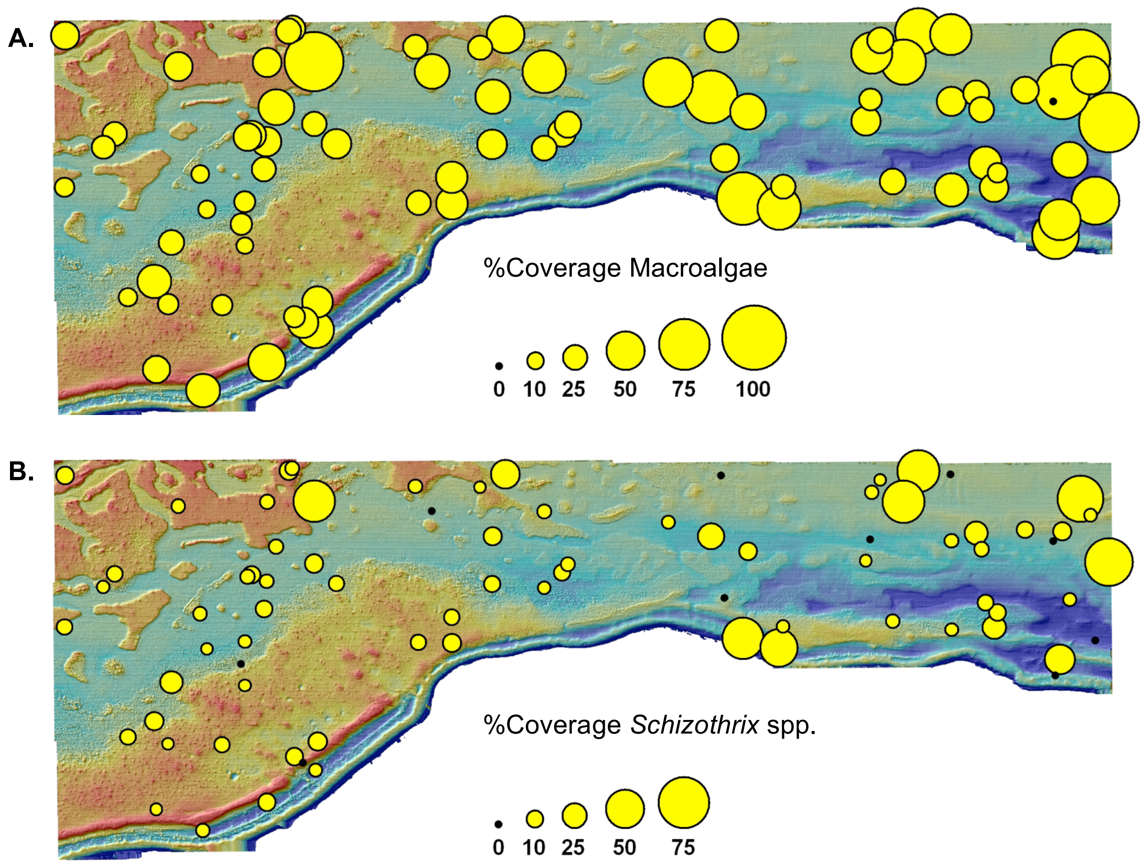

Figure 6. Percent coverage of A) macroalgae, B) *Schizothrix* spp., (following pages) C) *Lobophora variegata*, D) *Dictyota* spp., E) dead coral covered with turf algae, and F) crustose coralline algae in the Marine Conservation District.

C.

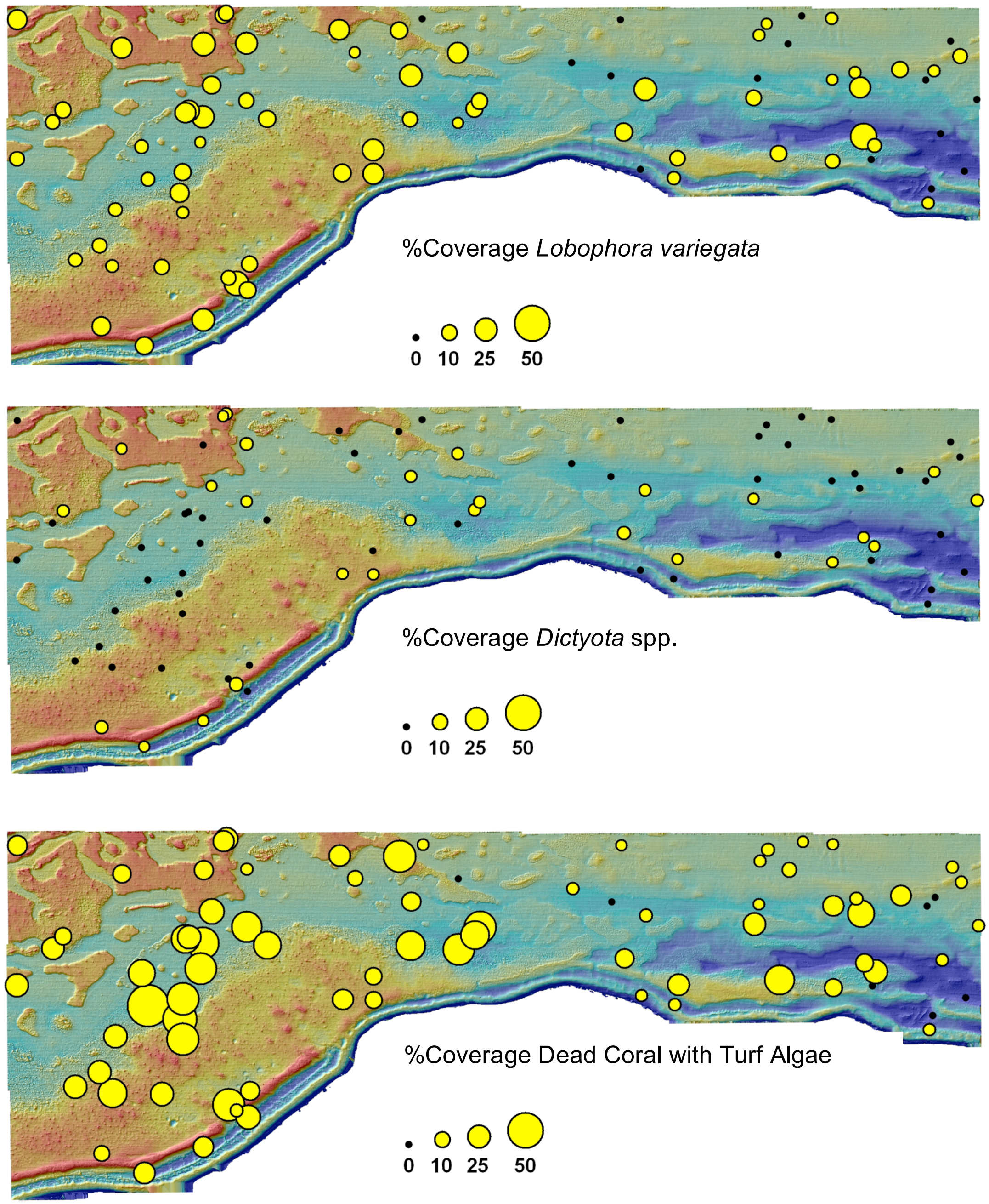

Figure 6. (continued)

F.

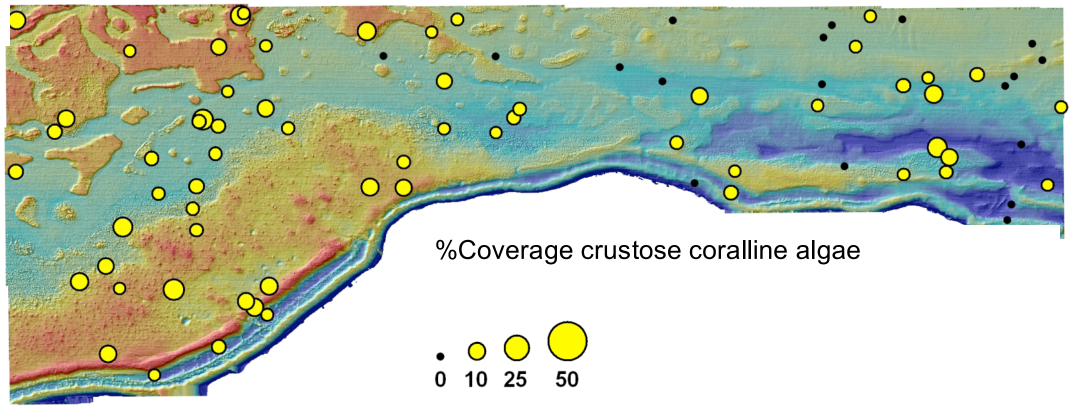

Figure 6. (continued)

Non-living Benthic Cover

Non-living benthic substrata formed the third highest benthic coverage category after algae and corals, and had a mean of 20.8% ± 2.3 SE and ranged from 0 to 97.5% (Fig. 7A). The majority of non-living substrata was composed of sand/sediment, and had a mean coverage of 15.7% ± 2.2 SE and ranged from 0 to 97.2% (Fig. 7B). Pavement formed the second highest portion of non-living substrata, and pavement had a mean coverage of 3.1% ± 0.6 SE and ranged from 0 to 27.5% (Fig. 7C). Coral rubble formed the third highest portion of non-living substrata, and had a mean coverage of 2.1% ± 0.7 SE and ranged from 0 to 38.5% (Fig 7D).

A.

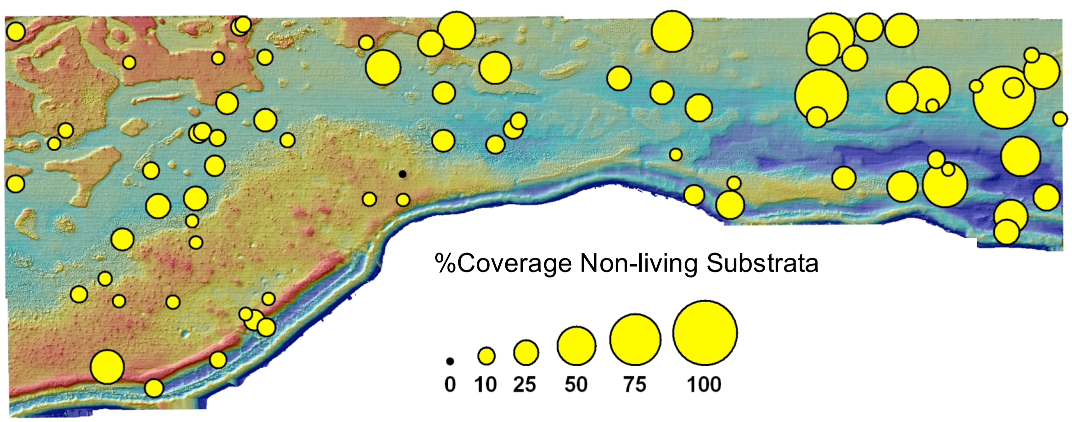

Figure 7. Percent coverage of A) all non-living substrata, (following page) B) sand/sediment, C) pavement, and D) rubble in the Marine Conservation District.

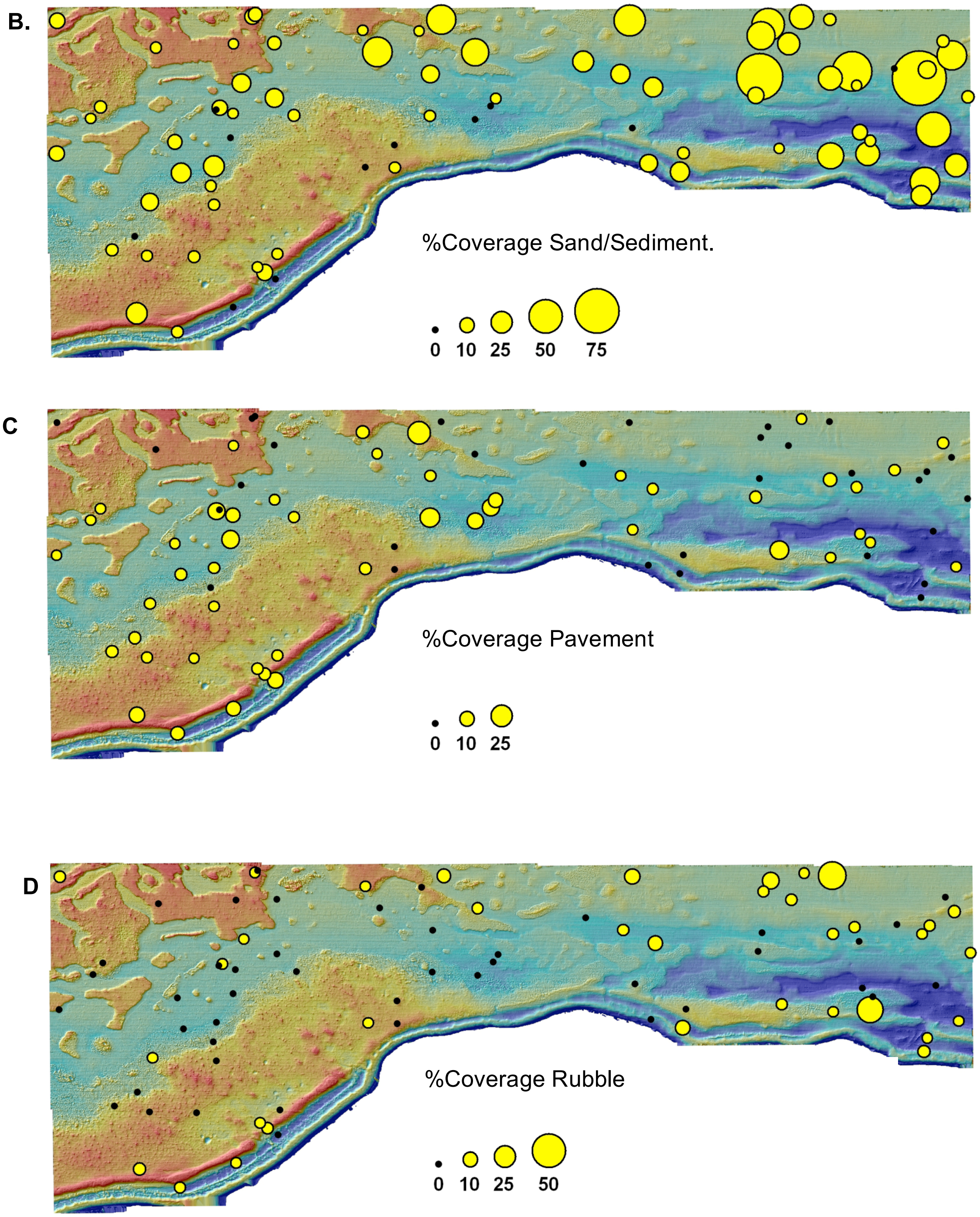

Figure 7. (continued)

Benthic Composition by Sampling Strata

The four predicted benthic strata used to stratify sampling effort had different characteristics for many of the examined variables. Depth was significantly different between strata ($F = 8.5$, $p < 0.0001$, $N = 80$), with the coral stratum significantly shallower than all other strata, which were not different from each other (Fig. 8).

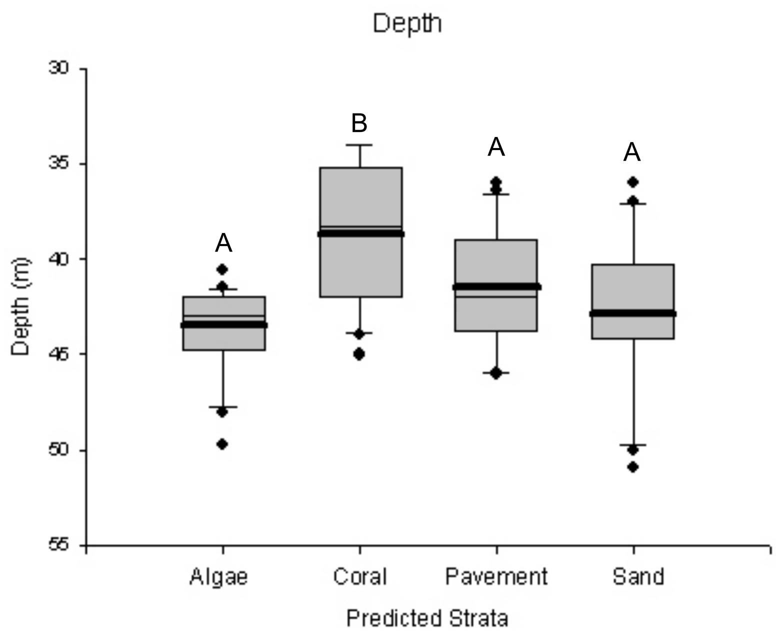

Figure 8. Depths of sampling locations among four predicted strata of the Marine Conservation District. Figure components are mean (thick black line), median (thin black line), 25th and 75th percentiles (bottom and top of box, respectively), 10th and 90th percentiles (bottom and top whiskers, respectively) and values outside 10th and 90th percentile (dots). Homogeneous subsets of means are indicated with letters.

Benthic Epifauna

Coral coverage was significantly different between strata ($\chi^2 = 55.1$, $p < 0.0001$). The coral stratum had significantly higher coral coverage than all other strata (nearly double), with the pavement and sand strata not significantly different from each other, but higher than the algae stratum, which was nearly zero (Fig. 9). Gorgonian coverage was significantly different between strata ($\chi^2 = 17.8$, $p < 0.0005$), and was highest in the coral and pavement strata, and over an order of magnitude less in the sand and algae strata (Fig. 9). However, pavement was not significantly different than the higher coverage coral stratum or the lower coverage sand and algae strata. Sponge coverage was significantly different between strata ($\chi^2 = 16.0$, p

< 0.0012), but gradually declined from the coral stratum, to the pavement and sand strata, and finally to the algae strata (Fig. 9). Only the coral and algae strata were significantly different from each other.

Algae

Algae coverage was significantly different between strata ($\chi^2 = 16.7$, $p < 0.0008$). The coral stratum had significantly less algal cover than all other strata, which were not significantly different from each other (Fig. 10). The cover of macroalgae was significantly different between strata ($\chi^2 = 22.3$, $p < 0.0001$). The coral stratum had the least cover of macroalgae and was significantly different from the algae stratum, which had the highest macroalgae cover (Fig. 10). Coverage of macroalgae in the sand and pavement strata was intermediate between the coral and algae strata. Sub-categories of macroalgae cover were only significantly different for *L. variegata* ($F = 9.4$, $p < 0.0001$). The coverage of *L. variegata* was highest in the coral and pavement strata, which were not significantly different from each other (Fig 10). Coverage of *L. variegata* was least in the algae stratum, and intermediate in the sand stratum. Other sub-categories of macroalgae cover were not significantly different between strata, and included *Schizothrix* spp. ($\chi^2 = 2.7$, $p = 0.438$) and *Dictyota* spp. ($F = 2.0$, $p = 0.122$). The remaining two categories of algal cover did show differences between strata. Dead coral covered with turf algae was significantly different between strata ($\chi^2 = 38.4$, $p < 0.0001$). The coverage of dead coral covered with turf algae was significantly lower in the algae stratum than all other strata, and was an order of magnitude less in the algae stratum than in the other strata (Fig. 11). The coverage of dead coral covered with turf algae was not significantly different between the coral, pavement, and sand strata. Crustose coralline algae coverage was significantly different between strata ($\chi^2 = 32.0$, $p < 0.0001$). The coral and the pavement strata had the highest coverage of crustose coralline algae and were not significantly different from each other (Fig. 11). The coral and pavement strata had coverage of crustose coralline algae that were significantly greater than the algae stratum, but not the sand stratum, which was intermediate between the coral and pavement strata, and the algae stratum.

Non-living Benthic Composition

Non-living benthic coverage was significantly different between strata ($\chi^2 = 35.5$, $p < 0.0001$). Non-living benthic coverage was significantly greater in the algae stratum than all other strata, which were not significantly different from each other (Fig. 12). Sand/sediment, the dominant component of non-living strata (see Benthic Composition Section), was significantly different between strata ($\chi^2 = 37.3$, $p < 0.0001$). Sand/sediment coverage was significantly greater in the algae stratum than all other strata, which were not significantly different from each other (Fig. 12). Pavement coverage was significantly different between strata ($\chi^2 = 22.8$, $p < 0.0001$). Pavement coverage in the pavement stratum was significantly greater than the algae and sand strata, which were not significantly different from each other (Fig. 12). Pavement coverage in the coral stratum was intermediate between the other strata. Rubble coverage was not significantly different between strata ($F = 1.9$, $p = 0.132$; Fig. 12).

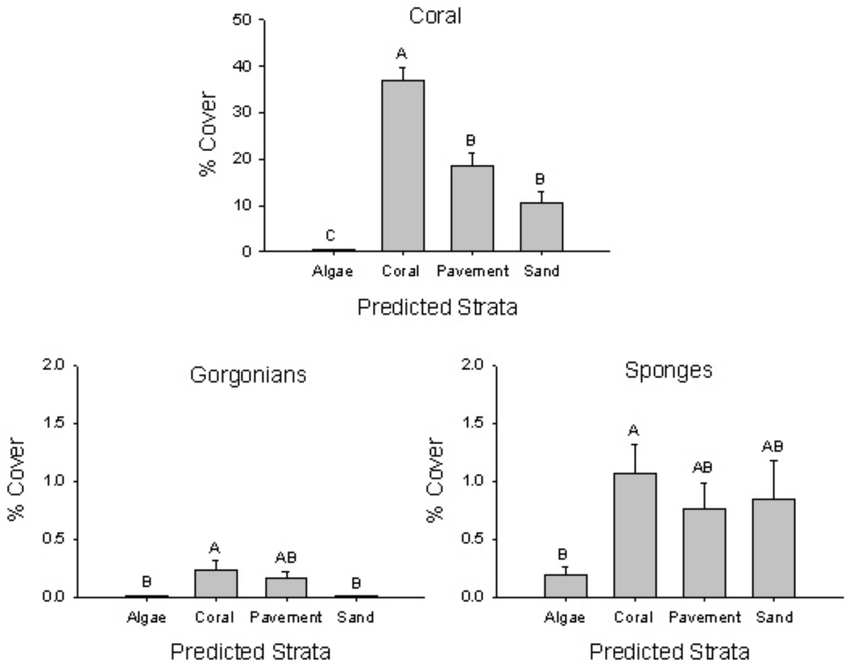

Figure 9. The percent coverage (±SE) of the benthic fauna categories coral, gorgonians, and sponges among the predicted benthic strata (N = 80). Homogeneous subsets of means are indicated with letters (Tukey HSD Post Hoc comparison).

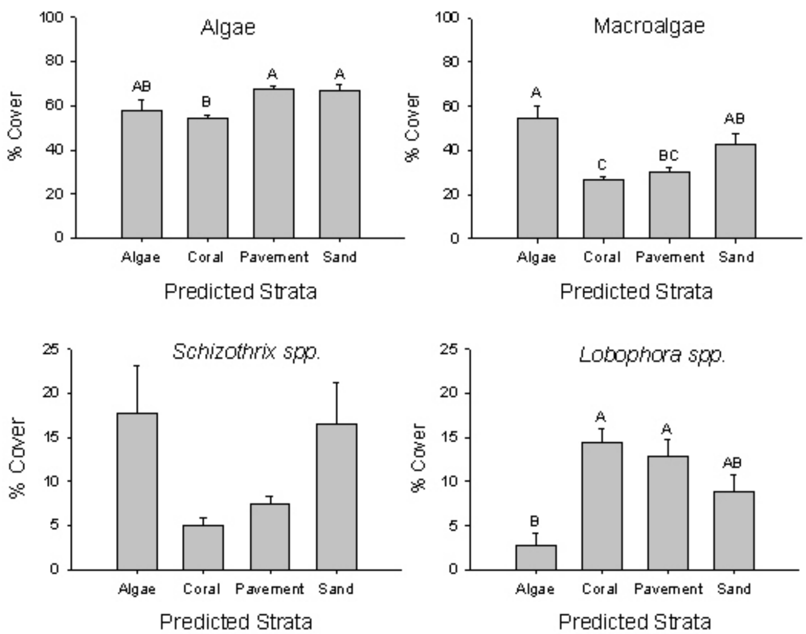

Figure 10. . The percent coverage (±SE) of the benthic algae categories total algae, total macroalgae, the filamentous cyanobacteria *Schizothrix* spp., and the phaephyte *Lobophora variegata* among the predicted benthic strata (N = 80). Homogeneous subsets of means are indicated with letters (Tukey HSD Post Hoc comparison).

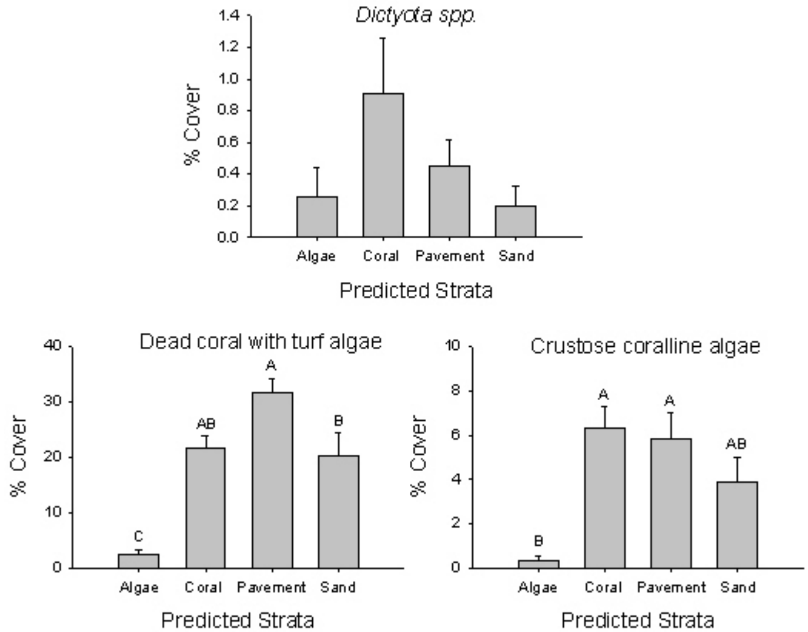

Figure 11. The percent coverage (±SE) of the benthic algae categories the phaephyte *Dictyota* spp., dead coral covered with turf algae, and crustose coralline algea among the predicted benthic strata (N = 80). Homogeneous subsets of means are indicated with letters (Tukey HSD Post Hoc comparison).

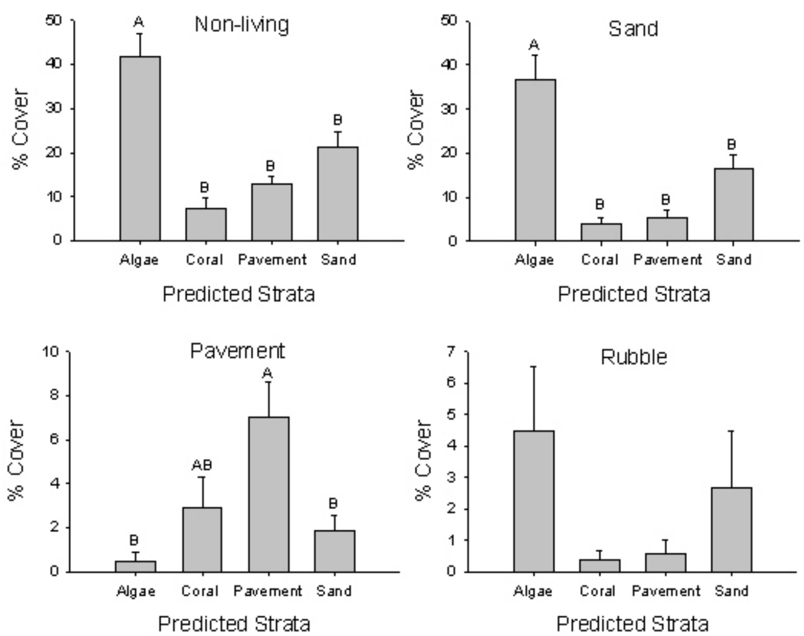

Figure 12. The percent coverage (±SE) of the abiotic benthic categories total non-living substrata, sand/sediment, pavement, and rubble among the predicted benthic strata (N = 80). Homogeneous subsets of means are indicated with letters (Tukey HSD Post Hoc comparison).

Predicted Versus Sampled Benthic Strata

The randomized stratified sampling design allows an assessment of the accuracy of multibeam and side-scan sonar benthic habitat characterization in the MCD. There was uncertainty in what proportionate coverage of various groups (e.g., macroalgae, pavement, coral) represented the four predicted benthic categories: algae, coral, pavement, sand. This makes it somewhat difficult to compare the results of this study with the predicted benthic habitat. However, it was assumed that large deviations from predicted habitat structure would indicate obvious areas requiring improvement in the benthic classification algorithms.

The percent composition of algae, coral, pavement, and sand strata are shown in Fig. 13. The predicted strata are broken into their constituent parts and represented as proportions of the total benthic coverage. In addition, the proportion of substrata that fell into hard substrata, soft substrata, or variable substrata is shown. Variable substrata are living benthic components (e.g., macroalgae, sponges) that are overlaying hard substrata (e.g., coral, dead coral with turf algae) or soft substrata (i.e., sand/sediment). Thus, their percent coverage could be representative of hard or soft substrata, but this was not determined from video records. Both in situ diver records and benthic cover reported in surveys deviate from predicted habitat types in many surveys. This problem was particularly evident in the pavement and sand strata. Each of the four predicted strata is assessed below:

<u>Algae</u>

The algae stratum was consistent and well predicted. Sites classified as algae were low relief algal communities atop unconsolidated sediment (Fig. 3A). Although 55% of the algae stratum had variable benthic composition, in situ observation strongly suggested that this largely overlaid unconsolidated sediment. Thus, about 92% of algae stratum was unconsolidated sediment, of which 55% was composed of macroalgae and filamentous cyanobacteria, and 37% was composed of sand/sediment. In these areas, expanses of unconsolidated sediment were broken by occasional coral colonies and dead coral rubble piles, and much less commonly by patch coral reefs and pavement. Site-attached fishes were often associated with these small habitat patches.

<u>Coral</u>

The coral stratum was consistent and well predicted. Sites classified as coral were medium to high relief coral reef. Although 28% of the coral stratum had variable benthic composition, in situ observation strongly suggested that this largely overlaid consolidated hardbottom. Thus, about 95% of the coral strata were composed of consolidated hardbottom, of which 38.7% ± 2.9 SE was composed of scleractinian corals.

This was unusually high coral cover compared to modern shallow Caribbean coral reefs (~10% coral cover; Gardener et al. 2003), and was particularly striking following coral mortality in shallow and deep coral reefs of the U.S. Caribbean following bleaching and disease in 2005 and 2006 (Smith et al. in prep.).

In situ observations also suggested that the coral stratum could be further divided into sub-types associated with edges, shallow coral bank tops (30-40 m), and deeper coral plains (35 – 45 m). In all cases the dominant matrix was formed of low or plating morphologies of the *M. annularis* species complex (Fig 3B, Appendix IV). Living upper surfaces of corals often rested upon pillars of dead coral, creating a complex interstitial network of overhangs, channels, and tunnels. This under-explored network may form a large habitat area that is likely to be an important component of essential fish habitat in the MCD.

<u>Pavement</u>

The pavement stratum was not well predicted. Sites classified as pavement were dominantly composed of coral reef that fell into the coral reef sub-categories of shallow coral reef bank tops, and deeper coral plains (see 'coral' section above). The pavement stratum had 31% variable benthic composition, and in situ observation suggested that this was largely composed of consolidated hardbottom. However, in the deeper coral plains there were patches of sand interspersed between coral pillars. Thus, for the shallower (30 – 37 m) coral reef bank tops found in the southwestern corner of the MCD (Fig. 2B), about 95% of the benthos was composed of consolidated hardbottom. In the deeper coral plains that ran as a channel through the center of the western MCD (Fig. 2B), there was higher variability in the variable substratum category, and it was estimated that consolidated hardbottom comprised about 80% of the benthos.

As with the coral stratum, the matrix of the pavement stratum was dominantly composed of low or plating morphologies of the *M. annularis* species complex (Fig 3C). Living upper surfaces of corals often rested upon pillars of dead coral, creating a complex interstitial network of overhangs, channels, and tunnels; however, this network was more open than in the coral strata, and had fewer tunnels. Corals of this stratum may undergo periodic mortality events that generate a more open network. Sampling in the pavement strata revealed a widespread and severe coral mortality event, particularly evident and general to the deeper coral plain (see 'Coral Health' section below).

<u>Sand</u>

The sand stratum was predicted to varying accuracy that depended on location in the MCD. Sites classified as sand were either sand/algae habitats or were coral reef. Accurately classified sand stratum sites were largely confined to the southeast corner of the MCD (Fig. 2B). In situ observations suggest that sand habitat classified outside the shelf edge coral reef banks at the south drop-off were largely soft bottom habitats to a depth of at least 65 m. The remainder of habitat classified as sand was formed in a complex area of coral pillars and hillocks interspersed with sand patches (Fig. 3D). This area comprised a large section of the western MCD, behind the primary and secondary shelf edge coral reef banks (Fig. 2B). The sand stratum had 44% variable benthic composition, and in situ observation suggested that in the majority of habitat in the western MCD this was composed of an equal mix of consolidated hardbottom and unconsolidated sediments. Thus, for the coral reef hillocks found in the southwestern corner of the MCD, approximately 60% of the benthos was composed of consolidated hardbottom, and the remaining 40% of unconsolidated sediments (i.e. sand/sediment)..

The majority of the sand stratum was comprised of coral hillocks that differed from the geomorphology of coral reefs in the coral and pavement strata. Instead of more horizontally uniform coral reef areas, the hillocks rose 2 to 7 m above the surrounding coral reef plain and were 5 to 15 in diameter (Fig. 3D). The hillocks and the surrounding reef was dominantly composed of low or plating morphologies of the *M. annularis* species complex. Living upper surfaces of corals often rested upon pillars of dead coral, creating a complex interstitial network of overhangs, channels, and tunnels; however, as in the pavement stratum, this network was more open than in the coral stratum, and had fewer tunnels.

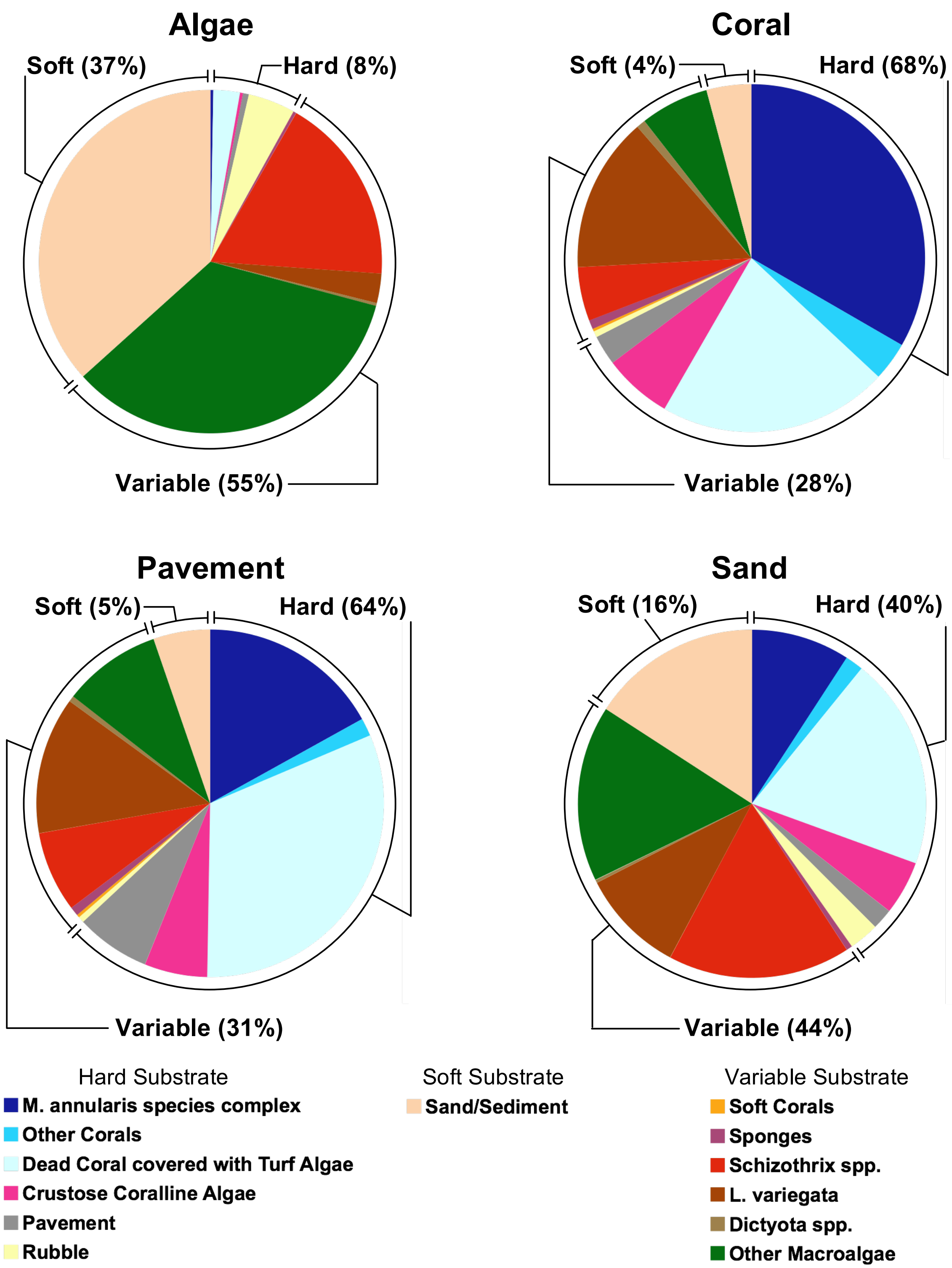

Figure 13. Proportionate benthic composition determined from in situ surveys across four general benthic strata determined from side-scan sonar processing: algae, coral, pavement, sand. In situ data within each benthic strata were apportioned into hard substrate, soft substrate, and variable substrate categories with proportion of total (%) in brackets.

Coral Health

Disease and Bleaching

Assessments of coral condition showed wide variations of coral health across sites and striking recent disease and degradation in a spatially coherent area of the MCD. Coral health was assessed on 1,233 colonies across 64 locations that contained coral within transects. Overall, coral disease (with the exception of bleaching) on coral colonies had a mean prevalence of 18.5% ± 0.03 SE and a mean severity (percent of colony affected) of 26.9% ± 3.9 SE (Fig. 14A). The vast majority of coral disease signs were caused by an unknown coral syndrome, named "unknown necrosis" (Fig. 14B). Unknown necrosis had a large mean prevalence of 17.4% ± 3.6 SE and mean severity of 32.8% ± 4.7 SE. This syndrome is described in further detail below. White Plague was the second most common disease, and had a mean prevalence of 0.8% ± 0.004 SE and a mean severity of 11.6% ± 3.2 SE (Fig. 14C). Bleaching had a mean prevalence of 12.4% ± 1.5 SE and a mean severity (ordinated levels) of 1.9% ± 0.1 SE (Fig. 14D). This severity most closely corresponds to level 2 bleaching: 10% – 50% coral colony bleached.

A.

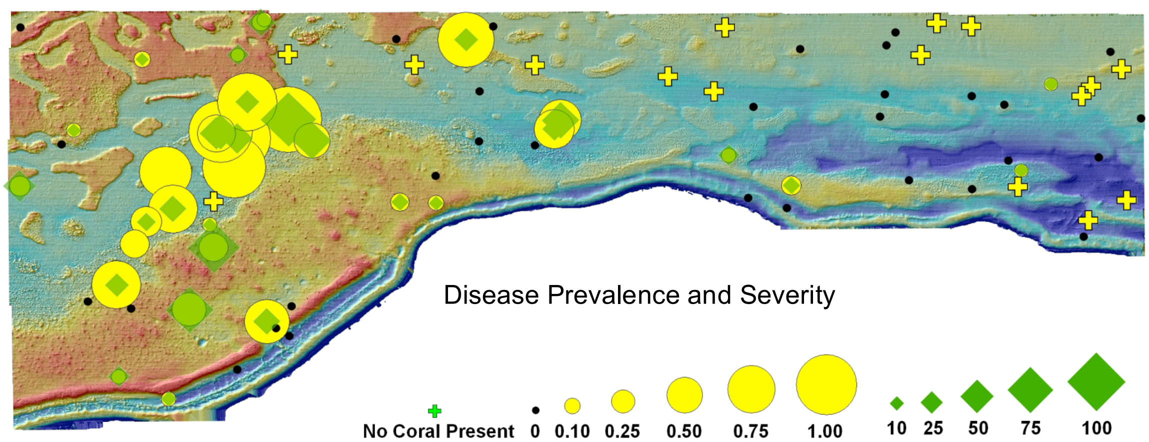

Figure 14. Prevalence and severity of A) total disease, (following page) B) unknown necrosis, C) white plague, and D) bleaching on hard corals of the Marine Conservation District.

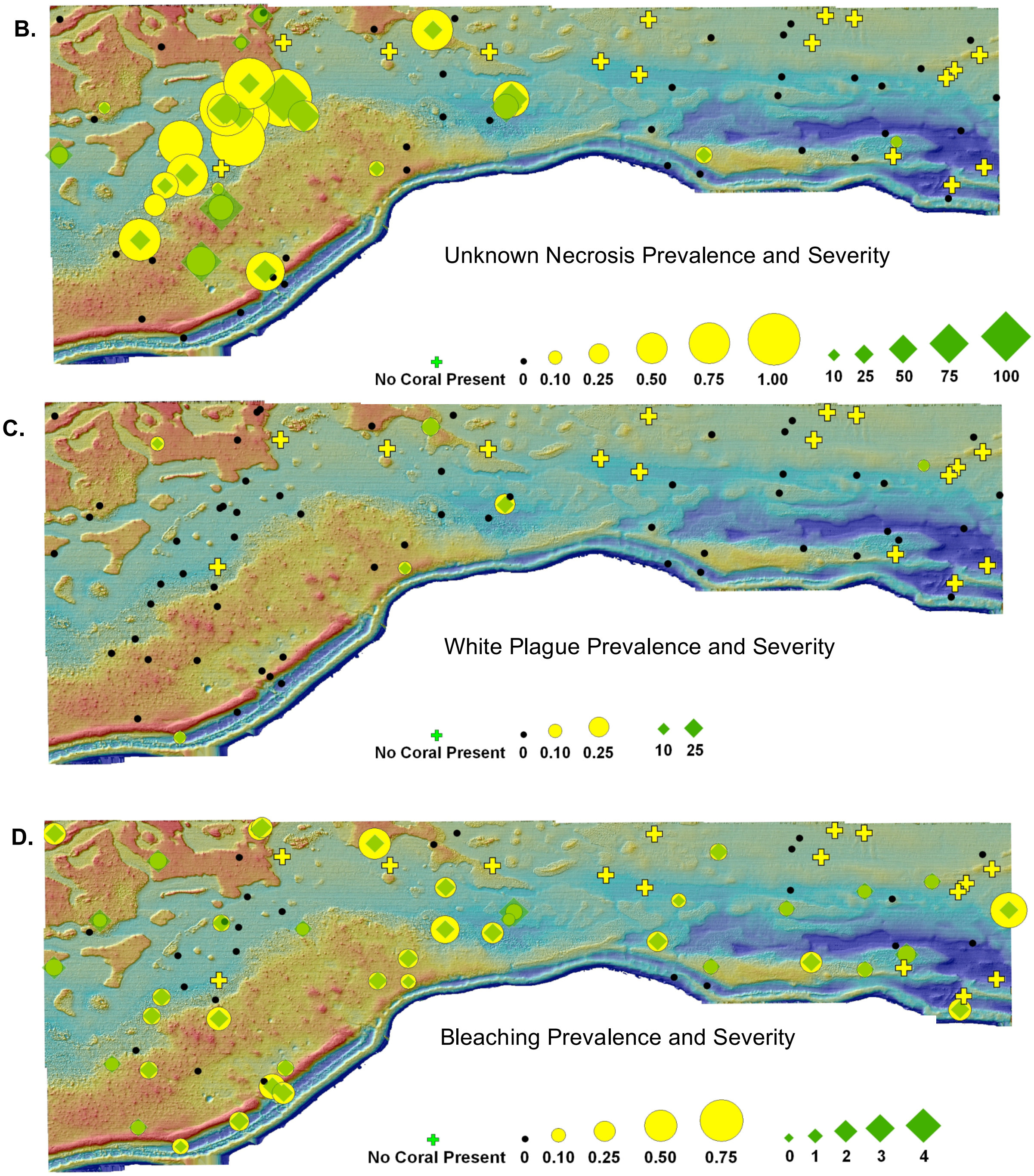

Figure 14. (continued)

Partial Mortality

Partial mortality of coral colonies was a common feature of coral reefs within the MCD. Recent partial mortality had mean prevalence of 30.6% ± 4.0 SE and mean severity of 22.7% ± 2.9 SE (Fig. 15A). The prevalence of recent partial mortality was strongly correlated with the prevalence of unknown necrosis ($R = 0.852$, $F = 171.1$, $p < 0.0001$). Old partial mortality had a mean prevalence of 65.0% ± 3.4 SE and a mean severity of 26.2% ± 1.8 SE (Fig. 15B). The prevalence of old partial mortality was a general characteristic of most coral harboring sites and was not significantly correlated with the prevalence of unknown necrosis ($R = 0.223$, $F = 3.4$, $p = 0.070$).

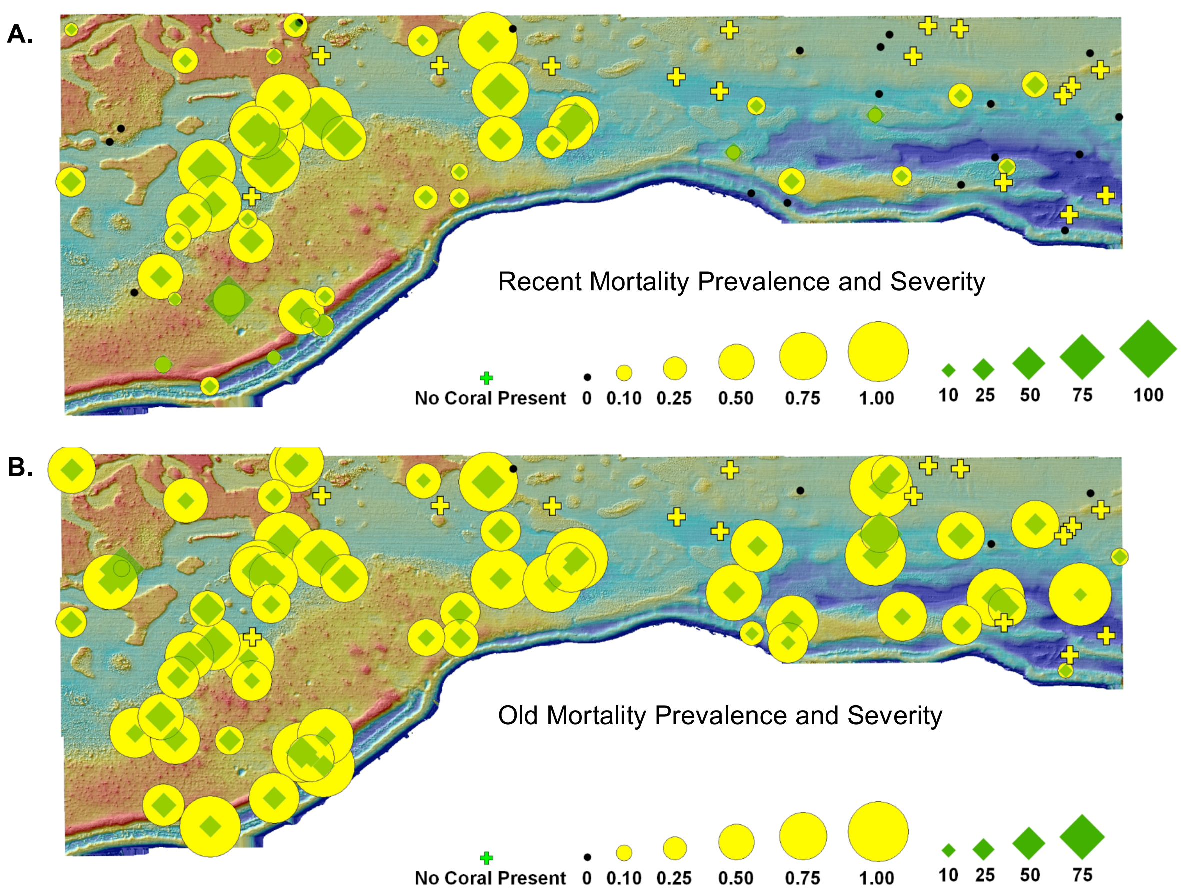

Figure 15. Prevalence and Severity of A) recent mortality, and B) old mortality on hard corals in the Marine Conservation District.

Unknown Necrosis

Coral disease sampling revealed an unusual, extensive, and dramatic syndrome affecting large numbers of coral. This unknown necrosis was manifested as white areas of tissue loss in a variable pattern. It was distinguished from white plague disease signs in that the areas of tissue loss were not present as a progressing linear lesion over colonies (Fig. 16). Instead, white areas of tissue necrosis appeared sporadically or generally over colonies. In members of the *M. annularis* species complex, presumably early stages of the disease primarily affected intercostal regions between the polyps (Fig. 17). These areas formed more general regions of necrosis in later stages of the disease (Fig. 18). Although the coral disease monitoring protocol was not longitudinal (individual colonies were not reassessed for pattern of disease progression), the progression of the disease was deduced from colonies displaying both sporadic intercostal necrosis and regional necrosis (Fig. 18). In coral species with meandering corallite structure (e.g., agariciids), signs of disease appeared as both tattered-appearing areas of necrosis and regional necrosis. Numerous colonies in affected areas were noticed that had recently suffered 100% mortality and 26 recently killed colonies were found in transects (2% prevalence). The disease was noted affecting three coral genera, however, prevalence was highest for the *M. annularis* species complex (Table 4).

Table 4. Species of scleractinian coral affected by unknown necrosis, and the prevalence, severity, and sample size among affected species in the Marine Conservation District.

Species	Prevalence	Severity	N
Agaricia agaricites	0.020	ND	49
Agaricia spp.	0.023	65%	86
Montastraea annularis species complex	0.203	40%	907
Siderastrea radians	0.167	50%	6
Siderastrea siderea	0.029	80%	35

Repeated observations and surveys of coral health in coral reefs affected by unknown necrosis suggested that that the disease peaked during earlier stages of sampling (October 2007) and had largely abated within three months. There was a high prevalence and severity of unknown necrosis in October 2007 and repeated observation after the start of 2008 revealed few cases of unknown necrosis. Furthermore, two locations sampled in October 2007 had a mean prevalence of unknown necrosis of 35.8%, but had no cases of unknown necrosis in January 2008. The abatement of unknown necrosis is also illustrated in the video mosaic image of location S166 recorded in January 2007 (Appendix IV – Sand 166). No visible signs of unknown necrosis are visible on this image, although unknown necrosis was present in October 2007.

The coral disease signs consistent with unknown necrosis were present over a large swath of the MCD. The occurrence of unknown necrosis on coral reefs was largely confined to the western-central area of the MCD in a basin behind the thin primary and wide secondary outer reef banks forming the southwestern corner of the MCD (see Fig. 14B). Observations and surveys of coral reefs adjacent to affected areas, but on topographic highs, such edges of reef banks or reef bank tops, showed that unknown necrosis was largely confined to the basin. The proximity of unaffected faunas and the spatial coherence of affected areas suggested that unknown necrosis was not being driven by a pathogen, but was a response to a common abiotic driver.

The effects and extent of unknown necrosis in the MCD suggest a strong structuring force of essential fish habitat (EFH) in this mesophotic reef system. The mean prevalence (42.4% ± 6.3 SE, N = 27) and severity (32.8% ± 4.6 SE) of unknown necrosis at affected sites suggested that the effects of the disease were intense in these areas. Extrapolation of the occurrence of unknown necrosis across the basin suggested that an area of approximately 9 km^2 was affected by the mortality event, over a fifth of the benthic habitat of the MCD shallower than 50m. While the driver of this disease and coral mortality were unknown, it is possible that cryptic mortality events are a recurrent and structuring force in these habitats. Importantly, the mass disease occurred outside of the two Territorial Coral Reef Monitoring Program sites maintained in the MCD. This mass disease and mortality event was captured opportunistically by coincidence with this research project to assess habitats and resources of the MCD. The occurrence, effects, and extent of large-scale mortality events in mesophotic reef systems may be an important consideration for EFH. The novel mass disease event presented in this research report should be an impetus for expanded and more intensive monitoring or coral health in mesophotic reefs.

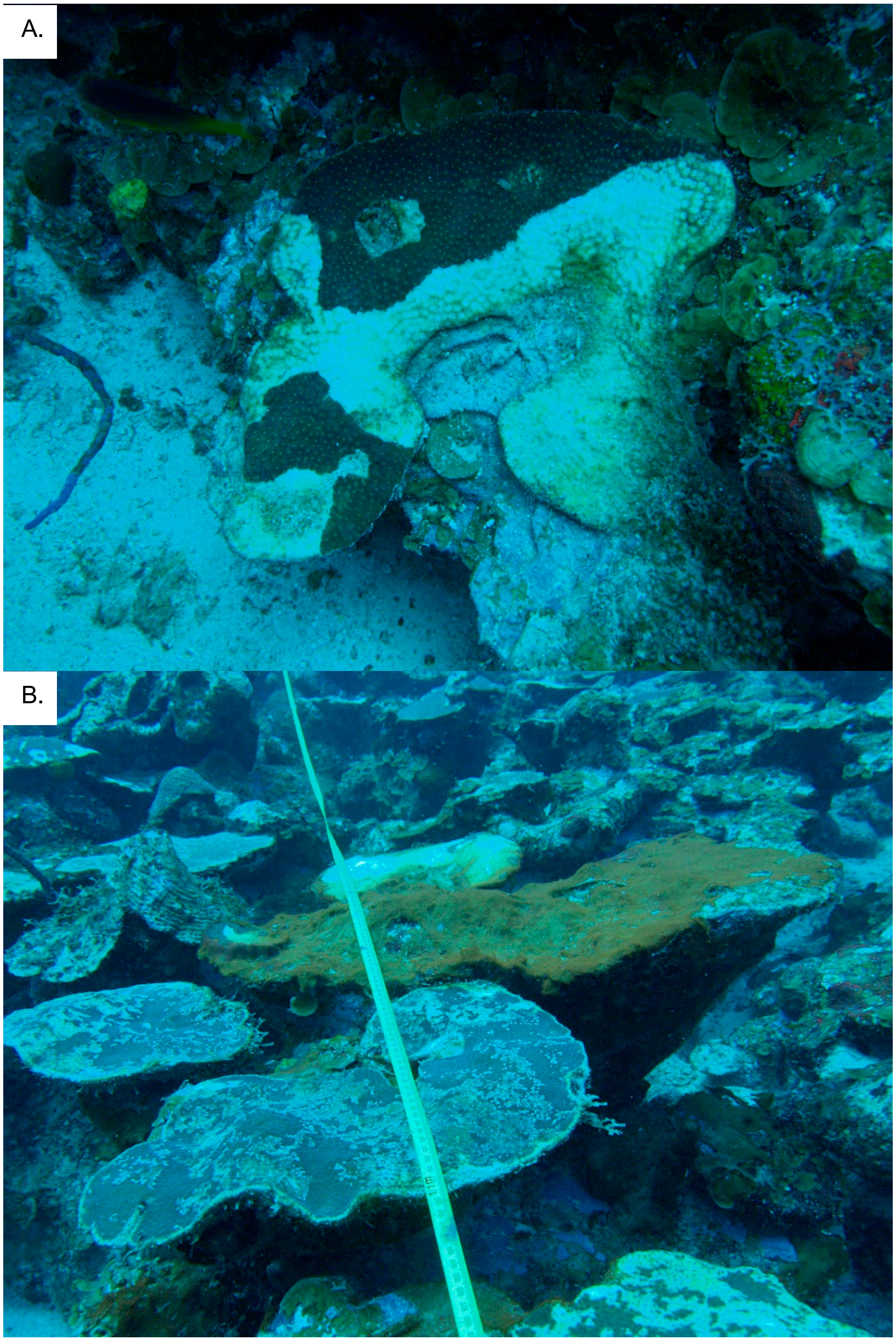

Figure 16. Photographic examples of coral disease in the Marine Conservation District: A) a coral colony affected by white plague (site: coral 58), B) corals affected by unknown necrosis. (site: Pavement 119, October 9, 2007).

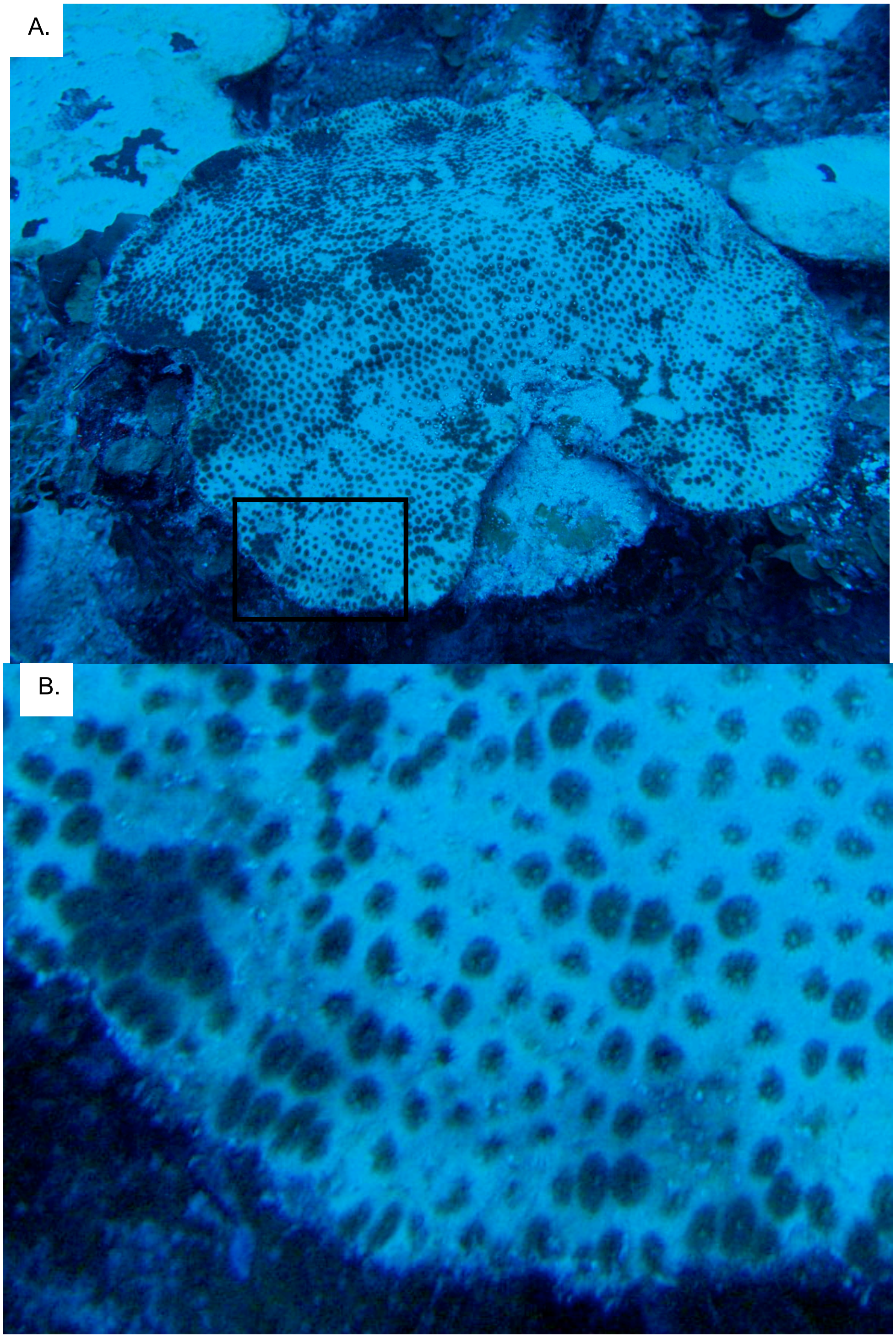

Figure 17. Photographic examples of coral disease in the Marine Conservation District: A) intecostal necrosis B) close-up of intercostal necrosis (site: pavement 111, October 29, 2007).

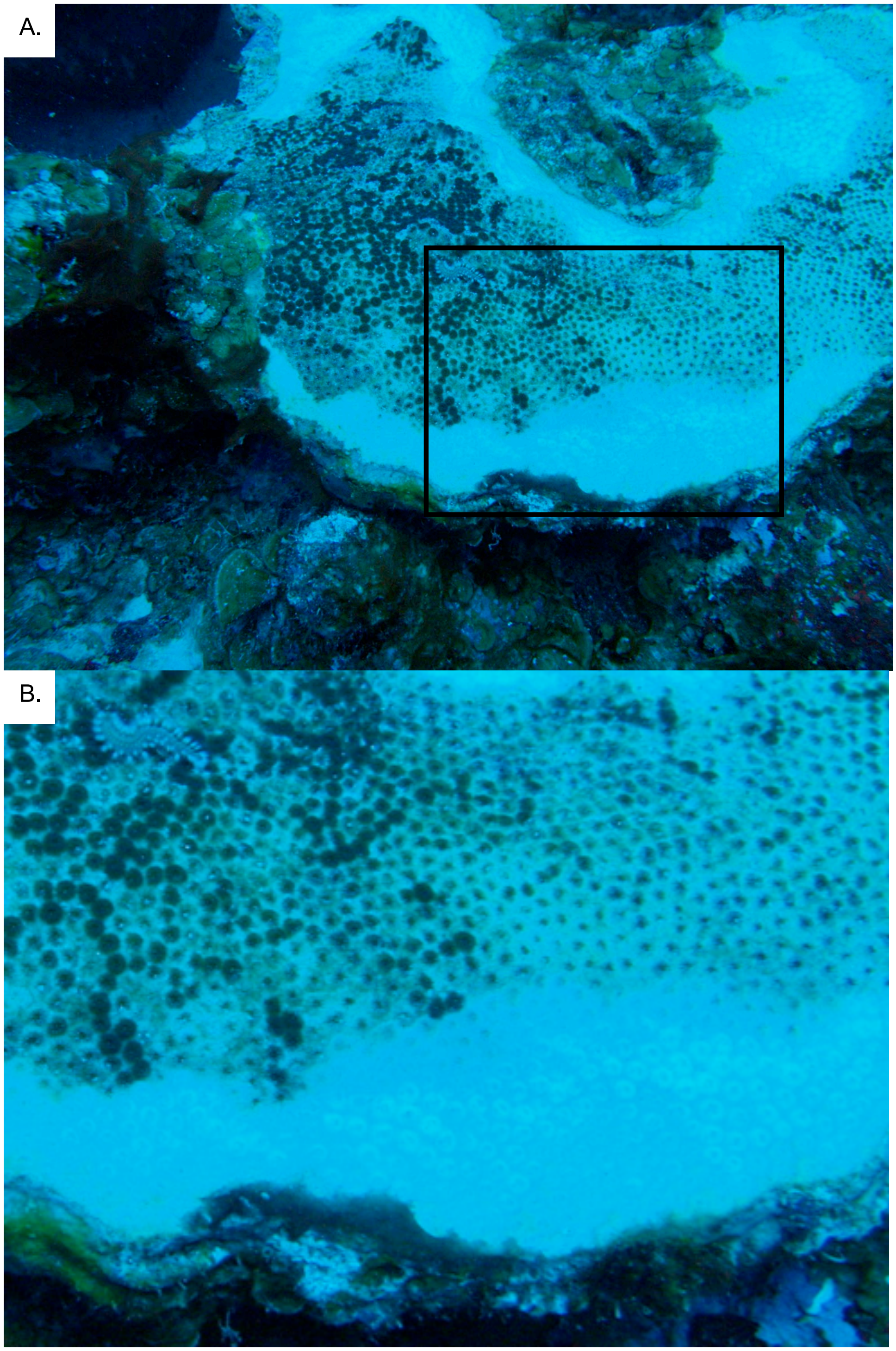

Figure 18. Photographic examples of coral disease in the Marine Conservation District: A) intercostals necrosis grading to general necrosis B) close-up of intercostal necrosis grading to general necrosis (site: pavement 111, October 9, 2007)

Assemblage Structure of Fish and Motile Mega-Invertebrates

The reef fish community structure at each sampling location in the Marine Conservation District is presented as density per 100 m^2 from belt transects. Motile mega-invertebrates were not observed in this study MCD.

Diversity, Abundance and Biomass of Reef Fishes

A total of 112 species were recorded throughout the MCD (see Table 6). Average fish species richness along belt transects was highest in coral habitats (mean = 14.4 100 m^{-2}, range = 6 to 25 spp), followed by sand habitats (mean = 12.6 spp 100 m^{-2}, range = 5 to 25 spp), pavement (mean = 11.5, spp 100 m^{-2}, range = 6 to 18 spp) and algal plains (mean = 6.0, spp 100 m^{-2}, range = 1 to 17 spp) (Fig. 19). Based on belt transects, Scarids showed the highest level of species richness followed by Serranids, Lutjanids and Haemulids (Fig. 20 A - D). Species richness was significantly lower in algal habitats ($p < 0.05$) than in the three other habitat types (i.e. coral, pavement and sand). The distribution of the most abundant species among the sampling strata is presented in Fig. 21.

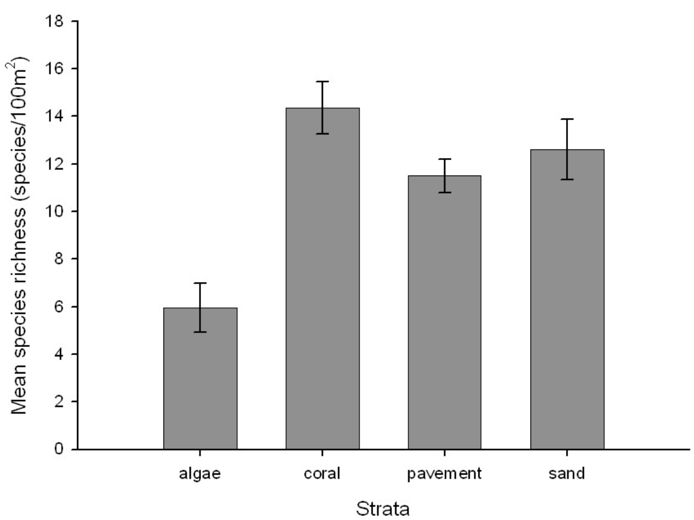

Figure 19. Mean species richness (±SE) for each habitat strata in the Marine Conservation District.

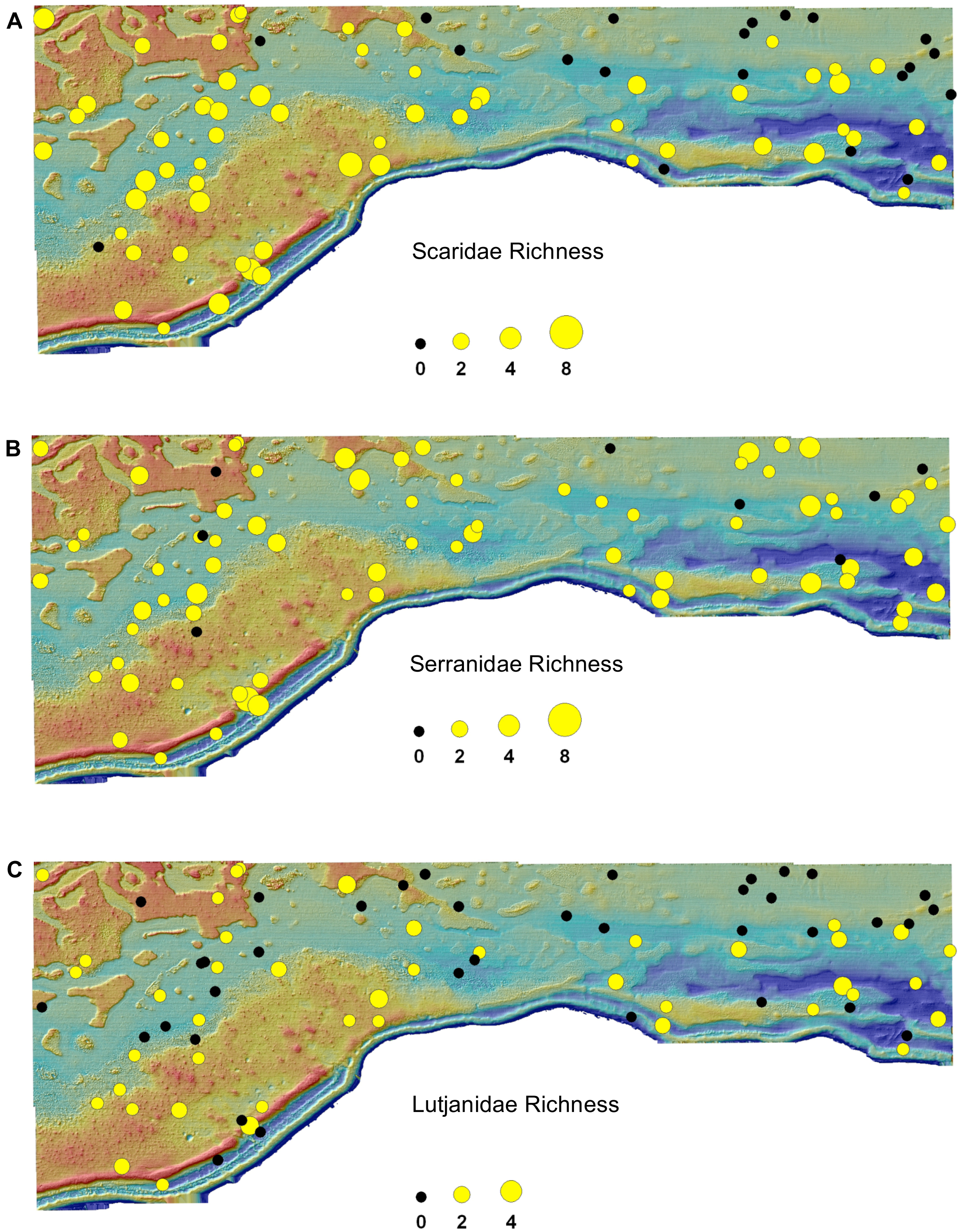

Figure 20. Family richness of A) Scaridae, B) Serranidae, C) Lutjanidae, and D) Haemulidae at each sampling location in the Marine Conservation District.

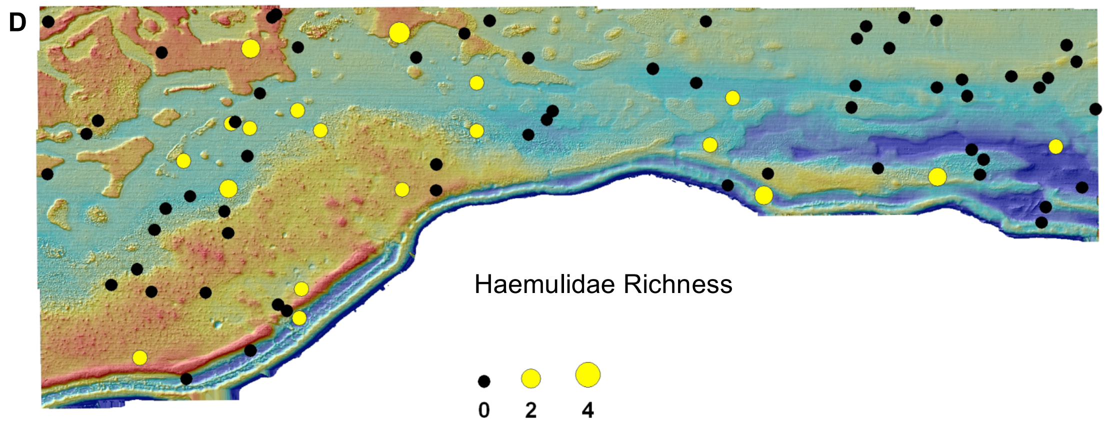

Figure 20. (continued)

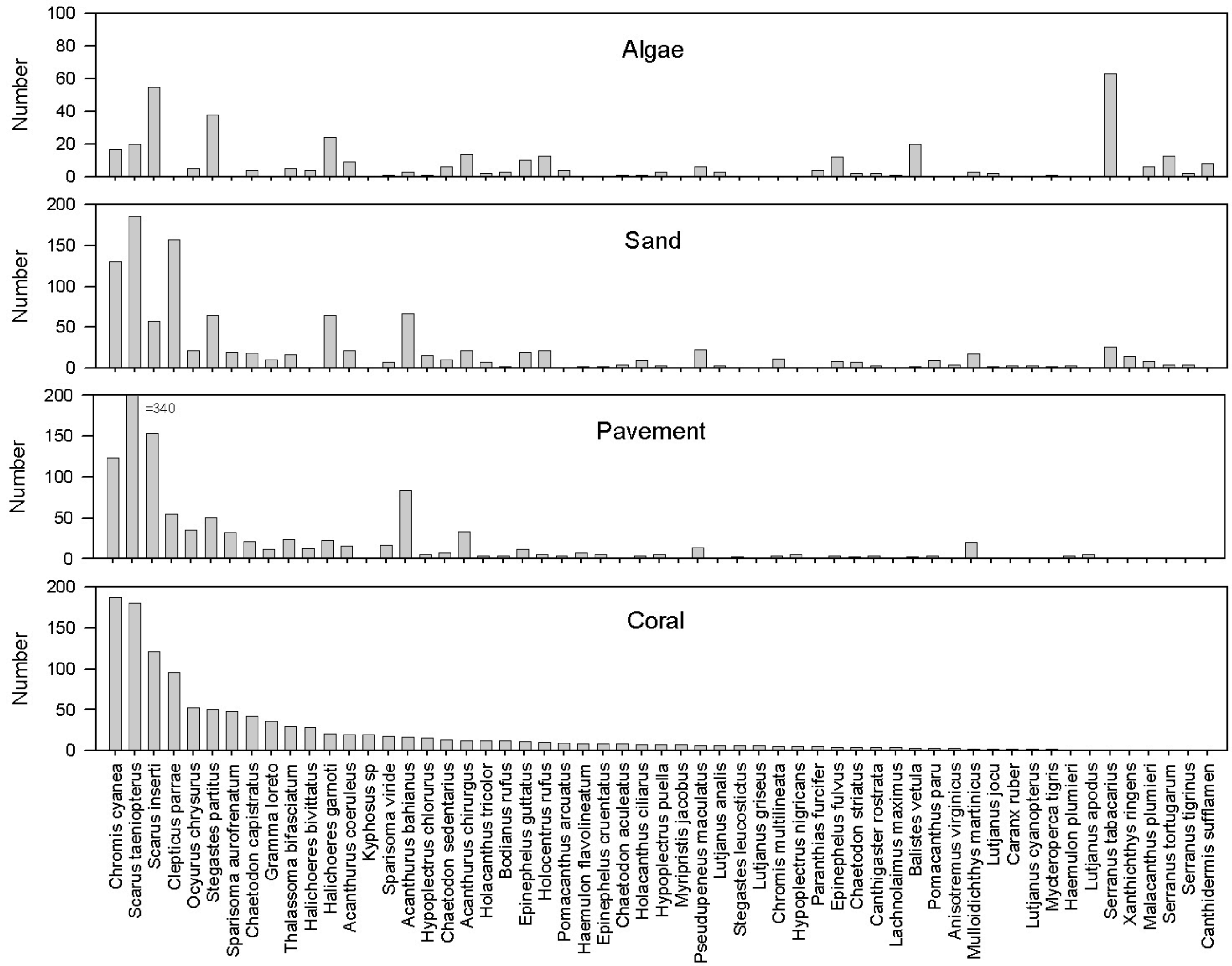

Figure 21. Total number of the most abundant species observed in belt transects in each habitat strata of the Marine Conservation District. Species were included if cumulative number in all habitats was ≥5 and then ordered from the most to least abundant from the coral habitat.

Abundance of reef fishes varied throughout the MCD depending upon taxa. Most commercially important species were commonly found in coral reefs and hard bottom habitats (Fig. 22), with higher concentrations near habitat edges and greater abundance near the shelf edge, but also along the northern and western MCD boundaries. Species with the highest abundances that were also of high economic and ecological importance were used to plot abundance distribution patterns. Acanthurids (*A. bahianus, A. coeruleus, A. chirurgus*) were fairly evenly distributed throughout the MCD with slightly lower abundances near the northern boundary of the closed area (Fig. 23A). The Scarids had similar distribution patterns as the Acanthrids (Fig. 23B) but were 4 times more abundant. Haemulids were uncommon within the MCD and were present at less than 25% of the 80 sampling locations (Fig. 23C). Serranid abundance was relatively evenly distributed across the MCD (Fig. 23D) and the group was largely composed of smaller species within the *Hypoplectrus* and *Serranus* genera (see Table 6). Lutjanids had a similar distribution as Haemulids, but were observed at just over 50% of the sampling sites (Fig. 23E). Balistids were more common on the eastern end of the MCD and were present at nearly 25% of the sites (Fig. 23F). The red hind (*Epinephelus guttatus*) was present at nearly 60% of all sites and had relatively high biomass levels (Fig. 24).

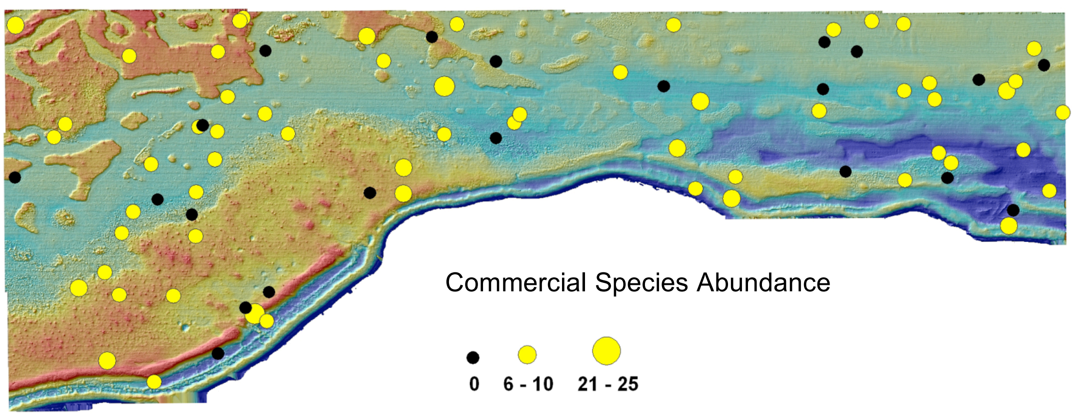

Figure 22. Abundance (ind. /100m²) of commercially important species (*E. guttatus, M. venenosa, E. striatus, L. analis, O. chrysurus and B. vetula*) at each sampling location in the Marine Conservation District.

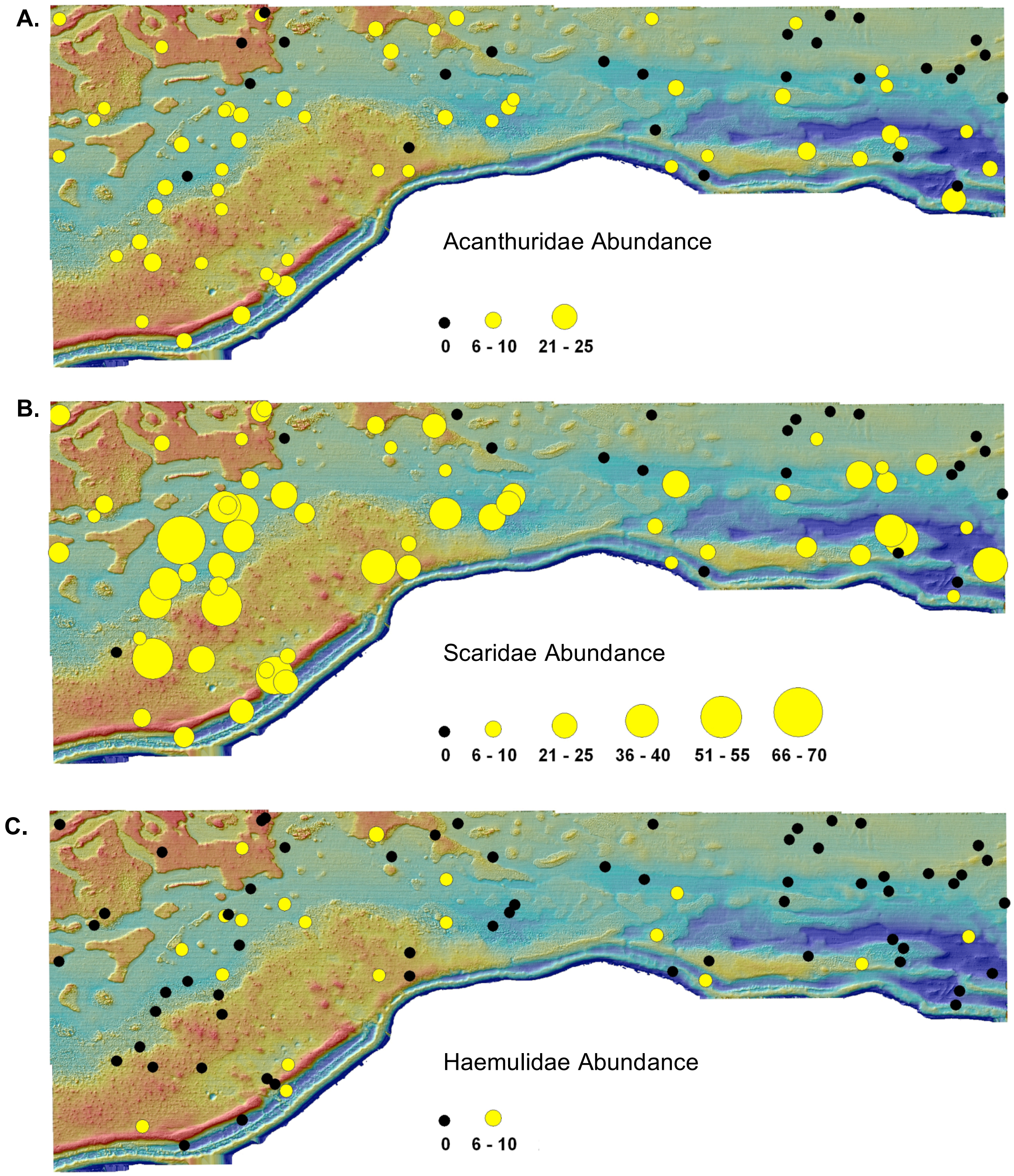

Figure 23. Family abundance (ind. /100m²) of A) Acanthuridae, B) Scaridae, C) Haemulidae, D) Serranidae, E) Lutjanidae, and F) Balistidae at each sampling location in the Marine Conservation District..

D. E. F.

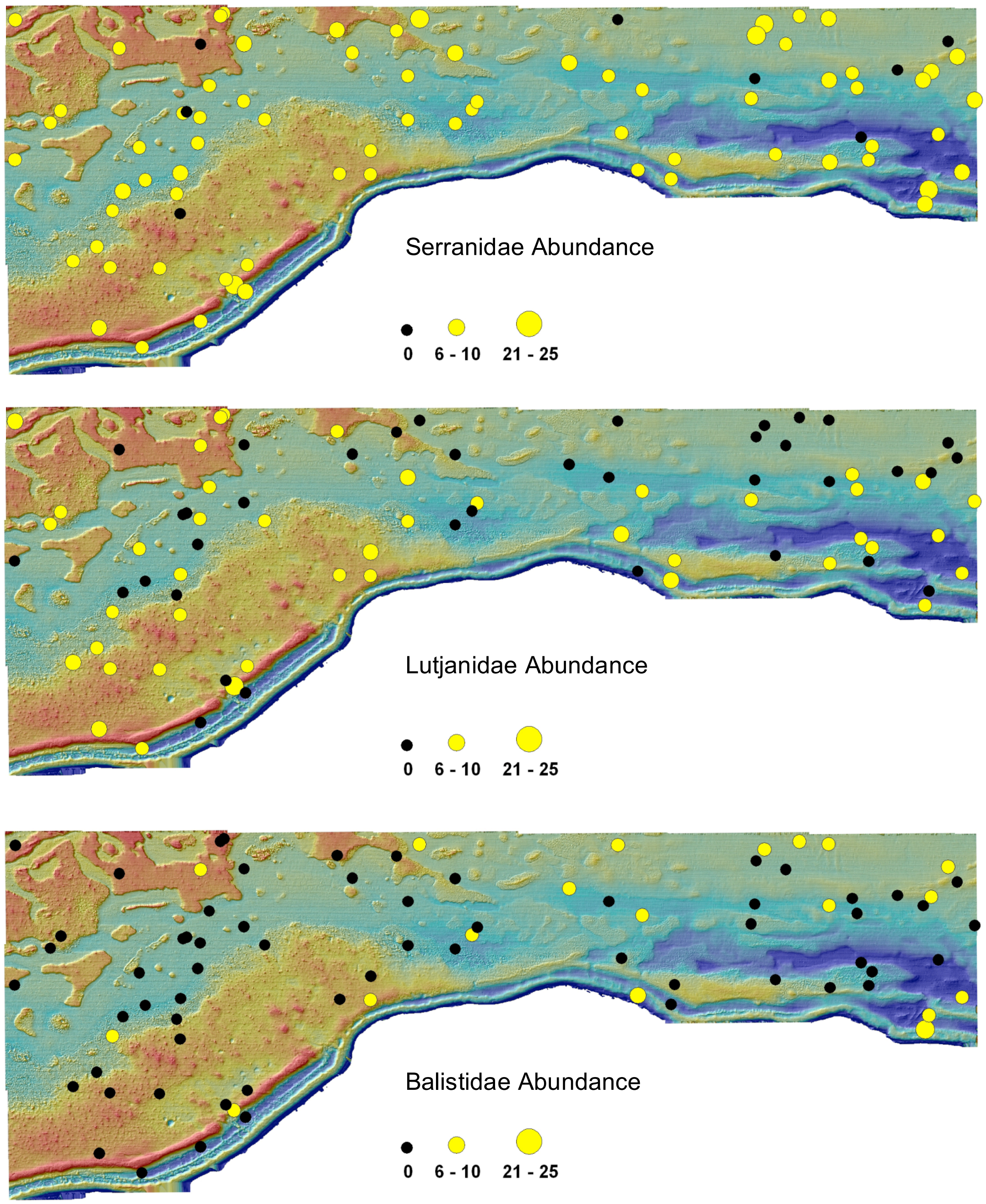

Figure 23. (continued)

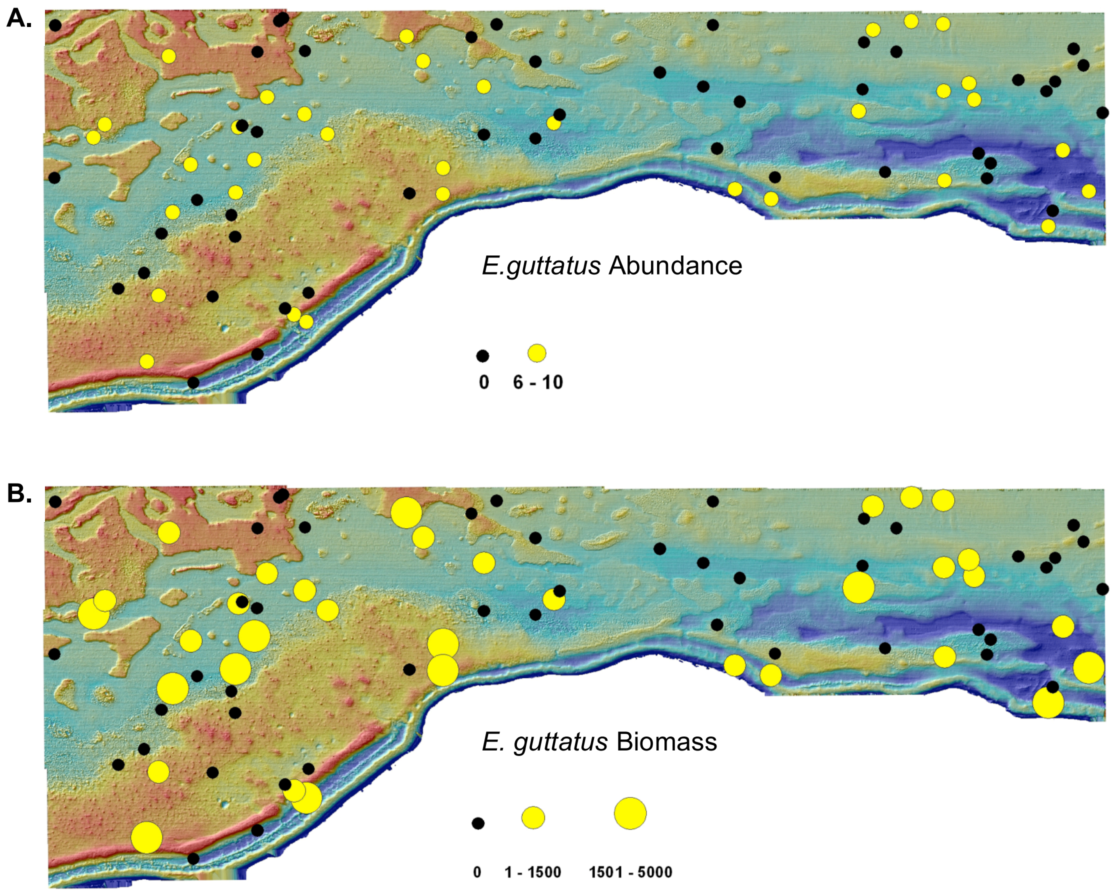

Figure 24. *E. guttatus* A) abundance (ind. /100m²) and B) biomass (g/100m²) at each sampling location in the Marine Conservation District..

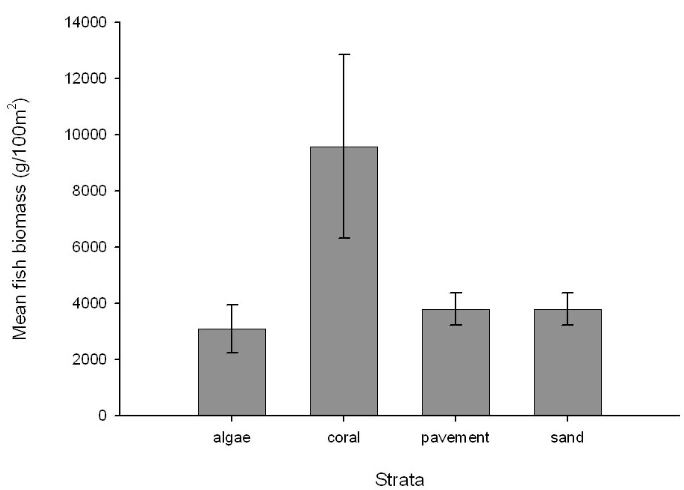

Figure 25. Mean biomass (SE bars) for all fish at each sampling location in the Marine Conservation District.

Fish biomass along belt transects, which ranged from <1 to >60,000 g 100m^{-2}, was highest in coral reef habitats, followed by sand, pavement and algal plains (Fig. 25). Due to high variability among transects no significant differences were found among habitat strata. The high biomass in sandy areas was partly due to the presence of significant coral cover that seemed to concentrate fish in these areas. At the family level, the biomass of Acanthurids was fairly uniform throughout sampling sites (Fig. 26A), whereas Scarid biomass biomass was more variable with respect to location (Fig. 26B). Haemulid biomass was relatively high at one coral reef site near the northern boundary of the MCD (Fig. 26C) and Lutjanid biomass was high at several sites located on coral reef and hardbottom habitats (Fig. 26D). Alternatively Balistid biomass was high near the northern boundary and eastern end of the MCD (Fig. 26F) in sand habitat. Serranid biomass was fairly uniform throughout MCD with one high biomass area near the shelf edge (Fig. 26D). Most of the Serranid biomass resulted from red hind being relatively abundant throughout the MCD (Fig. 24).

A.

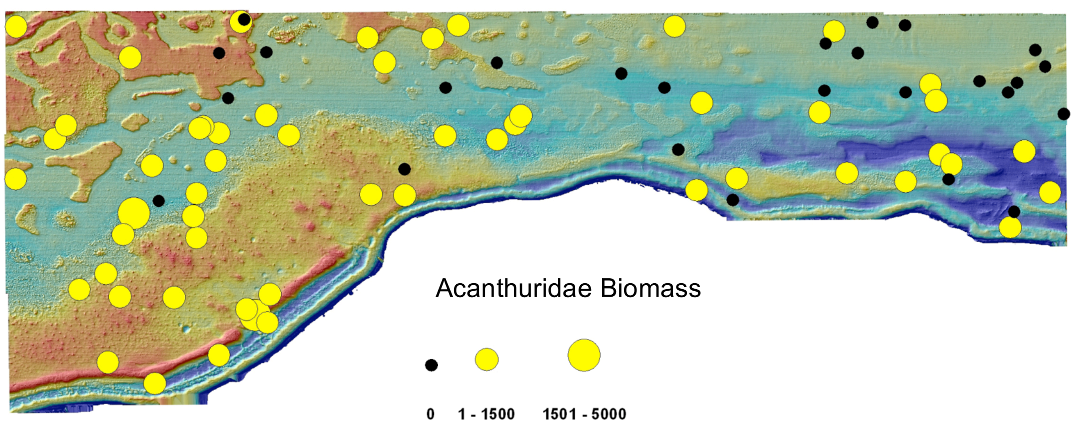

Figure 26. Family biomass (g/100m²) of A) Acanthuridae, (following pages) B) Scaridae, C) Haemulidae, D) Serranidae, E) Lutjanidae, and F) Balistidae at each sampling location in the Marine Conservation District.

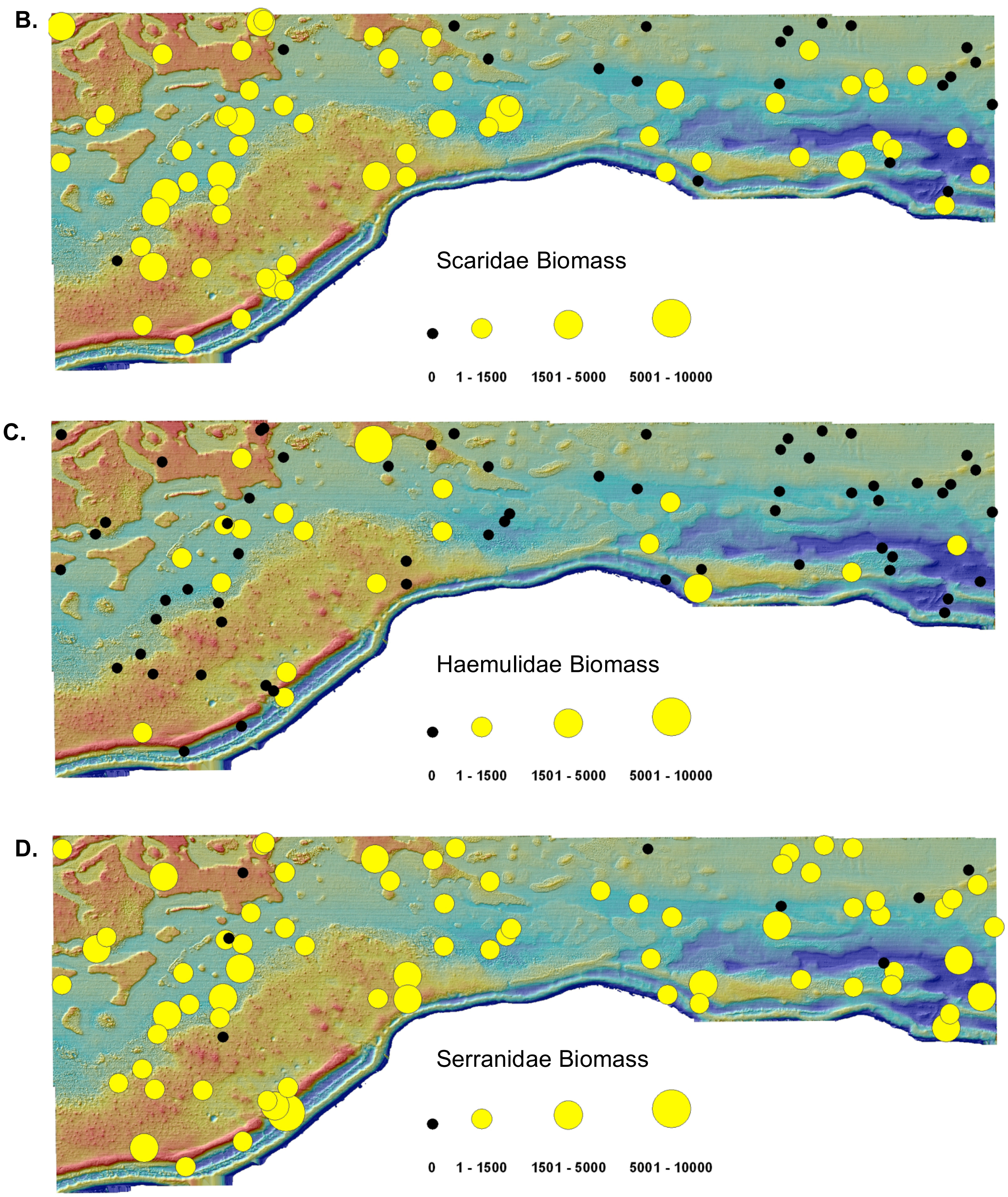

Figure 26. (continued)

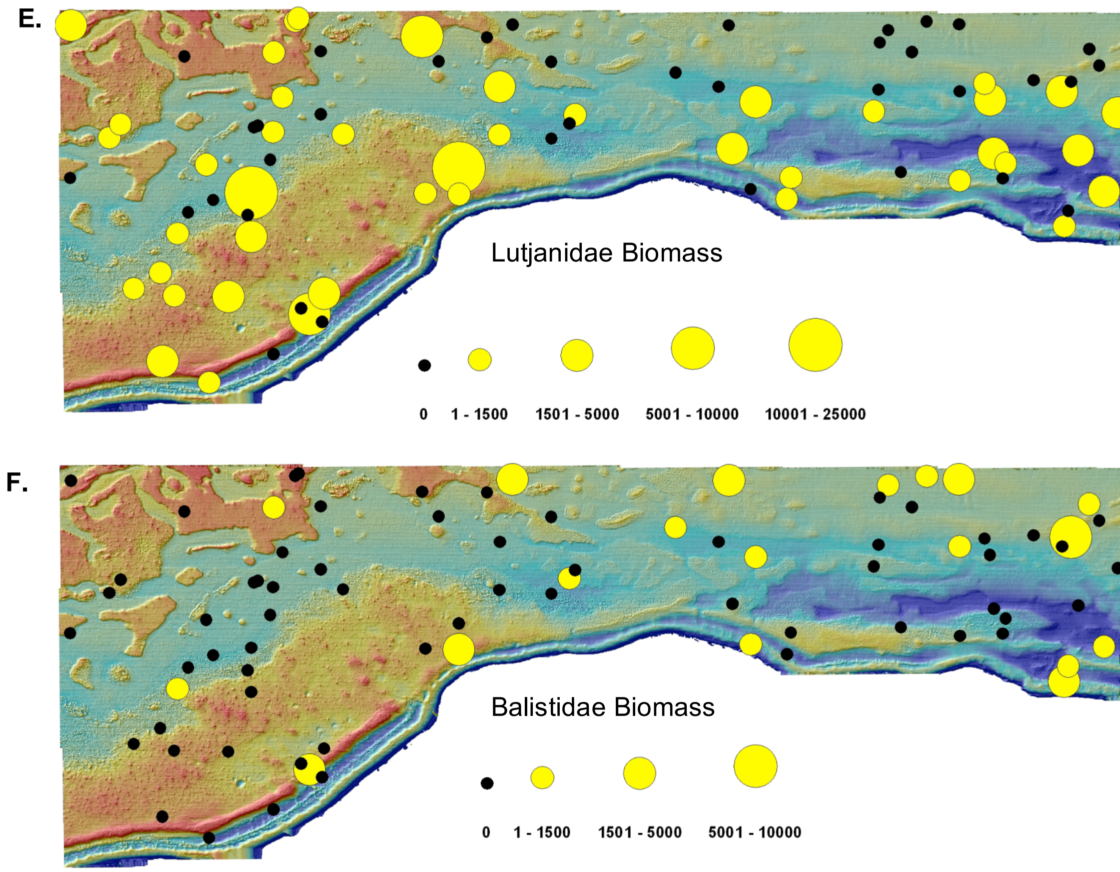

Figure 26. (continued)

Trophic composition among habitat strata

Invertivores were the most common trophic guild and were found at all but one site, with the largest abundances along the southern shelf edge (Fig. 27B). These were followed in abundance by herbivores (Fig. 27A) and omnivores (Fig. 27F). The other three trophic guilds examined, spongivores, piscivores, and plankitovres, were similar in abundance (Fig. 27C - E). In general, biomass and richness within trophic guilds followed abundance patterns except for the invertevores and piscivores, which showed spatially distinct biomass patterns.

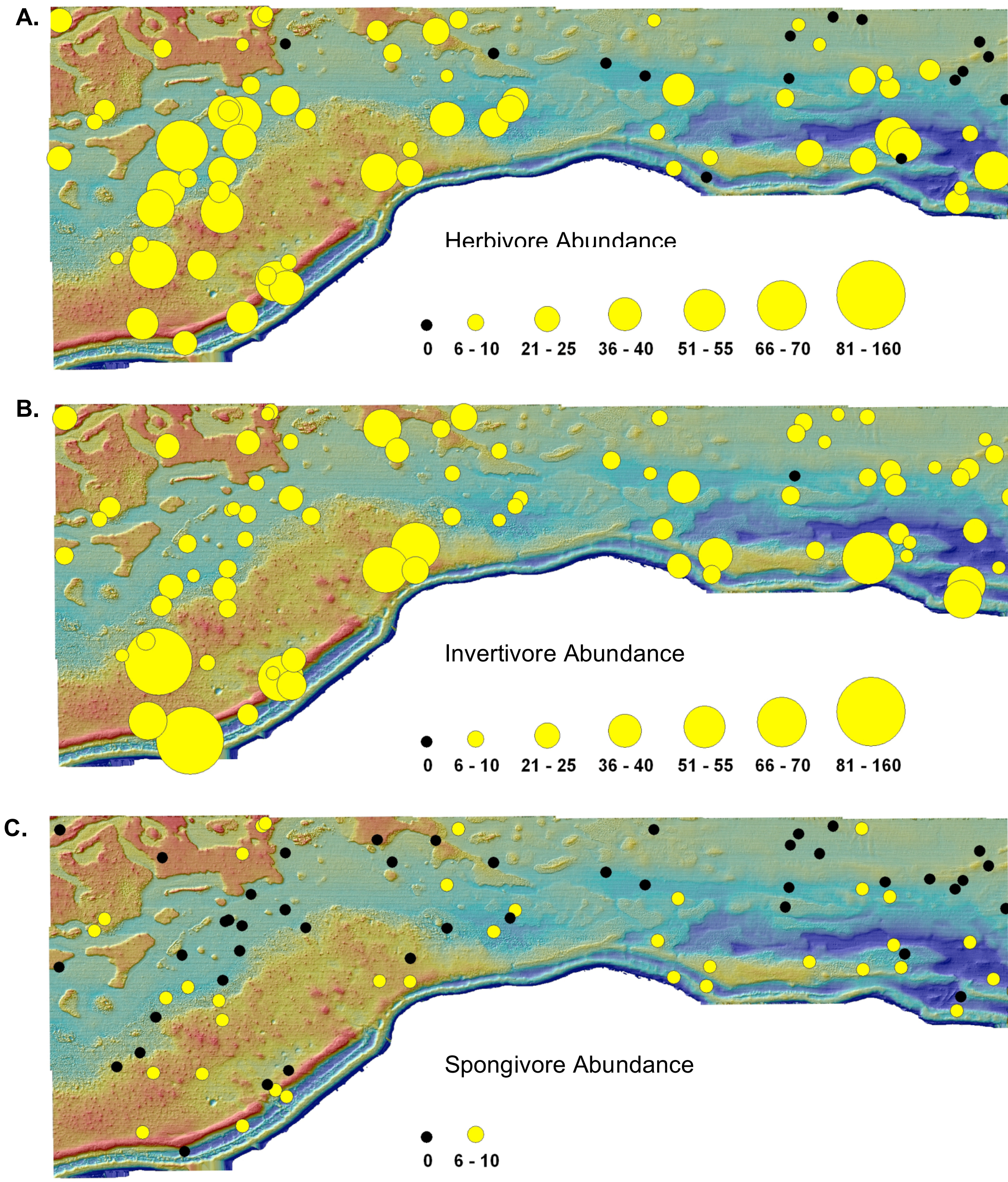

Figure 27. . Trophic level abundance (ind. /100m²) of A) herbivores, B) invertivores, C) spongivores, D) piscivores, E) planktivores, and F) omnivores at each sampling location in the Marine Conservation District.

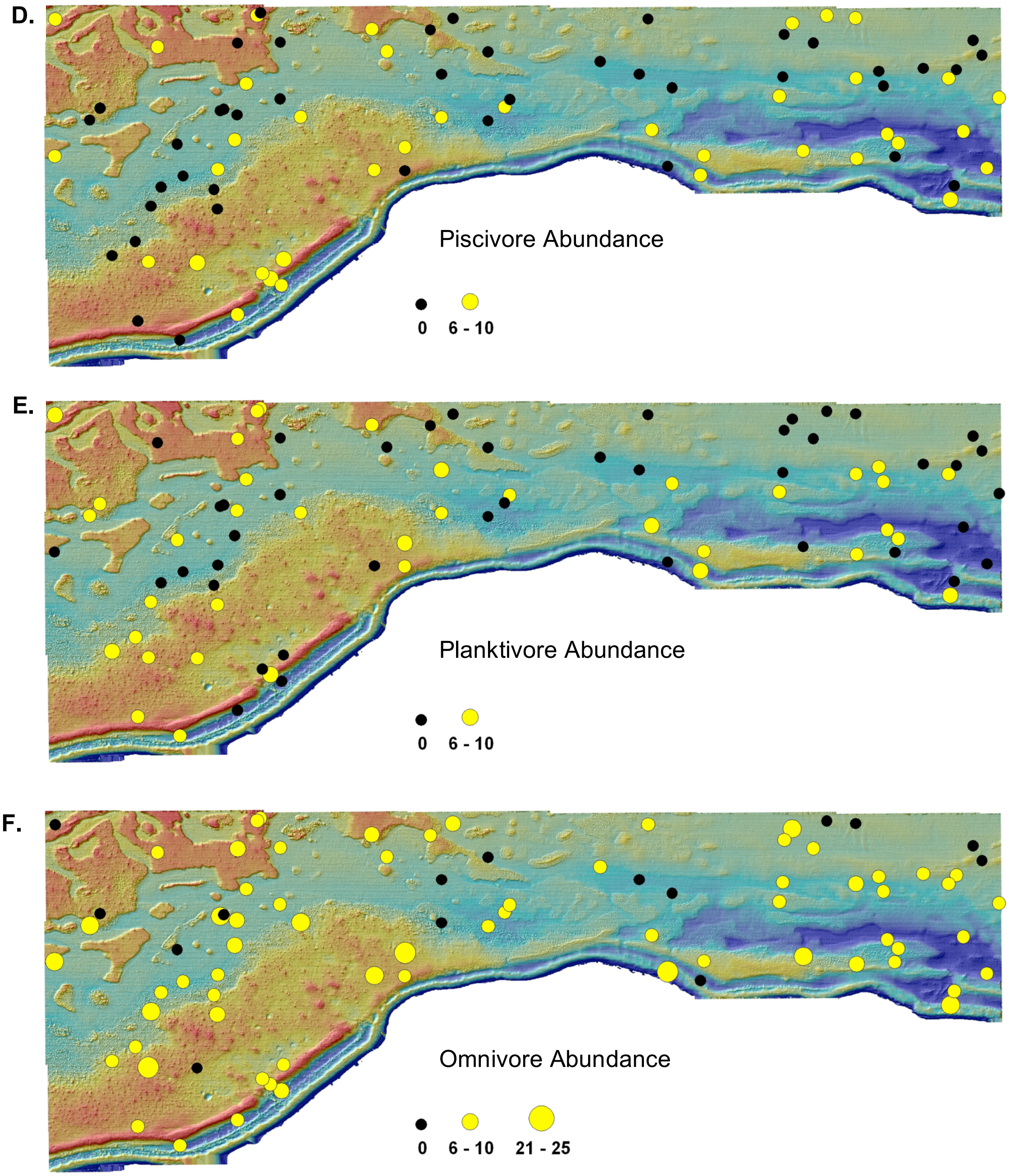

Figure 27. (continued)

Size structure of Reef Fishes

Size structure of selected commercially important species or species groups are shown in (Fig. 28). The herbivorous Acanthurids and Scarids had very similar size distributions, which ranged from 5 to 30 cm total length and averaged 10.7 cm TL and 11.0 cm TL, respectively (Fig. 28). The two most common Scarids were *Scarus taeneopterus* and *S. iserti*, which, when combined, were approximately three times more abundant than the three common Acanthurid species. The planktivorous yellowtail snapper (*Ocyurus chrysurus*) averaged 24.3 cm FL and ranged from 5 – 50 cm. Red hind (*E. guttatus*) averaged 32.8 cm TL and the queen triggerfish (*B. vetula*) averaged 33.6 cm FL. Both species had a similar size distribution (Fig. 28). The larger and commercially important species of grouper and snapper were rarely counted along transects within the MCD (Table 5).

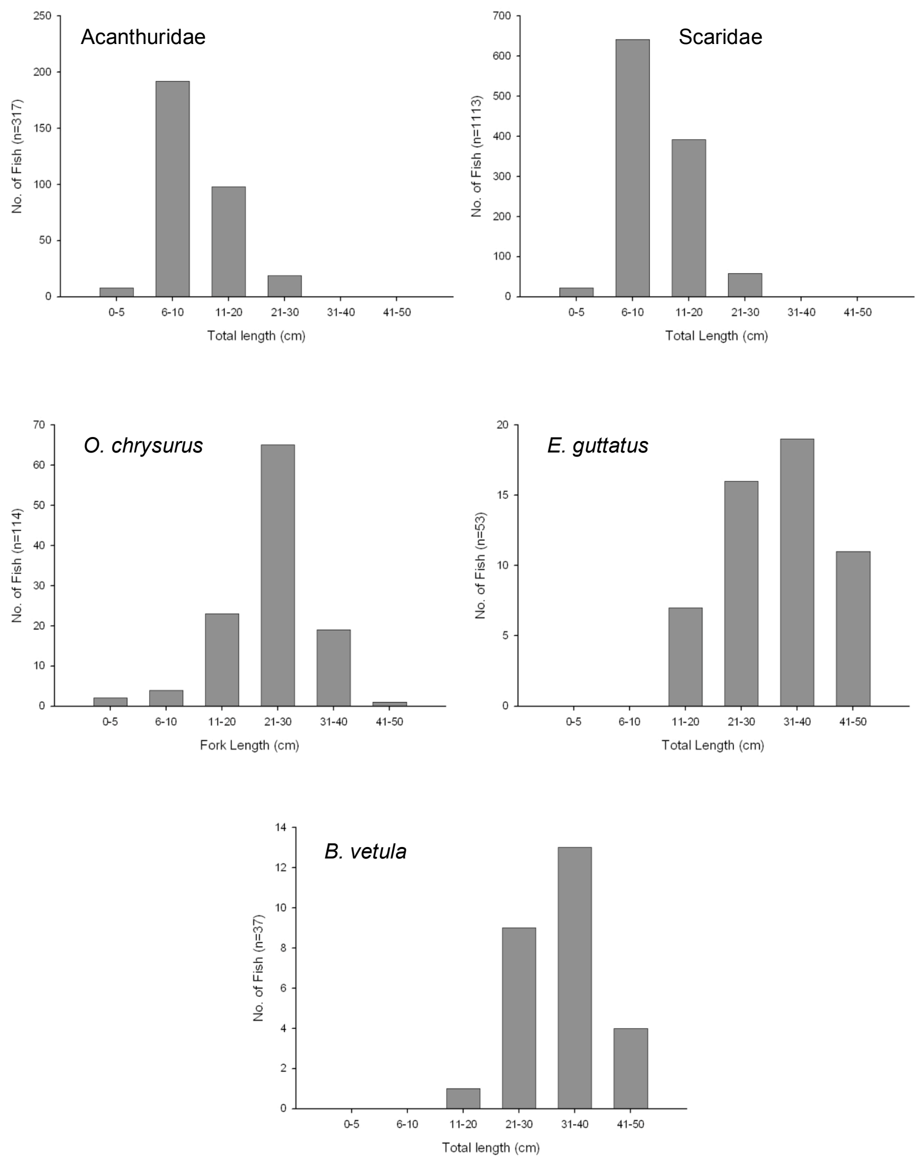

Figure 28. Length frequency histograms for selected commercially important families (Acanthuridae and Scaridae) and species (*O. chrysurus, E. guttatus* and *B. vetula*) in all habitat strata combined in the Marine Conservation District..

Table 5. Abundance, size and biomass of commercially important species of grouper and snappers in 80 fish transects from all habitat strata combined in the Marine Conservation District.

Species	N	Size (cm TL)					Total biomass (kg)
		0-20	20-40	40-60	60-80	80-100	
Epinephelus striatus	1	-	-	1	-	-	2.790
Mycteroperca venenosa	2	-	1	1	-	-	2.579
M. tigris	5	-	2	3	-	-	6.277
M. interstitialis	2	-	1	1	-	-	4.051
Lutjanus analis	12	-	7	5	-	-	12.768
L. cyanopterus	5	-	-	4	-	1	34.154
L. jocu	7	-	1	6	-	-	15.567
Lachnolaimus maximus	6	-	2	4	-	-	9.981

Assessment of total fish species diversity used a combination of approaches and reliance on previous fish surveys. The majority of fish diversity data was derived from the 25 x 4 m (100m^2) belt transects that were conducted at each of the 80 sampling sites. An additional timed roving diver survey was conducted at one randomly selected site within each habitat strata. Because of the limited time available at each site due to depth constraints we could not conduct a timed roving survey at each site. We also included data that has been collected over several years during annual monitoring at the Hind Bank and College Shoal East study sites, fish collected during research sampling (i.e. fish traps and hook and line) on the red hind spawning aggregation site, and incidental observations during numerous dives within the MCD. The compilation of these data produced a fish list of 122 species within 35 families (Table 6). Many of these species are rare, transient pelagic fishes[2] that form an important component of the trophic food web.

Due to the depth and complexity of the various habitat strata it is recommended that future surveys include a larger roving diver survey component with a minimum of 60 min search time per site. A portion of these surveys should also include dives during the changeover period during sunrise or sunset to observe the many cryptic and nocturnal species that exist within the complex interstitial spaces of these deep mesophotic reefs.

[2] This included an approximately 160 kg blue marlin (*Makaira nigricans*) that repeatedly charged one diver pair at a 5 m decompression stop over site Sand 166 on October 8, 2007.

Table 6. Species observed during roving dives in the MCD at fixed sites (sampled 2005-2007) and on four designated habitat types sampled during the MCD survey. Fixed sites, RHB and CSE, are both coral reef habitat. Designated habitat types on the MCD survey include algae (A), coral (C), pavement (P) and sand (S). Abundance categories are . (no fish), 1(one fish), 2 (2-10 fish), 3 (11-100 fish) and 4 (101-1000 fish).

Family Species	Common Name	Fixed Sites		MCD Survey			
		RHB	CSE	A	C	P	S
Acanthuridae							
Acanthurus bahianus	ocean surgeonfish	3	3	.	2	3	1
Acanthurus chirurgus	doctorfish	.	2	2	.	2	2
Acanthurus coeruleus	blue tang	2	2	.	2	3	.
Aulostomidae							
Aulostomus maculatus	trumpetfish	.	1	.	.	.	.
Balistidae							
Balistes vetula	queen triggerfish	1	.	2	.	2	1
Canthidermis sufflamen	ocean triggerfish	2	3	.	.	.	.
Melichthys niger	black durgeon	2	3	.	.	.	.
Xanthichthyes ringens	sargassum triggerfish	.	.	.	.	.	3
Carangidae							
Caranx crysos	blue runner	.	1	.	.	.	.
Caranx latus	horseeye jack	2	2	.	.	.	.
Caranx lugubris	black jack	2	3	.	.	.	.
Caranx ruber	bar jack	1	1	.	2	2	.
Elagatis bipinnulata	rainbow runner	.	1	.	.	.	.
Seriola dumerili	greater amberjack	1	.	.	.	.	.
Carcharhinida							
Negaprion brevirostris	lemon shark	2	2	.	.	.	.
Galeocerdo cuvier	tiger shark	1	1	.	.	.	.
Carcharhinus leucas	bull shark	1	.	.	.	.	.
Carcharhinus perezii	reef shark	1	.	.	.	.	.
Chaetodontidae							
Chaetodon aculeatus	longsnout butterflyfish	2	.	.	2	2	2
Chaetodon capistratus	foureye butterflyfish	2	3	.	2	2	.
Chaetodon sedentarius	reef butterflyfish	2	1	.	2	2	.
Chaetodon striatus	banded butterflyfish	2	2	.	2	2	.
Coryphaenidae							
Coryphaena hippurus	dolphinfish	1	.	.	.	.	.
Echeneidae							
Echeneis naucrates	sharksucker	1	.	.	.	.	.

Table 6. (continued)

Family Species	Common Name	Fixed Sites RHB	CSE	MCD Survey A	C	P	S
Ephipphidae							
Chaetodipterus faber	spadefish	.	2	.	.	.	.
Exocoetidae							
Cheilopogon melanurus	Atlantic flyingfish	3	3	3	3	3	3
Gobiidae							
Coryphopterus dicrus	colon goby	.	.	.	.	.	1
Coryphopterus glaucofraenum	bridled goby	.	.	2	2	.	2
Grammatidae							
Gramma loreto	fairy basslet	3	2	1	1	.	.
Haemulidae							
Anisotremus surinamensis	black margate	.	.	.	.	1	.
Anisotremus virginicus	porkfish	1	2	.	.	2	.
Haemulon album	white grunt	.	.	.	2	.	.
Haemulon aurolineatum	tomtate	.	.	.	3	3	.
Haemulon carbonarium	caesar grunt	2	.	.	.	1	.
Haemulon flavolineatum	French grunt	2	1	.	2	2	.
Haemulon macrostomum	Spanish grunt	0	1	.	.	1	.
Haemulon parra	sailors choice	.	.	.	1	1	.
Haemulon plumieri	white grunt	1	2	.	1	.	.
Haemulon sciurus	bluestriped grunt	2	1	.	1	2	.
Holocentridae							
Holocentrus adscensionis	squirrelfish	.	2	.	2	.	.
Holocentrus coruscum	reef squirrelfish	.	.	.	1	.	.
Holocentrus marianus	longjaw squirrelfish		.	.	1	.	.
Holocentrus rufus	longspine squirrelfish	2	.	2	.	2	.
Myripristis jacobus	blackbar soldierfish	2	1	2	3	.	.
Inermiidae							
Inermia vittata	boga	.	2	.	.	.	.
Istiophoridae							
Makaira nigricans	blue marlin	.	.	.	.	.	1
Kyphosidae							
Kyphosus spp.	chub	1	2	.	.	.	.

Table 6. (continued)

Family Species	Common Name	Fixed Sites		MCD Survey			
		RHB	CSE	A	C	P	S
Labridae							
Bodianus rufus	Spanish hogfish	1	2	.	2	2	.
Clepticus parrae	creole wrasse	4	4	.	.	4	.
Halichoeres bivittatus	slippery dick	1	1	.	.	.	2
Halichoeres garnoti	yellowhead wrasse	3	3	3	2	.	2
Lachnolaimus maximus	hogfish	1	1	.	1	.	.
Thalassoma bifasciatum	bluehead wrasse	3	3	.	2	.	2
Lutjanidae							
Lutjanus analis	mutton snapper	2	.	.	2	.	1
Lutjanus apodus	schoolmaster	4	2	.	3	1	.
Lutjanus buccanella	blackfin snapper	3	.	.	.	.	.
Lutjanus cyanopterus	cubera snapper	.	2	.	.	.	.
Lutjanus griseus	gray snapper	2	.	.	.	.	.
Lutjanus jocu	dog snapper	.	2	.	1	.	.
Ocyurus chrysurus	yellowtail snapper	3	2	.	2	2	.
Malacanthidae							
Malacanthus plumieri	sand tilefish	.	.	2	.	.	1
Mobulidae							
Manto birostris	manta ray	1	.	.	.	.	.
Mullidae							
Mulloidichthys martinicus	yellow goatfish	2	1	.	2	.	.
Pseudupeneus maculatus	striped goatfish	2	1	3	1	2	.
Muraenidae							
Gymnothorax funebris	green moray	2	.	.	.	.	.
Gymnothorax moringa	spotted moray	.	.	1	.	.	.
Myliobatidae							
Aetobatus narinari	spotted eagle ray	1	.	.	.	.	.
Lactophyrs quadricornis	scrawled cowfish	1	1	.	.	.	.
Lactophyrs triqueter	smooth trunkfish	2	1	.	.	2	.

Table 6. (continued)

Family Species	Common Name	Fixed Sites		MCD Survey			
		RHB	CSE	A	C	P	S
Pomacanthidae							
Centropyge argi	cherub fish	.	.	2	.	.	1
Holacanthus ciliarus	queen angel	2	1	.	2	2	.
Holacanthus tricolor	rock beauty	2	1	.	2	1	.
Pomacanthus arcuatus	gray angelfish	1	.	.	.	2	.
Pomacanthus paru	French angelfish	.	1	.	2	2	.
Pomacentridae							
Chromis cyanea	blue chromis	4	4	.	3	.	.
Chromis multilineata	brown chromis	1	4	.	2	.	.
Stegastes partitus	bicolor damselfish	3	3	2	3	3	3
Stegastes planifrons	threespot damselfish	.	.	.	.	2	.
Stegastes variabilis	cocoa damselfish	.	.	.	1	.	.
Priacanthidae							
Priacanthus cruentatus	glasseye snapper	1	.	.	.	.	.
Rhincodontidae							
Ginglymostoma cirratum	nurse shark	2	2	.	.	.	.
Scaridae							
Scarus guacamaia	rainbow parrotfish	1	.	.	.	.	.
Scarus iserti	striped parrotfish	2	1	.	3	3	.
Scarus taeniopterus	princess parrotfish	2	3	.	2	3	1
Scarus vetula	queen parrotfish	3	2	.	.	1	.
Sparisoma aurofrenatum	redband parrotfish	2	1	2	2	3	2
Sparisoma chrysopterum	redtail parrotfish	.	2	.	.	.	.
Sparisoma rubripinne	redfin parrotfish	2	.	.	.	.	.
Sparisoma viride	stoplight parrotfish	2	3	.	2	3	.
Scombridae							
Scomberomorus regalis	cero mackerel	1	2	.	.	.	.
Scomberomorus cavalla	king mackerel	1	.	.	.	.	.
Acanthocybium solandri	wahoo	1	.	.	.	.	.

Table 6. (continued)

Family Species	Common Name	Fixed Sites RHB	Fixed Sites CSE	MCD Survey A	MCD Survey C	MCD Survey P	MCD Survey S
Serranidae							
Epinephelus striatus	Nassau grouper	.	1	.	.	.	.
Epinephelus cruentatus	graysby	2	1	.	2	1	.
Epinephelus fulvus	coney	1	.	2	2	2	2
Epinephelus guttatus	red hind	2	.	.	1	2	2
Hypoplectrus chlorurus	yellowtail hamlet	2	.	.	2	2	.
Hypoplectrus nigricans	black hamlet	1	.	.	1	.	.
Hypoplectrus puella	barred hamlet	2	.	.	1	.	.
Hypoplectrus unicolor	butter hamlet	1	1	.	.	0	.
Mycteroperca interstitialis	yellowmouth grouper	1	.	.	.	.	.
Mycteroperca tigris	tiger grouper	2	1	.	.	.	.
Mycteroperca venenosa	yellowfin grouper	2	1	.	.	.	.
Liopropoma rubre	peppermint basslet	1	.	.	.	.	.
Paranthias furcifer	creole-fish	3	1	.	.	.	.
Serranus baldwini	lantern bass	.	.	3	.	.	4
Serranus tabacarius	tobaccofish	1	.	2	.	.	2
Serranus tigrinus	harlequin bass	1	1	2	.	.	2
Serranus tortugarum	chalkfish	.	.	2	.	.	.
Sparidae							
Calamus spp.	porgy	1	.	.	2	.	1
Sphyraenidae							
Sphyraena barracuda	great barracuda	1	1	2	1	.	.
Tetrodontidae							
Canthigaster rostrata	sharpnose puffer	1	2	.	2	.	1

CONCLUSIONS AND RECOMMENDATIONS

Improved Evaluation of EFH within the MCD

- Benthic habitat classification from sonar imagery was capable of distinguishing major blocks of habitat, but was less able to correctly allocate those blocks to the habitat they represented. This may be a problem of novel habitat types, such as low relief coral reef habitat types composed of plating corals, which are not represented in benthic habitat algorithms developed for shallow-water communities. A formal re-assessment of the of the benthic maps using the recently acquired in situ surveys should be a priority and will improve the next generation of habitat classification models for Caribbean mesophotic systems.
- Based on the limited sampling within the 39.5 km^2 of the MCD shallower than 50 m, we found a large diversity of reef fishes (112 species total) from all trophic groups. We anticipate that the number of species will continue to increase as sampling efforts expand to include more sites. The relationship between fish species richness and habitat type was only distinct between algae and all other habitats. The three other habitats (coral, pavement and sand), as classified in the original benthic mapping, had considerable overlap in habitat features. Specifically the sand habitat included up to 60% variable hard bottom, which contributed to a high degree of species richness. The influence of edges was also apparent. Many of the large piscivores were found along the transition between coral reef and pavement, sand and algal habitats. It is recommended that these transition zones between habitats be included as a separate classification in future biodiversity surveys.
- Large areas of coral reefs within the MCD are dominated by extensive interstitial space created by holes, tunnels, channels and ledges. These areas likely contain a high diversity of invertebrates and cryptic fishes, may contain commercially important species, such as the Caribbean spiny lobster (*Panularis argus*), and could serve as essential fish habitat. Effective surveys of these habitats could be accomplished with stationary visual censuses.
- While most species represented were adults, juveniles and sub-adults of many species were also present. This was especially apparent in the herbivorous Scaridae as well as the omnivorous Labridae and the planktivorous Pomacentridae. These species may well form the base of the food web for the larger piscivores (groupers, snappers), which in turn provide food for the top predators (sharks). In the absence of fishing, we anticipate that this large deepwater ecosystem will begin to show significant changes in the trophic structure of reef fishes and subsequent resilience to natural perturbations. The protection of the red hind spawning aggregation has already resulted significant improvements in the red hind population, and has improved the fishery as well (Nemeth 2005). Potential spill-over of commercially important reef fishes from the MCD to the surrounding

areas is anticipated but needs to be studied to better quantify the benefits of this closure to the local fishery (see below).

- Considerable habitat within the MCD lies on the outer shelf edge at depths greater than 50m. Dives to 70 m along this margin revealed a unique foliose agariciid coral reef community that may extend linearly along the shelf edge in suitable depths. This area may be particularly important as a movement corridor and as habitat for commercially important species, such as Nassau and yellowfin grouper, and blackfin snapper (Authors, unpub. obs.). Surveys by scientific divers in these deeper habitats are feasible with recent improvements in the reliability of technical diving systems (closed circuit rebreathers).
- Video methods offer minimum estimates of species richness for epifauna, with the exception of scleractinian corals. Better estimates of species richness and diversity could be obtained by in situ identification along belt transects or within quadrats.
- Little is known about the seasonality of the benthos, and motile fish and invertebrate communities in the MCD, nor the processes (e.g., oceanographic forcing) that drive seasonality. More intensive longitudinal studies could resolve these patterns and processes

Expansion of the Evaluation of EFH Outside the MCD

- Evaluation of the effectiveness of the MCD in promoting and sustaining regional fisheries via spillover requires comparative surveys outside the MCD. This could help to assure stakeholders that the reserve is functioning to improve local economic and ecological condition, at the expense of access to traditional fishing grounds.
- Comparative surveys outside the MCD would also serve to describe the extent of mesophotic reefs and associated species. These reef systems are probably widespread on the Puerto Rican Shelf and are likely critical fisheries areas.
- Other federal marine protected areas in the U.S. Virgin Islands would benefit from EFH assessment. These include the Grammanik Bank, Lang Bank, and the Mutton Snapper closed areas. Comparative studies could be conducted between these three CFMC management areas, and might provide valuable insights into factors affecting successful management strategies and avenues for improved management.
- In addition to closed areas, large areas of the Puerto Rican Shelf and the St. Croix shelf have recently been surveyed with high-resolution multibeam sonar by NOAA. In situ surveys in these areas could be useful, not only for expanding knowledge of mesophotic and mid-depth systems (see above), but also for validating improved benthic habitat classification and resource prediction models,

- Comparative surveys outside the MCD would also help to determine the processes controlling the formation and degradation of mesophotic reefs. The capture of a severe cryptic disease/mortality event outside annual monitoring locations, and recent work by Menza et al. (2007), underscores the lack of knowledge of processes that shape these deeper coral reef environments. These assessments will be crucial to understanding the potential of mesophotic reef systems to serve as refugia during a period of increasing sea surface temperatures and increasing frequency of coral bleaching events.

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APPENDICES

Appendix I Sampling locations in the Marine Conservation District and their general characteristics.

Strata	Location	Lat	Long	Depth (m)	Date Sampled
Algae	MCD A 1	18.21919744	-65.05030908	42	10/4/07
Algae	MCD A 10	18.21244379	-65.009961	43	12/5/07
Algae	MCD A 11	18.20610503	-64.98787572	49.7	12/7/07
Algae	MCD A 12	18.21506709	-64.98559179	42	12/5/07
Algae	MCD A 14	18.21329212	-64.9887041	43	10/29/07
Algae	MCD A 15	18.20710693	-65.02136999	48	11/28/07
Algae	MCD A 16	18.21925007	-65.04407546	42	10/4/07
Algae	MCD A 17	18.21949375	-64.98597395	43	11/29/07
Algae	MCD A 18	18.21494988	-65.01856664	45	12/5/07
Algae	MCD A 19	18.21925069	-65.04407546	43	10/29/07
Algae	MCD A 2	18.21679587	-64.98672594	42	10/24/07
Algae	MCD A 20	18.20824479	-65.01694758	45.2	12/17/07
Algae	MCD A 21	18.21248121	-65.02591478	43	12/7/07
Algae	MCD A 3	18.21329212	-64.9887041	42	12/6/07
Algae	MCD A 4	18.21309074	-64.99823373	43.3	11/29/07
Algae	MCD A 5	18.21702446	-65.01869904	40.6	10/25/07
Algae	MCD A 6	18.21644204	-65.00624863	41.8	11/28/07
Algae	MCD A 7	18.21230098	-65.00099196	44	10/25/07
Algae	MCD A 8	18.21870191	-65.00884722	41.5	11/28/07
Algae	MCD A 9	18.21268362	-65.02757053	45	10/29/07
Coral	MCD C 51	18.19190106	-65.08136049	38	11/6/07
Coral	MCD C 52	18.19680569	-65.07908419	38.5	12/4/07
Coral	MCD C 53	18.20295433	-65.09902033	40	12/4/07
Coral	MCD C 54	18.21140366	-64.99764917	43	10/25/07
Coral	MCD C 55	18.18369391	-65.088798	36	11/12/07
Coral	MCD C 56	18.20718602	-65.09472463	43	10/12/07
Coral	MCD C 57	18.21783608	-65.05311238	44	11/28/07
Coral	MCD C 58	18.2062122	-65.02601558	41	10/9/07
Coral	MCD C 59	18.2040901	-65.05618887	38	10/4/07

Strata	Location	Lat	Long	Depth (m)	Date Sampled
Coral	MCD C 60	18.20317584	-65.01958624	39	11/28/07
Coral	MCD C 61	18.20133302	-65.05618714	35	12/5/07
Coral	MCD C 62	18.21579034	-65.08645536	34	12/5/07
Coral	MCD C 63	18.21983358	-65.07391212	34	12/5/07
Coral	MCD C 64	18.20857843	-65.09350606	42	10/26/07
Coral	MCD C 65	18.21953265	-65.07429684	36	11/7/07
Coral	MCD C 66	18.20143394	-65.05989331	35	10/4/07
Coral	MCD C 67	18.21345617	-64.99281415	42	10/24/07
Coral	MCD C 68	18.18867811	-65.07260203	34	12/4/07
Coral	MCD C 69	18.21625361	-65.0766646	37	11/7/07
Coral	MCD C 70	18.20476208	-64.99586234	45	10/15/07
Pavement	MCD P 101	18.21115147	-65.02349829	44	10/24/07
Pavement	MCD P 102	18.19062453	-65.08751514	38.5	12/4/07
Pavement	MCD P 103	18.21899776	-65.0990227	36.4	10/8/07
Pavement	MCD P 104	18.19062453	-65.08751514	36	10/5/07
Pavement	MCD P 105	18.21020925	-65.01042807	46	10/24/07
Pavement	MCD P 106	18.2085	-65.07838436	43	11/7/07
Pavement	MCD P 107	18.19091406	-65.0710052	41	10/15/07
Pavement	MCD P 108	18.2072325	-65.04598339	45	11/27/07
Pavement	MCD P 109	18.19091406	-65.0710052	41	10/4/08
Pavement	MCD P 110	18.21267149	-65.05171893	43	12/5/07
Pavement	MCD P 111	18.20883751	-65.04400212	46	10/21/07
Pavement	MCD P 112	18.20491757	-65.07700044	43	11/30/07
Pavement	MCD P 113	18.18449445	-65.07658781	39	11/6/07
Pavement	MCD P 114	18.18929168	-65.07357517	39	11/6/07
Pavement	MCD P 115	18.2076195	-65.05173277	40	11/27/07
Pavement	MCD P 116	18.19190106	-65.08136049	38	11/7/07
Pavement	MCD P 117	18.20974776	-65.07146111	43	10/30/07
Pavement	MCD P 118	18.20971644	-65.04337465	41	10/29/07
Pavement	MCD P 119	18.20781846	-65.07670851	43	10/9/07
Pavement	MCD P 120	18.20442269	-65.084038	44	11/7/07
Sand	MCD S 151	18.20310948	-64.99622517	45	10/15/07
Sand	MCD S 152	18.20289399	-65.0009099	43	10/15/07

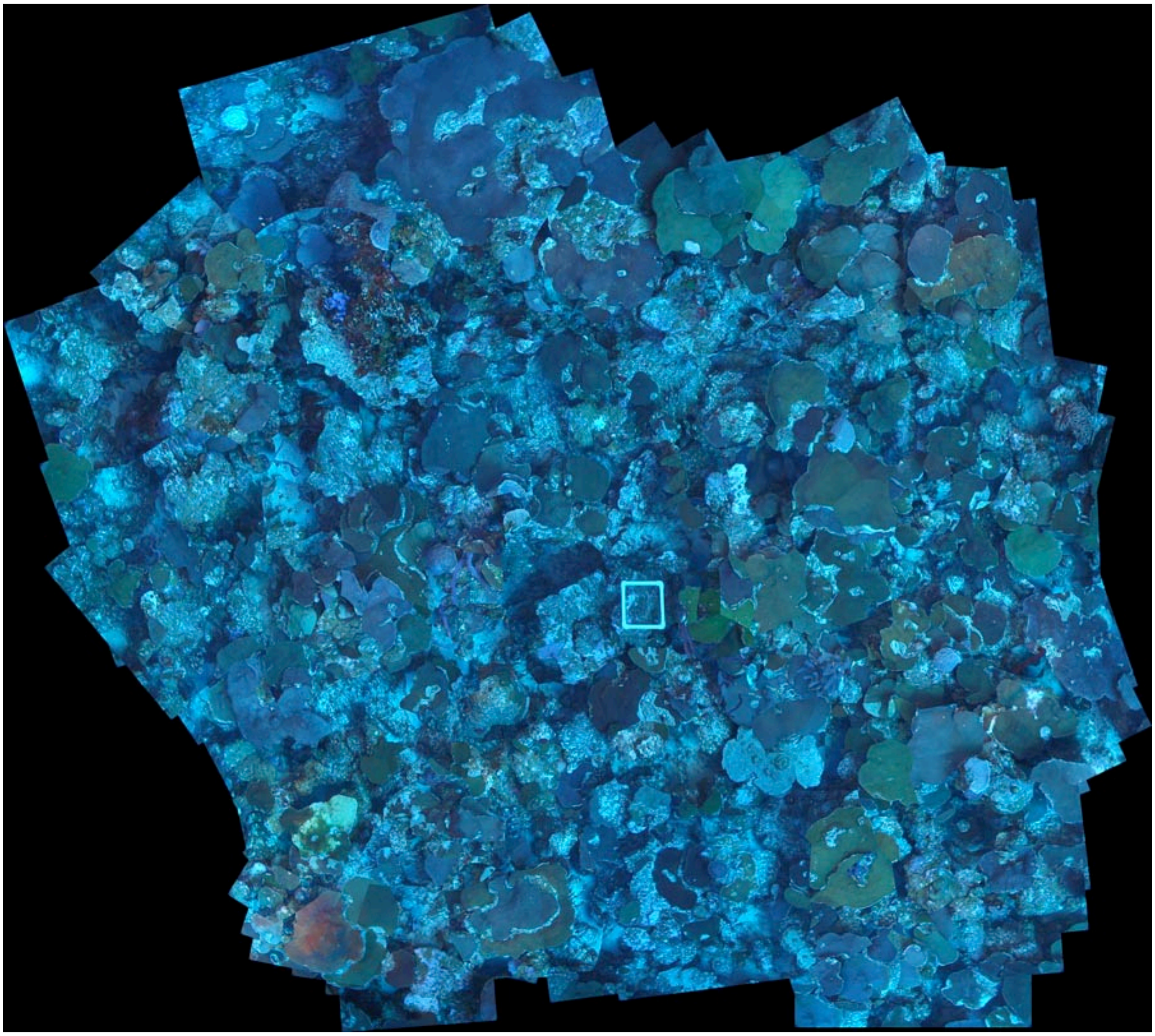
Strata	Location	Lat	Long	Depth (m)	Date Sampled
Sand	MCD S 153	18.19811209	-64.98942559	44	10/25/07
Sand	MCD S 154	18.2057528	-64.99717632	47	11/29/07
Sand	MCD S 155	18.21150359	-65.07562486	43	10/30/07
Sand	MCD S 157	18.1930068	-65.08909274	36	10/26/07
Sand	MCD S 158	18.19974027	-64.98898819	50.9	12/6/07
Sand	MCD S 159	18.20193636	-65.02400739	40	10/9/08
Sand	MCD S 160	18.18786959	-65.07122747	41	11/12/07
Sand	MCD S 161	18.19710077	-65.08721552	43	11/19/07
Sand	MCD S 163	18.19908495	-65.07949955	37	1/30/08
Sand	MCD S 164	18.2100459	-64.98351194	43	11/29/07
Sand	MCD S 165	18.19132967	-65.09198426	39	12/4/07
Sand	MCD S 166A	18.19939785	-65.08599282	42	10/8/07
Sand	MCD S 167	18.18146399	-65.08364693	44	11/12/07
Sand	MCD S 168	18.20763223	-65.0689303	38	10/9/07
Sand	MCD S 169	18.20093822	-65.02001809	50	12/6/07
Sand	MCD S 170	18.20065975	-65.08328427	44	1/11/08
Sand	MCD S 172	18.20143232	-65.07907089	44.2	12/17/07
Sand	MCD S 173	18.21532859	-65.05840878	42.4	12/17/07

Appendix II Electronic supplement (DVD). Doted images used in benthic composition assessments.

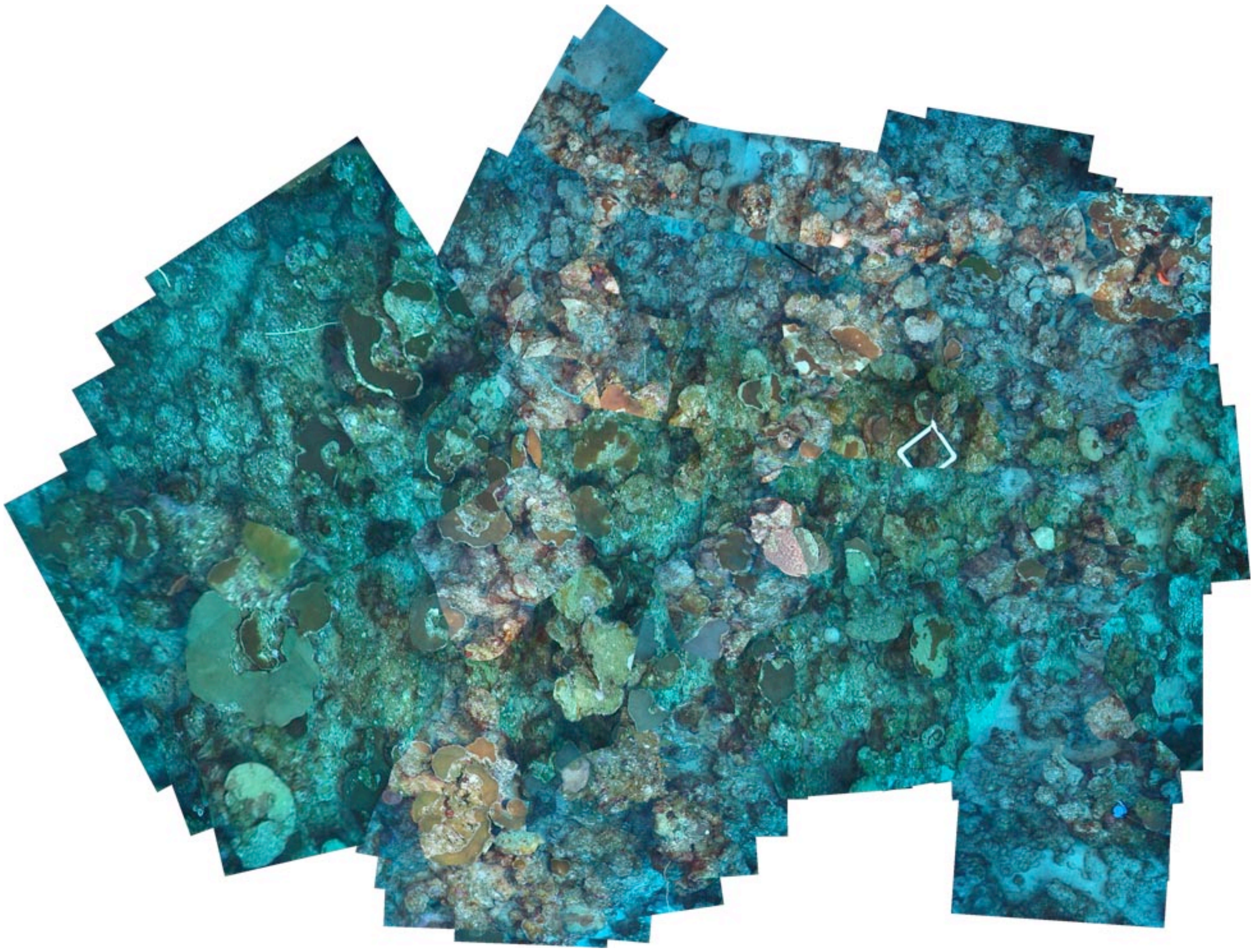
Appendix III Electronic supplement (DVD). Video captures of each sampling location.

Appendix IV Video mosaic images of representative coral reef locations from the strata coral (Coral 52) and sand (Sand 166). Scaling quadrat is 25 X 25 cm. Video mosaic analysis courtesy of A. Gleason and P. Reid (RSMAS-University of Miami).

Coral 52. January 16, 2008



S166. January 11, 2008



Appendix V Electronic supplement (DVD). Benthic cover data for each location sampled in the Marine Conservation District.

Appendix VI Electronic supplement (DVD). Coral health data for coral harboring locations sampled in the Marine Conservation District.

Appendix VII Electronic supplement (DVD). Fish data for each location sampled in the Marine Conservation District.

Appendix VIII Literature Review: literature pertinent to the Marine Conservation District

Marine Conservation District Habitat Project Literature Review

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