CHAPTER 3: CHARACTERIZATION OF REEF AND HARDBOTTOM HABITATS, ASSOCIATED FISH COMMUNITIES, AND MARINE DEBRIS IN VIEQUES

Laurie J. Bauer[1,2,] and Matthew S. Kendall[1]*

[1]Center for Coastal Monitoring and Assessment, National Centers for Coastal Ocean Science, National Ocean Service, NOAA, 1305 East-West Hwy, Silver Spring, MD 20910

[2]Consolidated Safety Services, Inc., Fairfax, VA 22030, under NOAA Contract No. DG133C07NC0616

[*]Corresponding author: laurie.bauer@noaa.gov

3.1 INTRODUCTION

In Part I of the ecological characterization (Bauer et al. 2008), prior research and monitoring activities of the benthic habitats and fish communities of Vieques were summarized. An island-wide stratified random survey of benthic habitats and associated fish communities has never been conducted around Vieques. Such surveys are useful for management of marine resources and marine spatial planning, and can be used to inform future research and monitoring decisions.

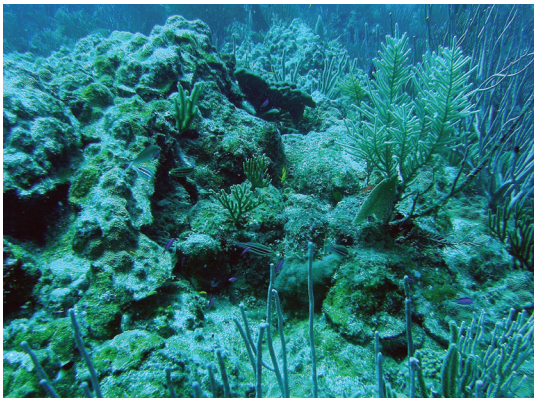


Image 3.1. Vieques coral reef.

The objectives of this section are to characterize fish assemblages, benthic communities, and marine debris on coral reef and other hardbottom habitats around Vieques using a comprehensive island-wide survey. These data will serve as a baseline to monitor future changes in benthic cover, population estimates and size spectra of fish over time. Although submerged aquatic vegetation and mangroves are also utilized by many fish species, efforts for the island-wide survey were concentrated on hardbottom habitats due to logistical limitations. Fish populations in several Vieques lagoons (Puerto Mosquito, Puerto Ferro, Ensenada Honda, Puerto Negro) and softbottom shelf areas were also surveyed and will be discussed in Chapter 4.

3.2 METHODS

Site Selection

Field surveys were conducted from May 14-26, 2007 to characterize the coral reefs, hardbottom habitats, and their associated fish communities around Vieques. Reef/hardbottom habitat out to 3 nm (5.6 km) offshore and shallower than 100 ft depth was designated as the survey area. An important issue identified by local interest groups was how the condition of reefs differs in regions that have experienced varying degrees of human activity. Another important consideration in survey design was to partition sites on both the north and south sides of the island, which have inherent differences in shelf morphology, currents, and bathymetry. Based on these two factors, ten strata were defined (Figure 3.1, Table 3.1). The five former land use zones were identified, from west to east, as the 1: Naval Ammunition Support Detachment (NASD, also known as the Naval Ammunition Facility), 2: the Civilian Area (CA), 3: the Eastern Maneuver Area (EMA) and the Secondary Impact Area (SIA), 4: the Live Impact Area (LIA), and 5: the Eastern Conservation Area (ECA). Each zone was further subdivided into north and south regions. Hereafter, the strata will be referred to as 1-5 heading west to east, followed by north/south (e.g., 1-North).

Table 3.1. Allocation of survey sites by strata.

Stratum	Former Land Use Zone	Number of Survey Sites		
		North	South	Total
1	Naval Ammunition and Support Detachment (NASD)	6	10	16
2	Civilian Area (CA)	8	9	17
3	Eastern Maneuver Area (EMA) / Secondary Impact Area (SIA)	6	11	17
4	Live Impact Area (LIA)	6	8	14
5	Eastern Conservation Area (ECA)	5	6	11
	Total	31	44	75

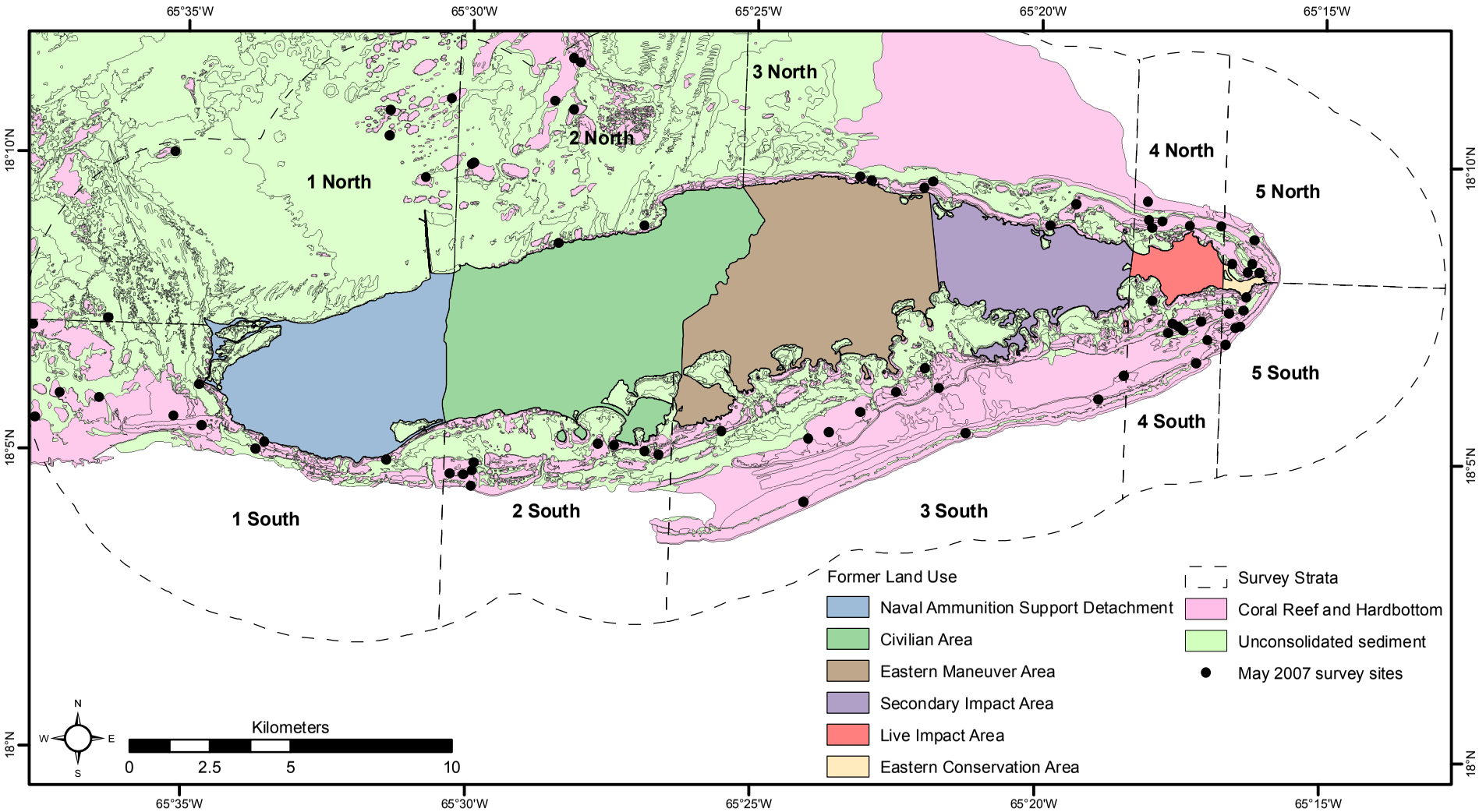


Figure 3.1. Former land use, survey strata and site locations of the May 2007 survey of hardbottom benthic habitats, fish communities, and marine debris.

A total of 75 sites were surveyed. The number of total sites was pre-determined by the time allotment for the survey and an estimate of the number of sites that could be completed each day. A minimum of five sites was included in each stratum to ensure an adequate minimum number of surveys for statistical comparisons. Remaining survey effort was then divided among strata based on proportional area of reef and hardbottom within an individual stratum in relation to the total amount of reef/hardbottom in the survey area (Table 3.1). As the new benthic habitat map (Chapter 2) was not complete at the time of the survey, the amount of reef/hardbottom in a previous benthic habitat map of Vieques (Kendall et al. 2001) was used as the basis for site selection purposes. Sites were randomly selected within the ten strata in ArcGIS using Hawth's Spatial Analysis Tools v.3.27 (Beyer 2004) (Figure 3.1).

Table 3.2. Distribution of survey sites by detailed hardbottom habitat structure. See Chapter 2 for classification scheme.

Detailed Structure Type	Number of Survey Sites	Percent of Sites
Aggregate Reef	19	25.3
Individual Patch Reef	11	14.7
Aggregated Patch Reefs	2	2.7
Pavement	29	38.7
Pavement w/ Sand Channels	6	8.0
Rhodoliths	1	1.3
Sand w/ Scat. Coral/Rock	7	9.3
Total	75	100.0

In Chapter 2, reef and hardbottom was categorized into detailed geomorphological structure types in the new benthic habitat map. The number of sites surveyed relative to detailed geomorphological structure type, based on the new map are displayed in Table 3.2. The majority of sites were located in hardbottom types that account for the highest coverage by area (e.g., pavement, aggregate reef). In contrast, a relatively small percentage of sites were surveyed in aggregated patch reefs, which represents a relatively small proportion of the hardbottom types around Vieques by area. Although the new benthic habitat classification scheme (Chapter 2) now includes sand w/ scattered coral and rock as a softbottom structure type, this was previously designated as coral reef and hardbottom and was hence included in the survey area. Only one site was surveyed in the rhodolith class; although this structure type encompasses a large area (Chapter 2), most of this area had been unclassified in the previous map and not considered in site allocation.

Field Methods

The survey of benthic features, fish communities and marine debris were all conducted within a 25 x 4 m transect (100 m^2), along a random compass heading. Two divers performed the survey at each site. One diver was responsible for visual counts and size estimation of fish species. The second diver quantified benthic features and marine debris.

Benthic Habitat Composition

The habitat diver assigned an overall bottom type (i.e., hard or soft bottom) to each transect based on *in situ* observation. Data on the percent cover of abiotic and biotic composition at each survey site were recorded within five 1 m^2 quadrats placed randomly along the 25 x 4 m transect. The quadrat was placed at each randomly chosen distance and systematically alternated from one side to the other side along the transect tape (Figure 3.2). Several variables were measured to characterize benthic composition and structure (Table 3.3). The quadrat was divided into 100 smaller 10 x 10 cm squares (1 small square = 1% cover) to help the diver with estimation of percent cover. Percent cover was determined by looking at the quadrat from above and visually estimating percent cover in a two dimensional plane. The information recorded included:

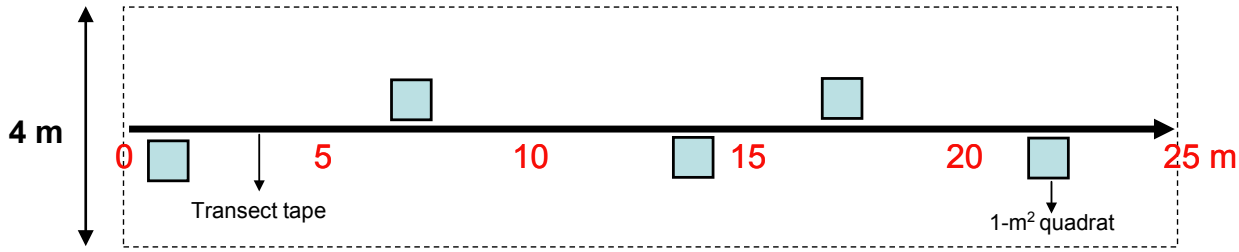


Figure 3.2. Schematic representation of the placement of the 1 m^2 quadrat along a 25 m transect tape during fish and benthic substrate surveys. Broken line represents total survey area (100m^2).

Abiotic cover - the percent cover (to the nearest 1%) of four abiotic substrate categories (hardbottom, sand, rubble, fine sediments/silt) was estimated within each 1 m^2 quadrat. The maximum height of the hardbottom was also measured.

Biotic cover - the percent cover (to the nearest 0.1%) of algae, seagrass, live corals, sponges, gorgonians, and other biota was estimated within each 1 m^2 quadrat. Taxa were identified to the following levels: stony coral-species, algae-morphological group, sponge-morphological group, and gorgonians-morphological group. Species identified as *Montastrea annularis* refer to the *M. annularis* complex. For stony and fire corals, the percentage of bleached coral and diseased/dead coral was estimated to the nearest 0.1 percent.

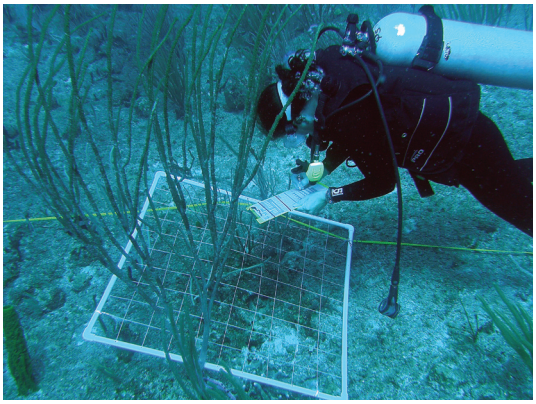


Image 3.2. Diver quantifying habitat composition.

Maximum canopy height - the maximum canopy height of sponges, gorgonians, and soft algal groups was recorded to the nearest 1 cm in each quadrat.

Number of individuals - the number of individual upright sponges, gorgonians, non-encrusting anemones, and non-encrusting hydroids was recorded in each quadrat.

Rugosity - rugosity was measured by placing a 6 m chain at two randomly selected and non-overlapping positions, ensuring no overlap, along the 25 m belt transect. The chain was positioned along the centerline of the transect such that it followed the substrate's relief, and the straight-line horizontal distance covered by the chain was measured.

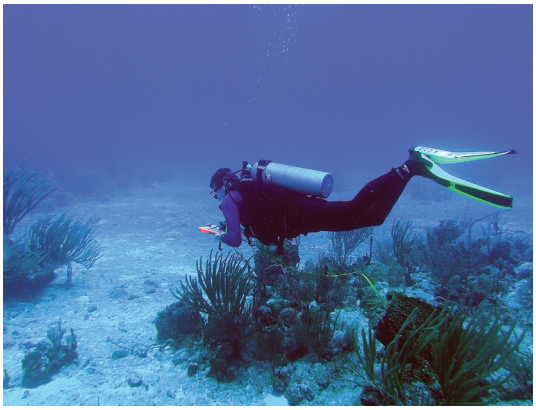


Image 3.3. Diver conducting fish survey.

The habitat diver also counted the abundance of spiny lobsters (*Panulirus argus*), long-spined urchins (*Diadema antillarium*), and the abundance/maturity of queen conchs (*Strombus gigas*) within the 25 x 4 m transect at each site.

Fish Census

Fish surveys were conducted along the 25x4 m transect (100 m^2) using a fixed survey duration of 15 minutes regardless of habitat type or complexity. The number of individuals per species was recorded in 5 cm size class increments up to 35 cm using visual estimation of fork length. Individuals greater than 35 cm were recorded as an estimate of the actual fork length to the nearest centimeter. Fish were identified to the lowest possible taxonomic unit.

Marine Debris

The number and type of marine debris within the 100 m^2 transect were recorded. The size of marine debris and the area of affected habitat were estimated. The degree of colonization and any injuries to benthic organisms were also noted. Special attention was paid to the presence of unexploded ordnance. For safety reasons, a Navy UXO (unexploded ordnance) safety contractor diver accompanied divers at all dive sites where munitions could potentially be present. In addition to recording any debris, including ordnance, within the survey area, ordnance observed outside the 100 m^2 transect was also described, photographed, and documented for U.S. Navy records.

Data Analysis

Benthic Habitat

The five quadrat measurements within each transect were averaged and cumulative coral species richness was calculated for each survey location. Average site values were used to calculate means and standard er-

rors of measured variables for the entire study area, by strata, and by detailed geomorphological structure type using the sampling weights for the study area (SAS v9.1, Proc SurveyMeans). Potential differences in metrics among strata were investigated using parametric ANOVA for normally distributed data (e.g., coral species richness) and non-parametric Wilcoxon tests for non-normally distributed data (e.g., percent cover of major cover groups). When the overall test was significant, pairwise comparison's were made using Tukey's HSD (Honestly Significant Difference) or the corresponding non-parametric Dunn's test (Zar 1999). Data were plotted in ArcGIS (v9.3, ESRI) to examine broad spatial patterns in the benthic cover variables.

Fish Assemblages

A summary of all species observed in this characterization was created. Domain-wide estimates were computed employing methods described by Cochran (1977) for a stratified sampling design using the data, strata and corresponding sampling weights. Percent occurrence, mean density and biomass (per 100m^2) and corresponding standard errors (SE) were calculated for each species. Mean density and biomass were also calculated for each family and trophic group for the overall survey area. Trophic groups include piscivores, herbivores, invertivores, and zooplanktivores and were defined for each species based on diet information from Randall (1967). However, it is important to note that the diet of many species is composed of a mix of these groups; generally when a species' diet consisted of more than one trophic group, the group that comprised the higher percentage of the diet was chosen. Biomass was calculated using published length-weight relationships using the formula,

$$W = \alpha L^{\beta}$$

where L is length in centimeters and W is weight in grams. The midpoint of each size class was used for L values, or actual length was used for fish >35 cm (for fish 0-5 cm in length, 3 cm was used as we don't typically observe fish <1 cm). Values for the α and β coefficients were obtained from FishBase (Froese and Pauly, 2008). Biomass for species with no published length-weight relationships was calculated using terms for the closest congener with most similar morphology.

Species diversity was calculated using the Shannon Index (H'), a measure that incorporates both richness and evenness:

$$H' = \Sigma_i p_i (\log_e p_i)$$

Total fish density, biomass, richness, and diversity were compared among strata. Parametric Analysis of Variance (ANOVA) was used when assumptions of normality and homogeneity of variance were met (i.e., richness and Shannon diversity); and non-parametric Wilcoxon tests when assumptions were not met (i.e., total abundance and total biomass). When the overall test was significant, pairwise comparisons were made using Tukey's HSD (Honestly Significant Difference) or the corresponding non-parametric Dunn's test (Zar 1999). Data were plotted in ArcGIS (v9.3, ESRI) to examine broad spatial patterns in the fish metrics.

Correlations between fish community metrics (total abundance, total biomass, richness, diversity) with benthic habitat parameters such as depth, rugosity, and percent cover of major benthic groups were examined using non-parametric Spearman's Rho (ρ) coefficients.

In addition, key families and species of commercial and/or ecological interest were selected for further analysis. For each species/family, a summary of the species distribution, mean density among strata, and size frequency is provided. Juveniles/subadults were identified based on length at maturity information provided by FishBase (Froese and Pauly 2008), Garcia-Cagide et al. (1994) and Ault et al. (2008). Fish less than the mean length at maturity were classified as juveniles/subadults. Where length at maturity was unknown, 1/3 of maximum size was used as a proxy (Pittman et al. 2008).

Differences and similarities in species composition were examined using multivariate statistical techniques (Primer v.6, Clarke and Warwick 2001). Data were arranged in a species abundance by site data matrix, which was used to construct a triangular matrix of the percentage similarity in community composition between all pairs of sites using the Bray-Curtis Coefficient. The coefficient is a measure of how similar samples are to each other, ranging from 0% (complete dissimilarity) and 100% (complete similarity). Next, non-metric multidimensional scaling (nMDS) was used to place samples in a two-dimensional configuration such that the rank

order of the distances between the samples agrees with the rank-order of the similarities from the Bray-Curtis matrix. Sites were coded by strata (North/South, 1-5) and hardbottom type for examination of visual patterns of between site similarity. These factors were also used to test for significant differences in similarity using Analysis of Similarities (ANOSIM), a multivariate, non-parametric version of ANOVA. Finally, similarity percentages (SIMPER) were calculated to identify the species that contributed most to the differences between factors.

3.3 RESULTS AND DISCUSSION

Benthic habitat

As expected, hard substrate was the dominant abiotic cover type, with small amounts of sand and rubble (Figure 3.3). The mean maximum height of hard substrate was 31.8 (±2.4 SE) cm.

Turf algae accounted for the highest overall mean percent cover, followed by macroalgae, gorgonians, crustose/calcareous algae, hard coral, and sponges (Figure 3.4, Table 3.3). In general, macroalgal and gorgonian cover tended to be higher in the strata on the western half of the island, while crustose algae became an increasingly abundant component of the community in the eastern strata (Figure 3.5). However, there was a large degree of variability among sites within the same strata. In addition, there was a high degree of variability among sites within the same structure type (Figure 3.6). Sand w/ scattered coral and rock had the highest percentage of uncolonized substrate (67.3 ± 8.1)%, primarily due to the high amount of bare sand found in that bottom type.

Hard coral cover was generally low, with an overall mean of 3.4 (±0.5)%. Mean cover ranged from a high of 6.7 (±1.8)% in the southwestern most stratum (1-South) to less than 2% in the six eastern strata. However, when compared with the other strata, coral cover in 1-South was only significantly different from 4-North and 5-North ($p<0.05$). Coral cover exceeded 10% at four sites, three of which were located on reefs southwest of the island (Figure 3.7). Coral cover was highest on aggregate reef and patch reef structure, and lowest on sand w/ scattered coral and rock (Figure 3.6).

The coral community observed in the study was represented by 10 taxonomic families and 26 species. Coral species richness averaged 6.6 (±0.4), with a range of 0-14 species recorded at individual sites (Figure 3.8). Similar to the coral cover variable, species richness was significantly greater in 1-South compared to 4- and 5-North, and in 2-South compared to 5-North ($p<0.05$). The most abundant coral was *Montastrea annularis*, followed by *M. cavernosa*, *Porites*

Table 3.3. Summary statistics for biotic composition across all Vieques surveys.

Benthic Taxa	Mean (±SE) Percent Cover	Mean (±SE) Height (cm)	Mean (±SE) # Individuals
Live coral	**3.4 (0.5)**		
Montastrea annularis	0.9 (0.3)	x	x
Montastrea cavernosa	0.7 (0.1))	x	x
Porites astreoides	0.4 (0.1)	x	x
Diploria strigosa	0.4 (0.1)	x	x
Siderastrea siderea	0.2 (<0.1)	x	x
Siderastrea radians	0.2 (<0.1)	x	x
Diploria labyrinthiformis	0.1 (<0.1)	x	x
Porites porites	0.1 (<0.1)	x	x
Fire coral (*Millepora sp.*)	0.3 (<0.1)		
Algae	**41.9 (3.3)**		
Turf algae	19.0 (3.3)	x	x
Macroalgae	17.7 (2.6)	4.8 (0.3)	
Crustose algae	4.1 (0.8)	x	x
Cyanobacteria	0.6 (0.1)	0.9 (0.2)	x
Rhodoliths	0.3 (0.3)	<0.1 (<0.1)	x
Filamentous algae	0.2 (0.1)	0.4 (0.1)	x
Gorgonians	**5.9 (0.7)**		
Sea plume/rod/whip	4.6 (0.6)	34.2 (2.8)	5.2 (0.5)
Sea fans	1.1 (0.2)	12.7 (1.7)	0.6 (0.1)
Encrusting gorgonians	0.3 (0.1)	x	x
Sponges	**2.6 (0.3)**		
Barrel/tube/vase	2.0 (0.3)	11.0 (1.1)	2.6 (0.2)
Encrusting	0.7 (0.1)	x	x
Zoanthids	0.1 (<0.1)	x	x
Tunicates	<0.1 (<0.1)	x	x
Anemones	<0.1 (<0.1)	x	<0.1 (<0.1)
Bare substrate	45.7 (3.3)	x	x

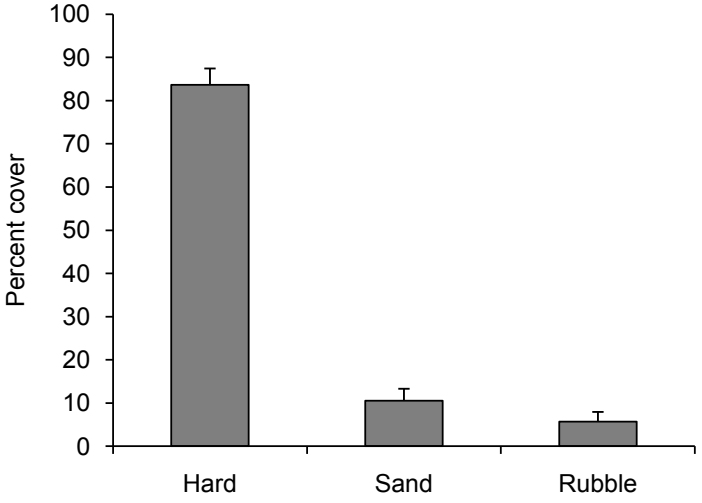


Figure 3.3. Mean (±SE) percent cover of abiotic substrate composition across sites.

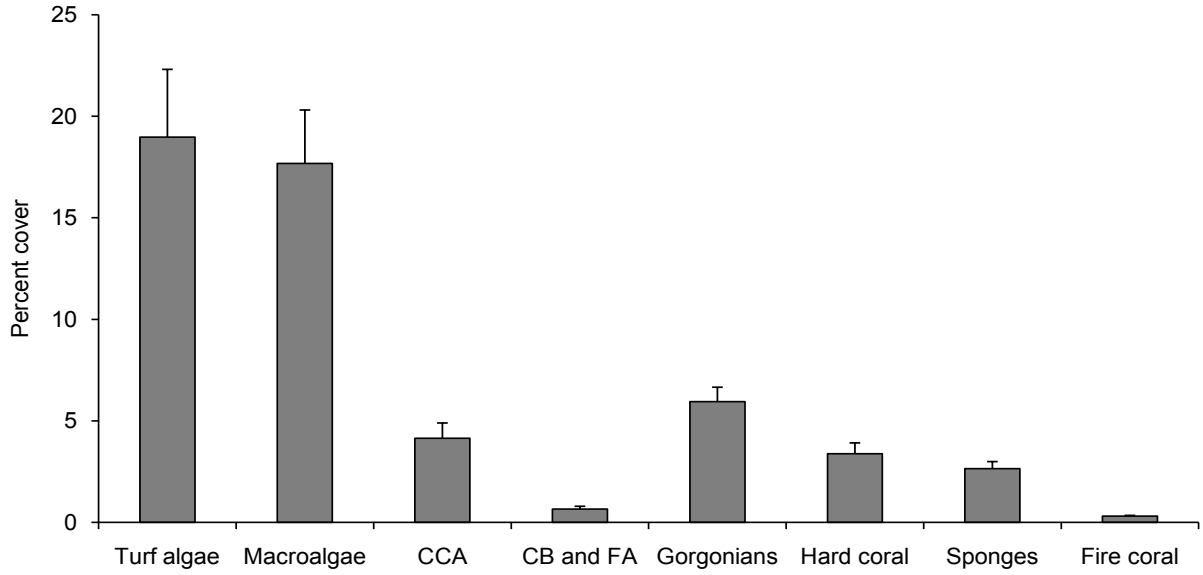


Figure 3.4. Mean (±SE) percent cover for key components of benthic community across sites. CCA = crustose coralline algae; CB and FA = cyanobacteria and filamentous algae.

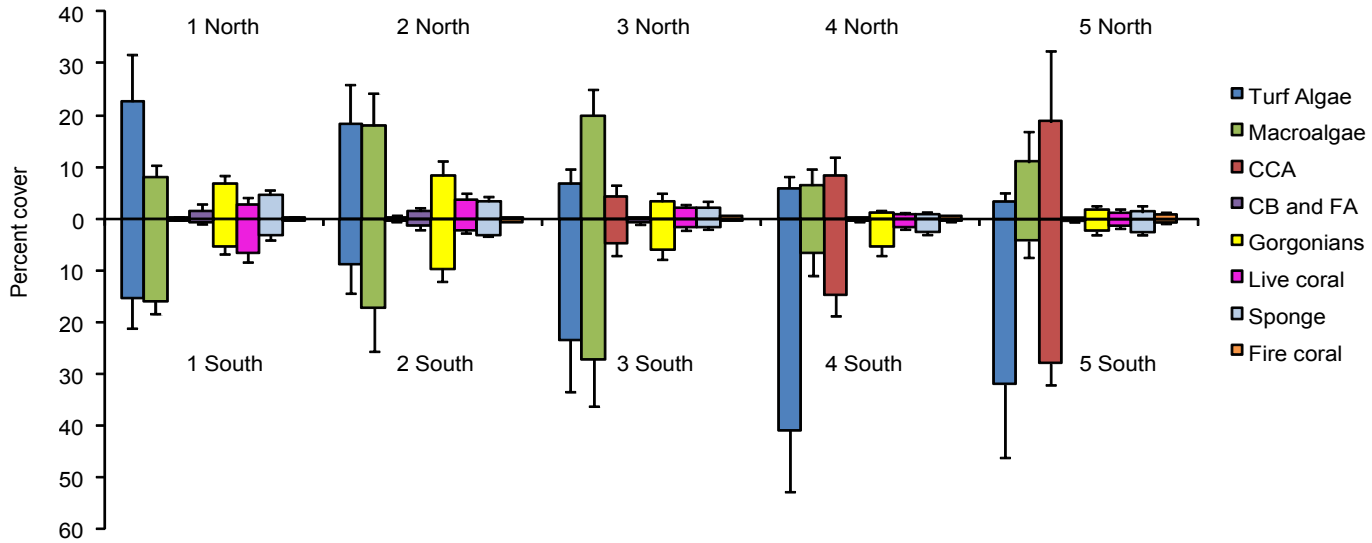


Figure 3.5. Mean (±SE) percent cover for key components of benthic community across strata.

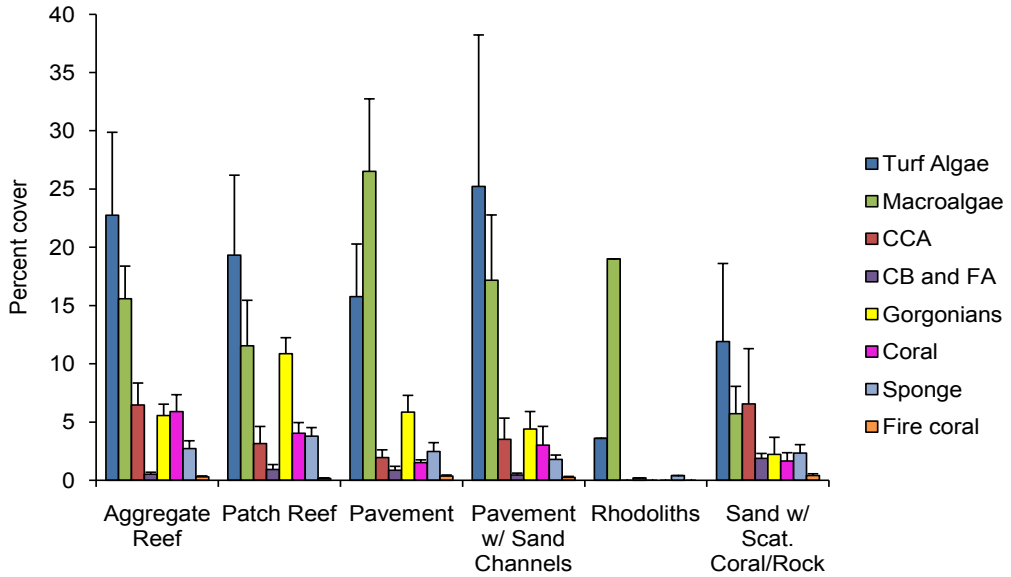


Figure 3.6. Mean (±SE) percent cover for key components of benthic community across hardbottom habitat types.

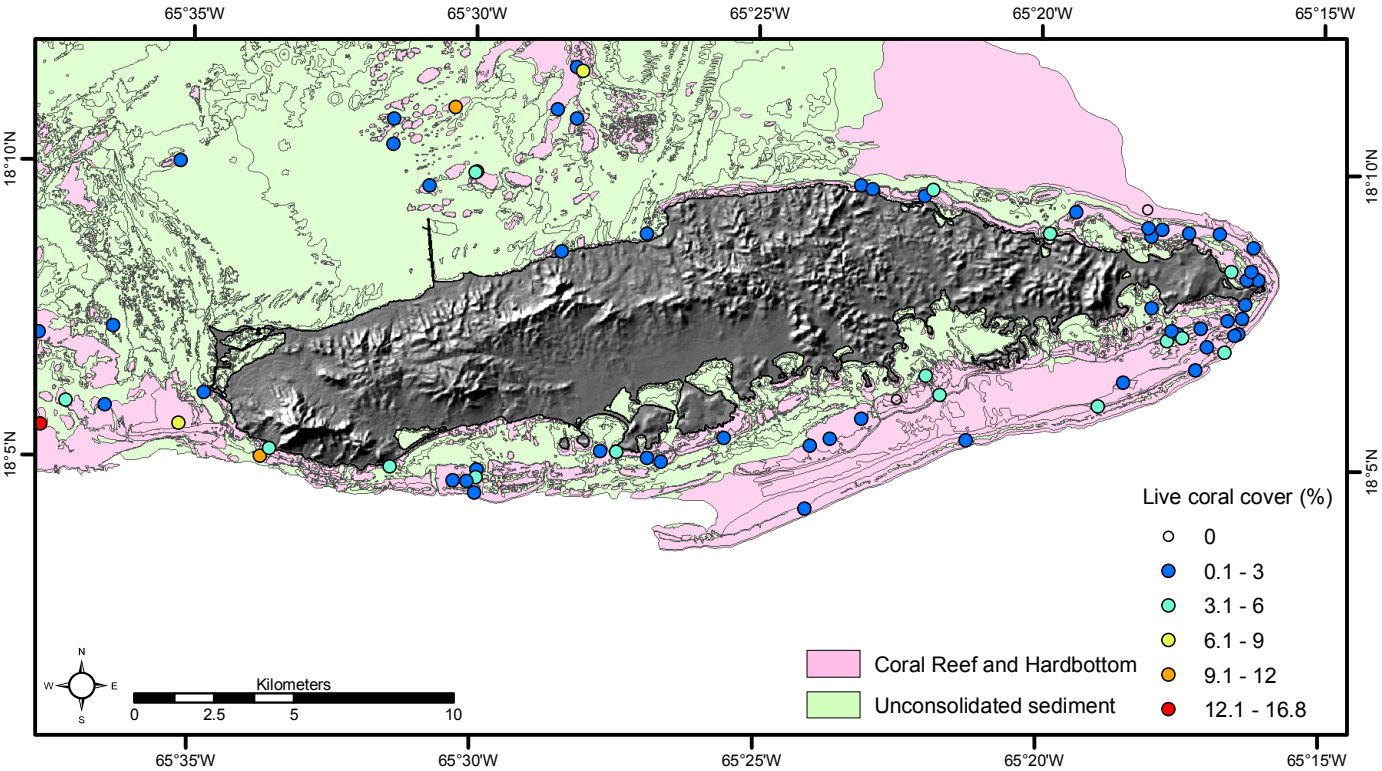


Figure 3.7. Percent live coral cover.

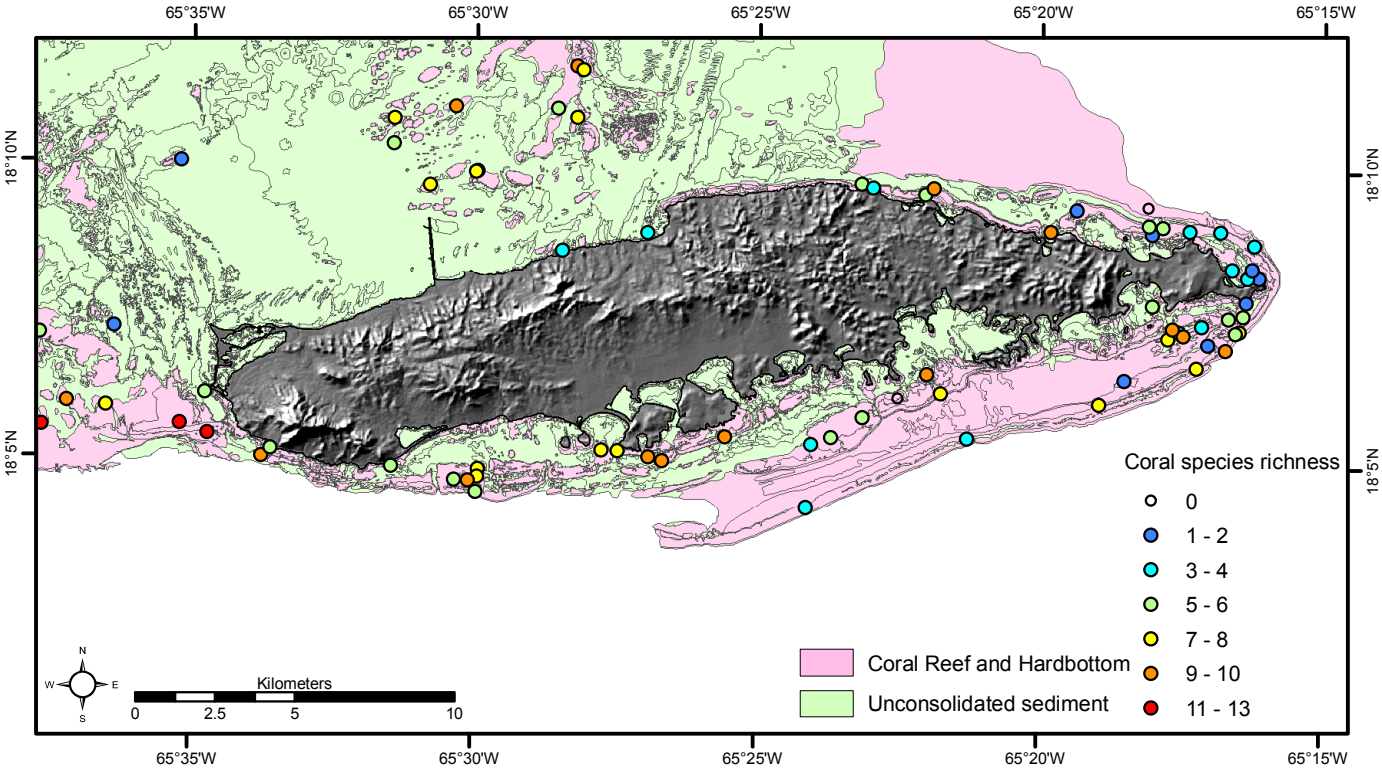


Figure 3.8. Coral species richness.

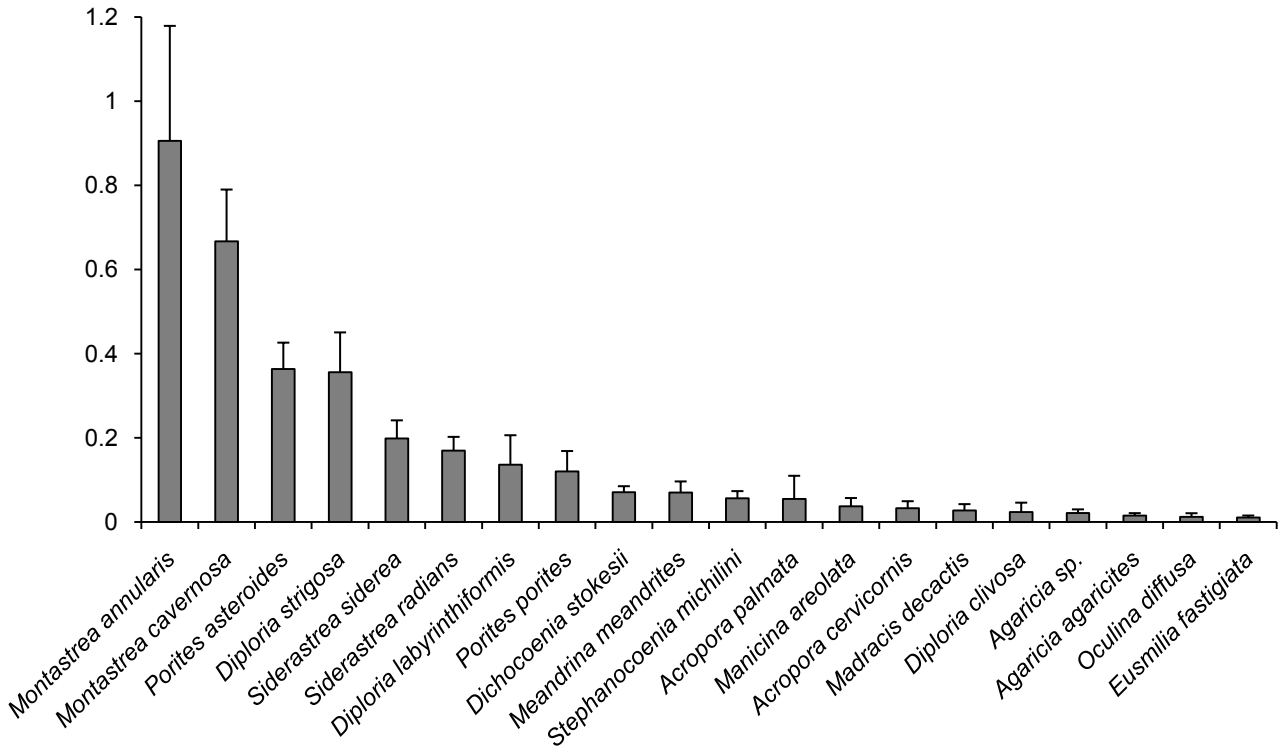


Figure 3.9. Mean (±SE) percent live coral cover of the 20 most abundant coral species on reef/hardbottom across all surveys. Species identified as *Montastrea annularis* refer to the *M. annularis* complex.

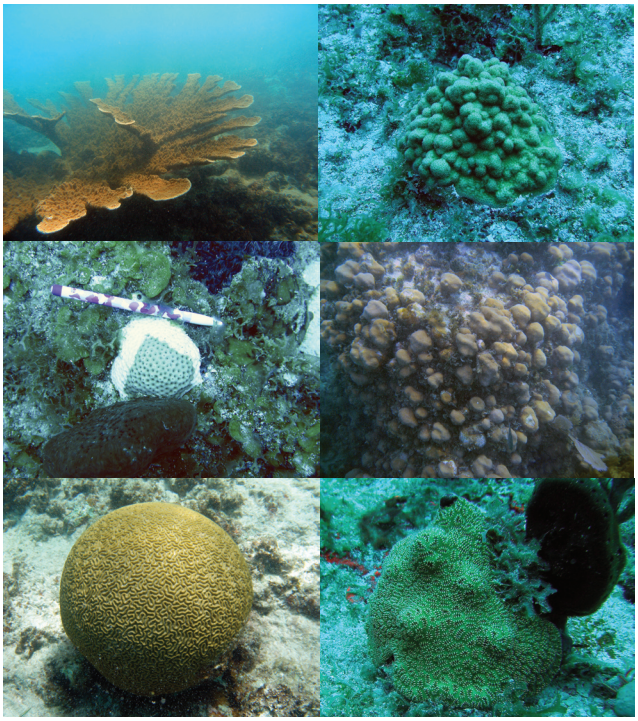


Image 3.4. Clockwise from top-left: *Acropora palmata*, *Porites astreoides*, *Montastrea annularis*, *Dichocoenia stokesi*, *Diploria strigosa,* and *Siderastrea siderea* (partially bleached). Photos: CCMA Biogeography Branch.

astreoides, and *Diploria strigosa* (Figure 3.9). Incidences of bleaching and diseased coral were rare, with each malady occurring in only 4% of the surveyed transects. *Acropora palmata* (elkhorn coral), an important reef-building species that is currently enlisted as threatened under the ESA (Endangered Species Act), was rarely observed, occurring in only one survey. Cover of staghorn coral (*A. cervicornis*) was also low, but the species was more frequently present (12% of surveys) than *A. palmata*.

Mean gorgonian cover was 5.9 (±0.7)% and ranged from 0-25%. Sea plumes/rods/whips were the dominant gorgonian type in terms of both percent cover and number of individuals (Table 3.3), followed by sea fans. Encrusting gorgonians typically made up a small percentage of the benthic community and were recorded at fewer sites than the other gorgonian types. In general, gorgonian cover was higher in the western portion of the study area and decreased further east. The stratum with the highest mean cover was 3-South (Figure 3.5; Figure 3.10), although cover was only significantly greater than the stratum with the lowest mean percent cover, 4-North ($p<0.05$). Gorgonian cover was highest on patch reefs (10.9 ± 1.4)% followed by aggregate reef and pavement, where mean cover was slightly below 6% (Figure 3.6).

Sponge cover averaged 2.6 (±0.3)% and ranged from 0-10.4%. Barrel/tube/vase sponges accounted for the majority of percent cover (2.0 ± 0.3%), while encrusting sponges made up a smaller component of the sponge community (0.7 ± 0.1%). Among strata, the highest cover was found in 1-North, which was significantly greater than cover in 4-North. No other pairwise comparisons were significant, and there were no other distinct spatial patterns in sponge cover (Figure 3.11).

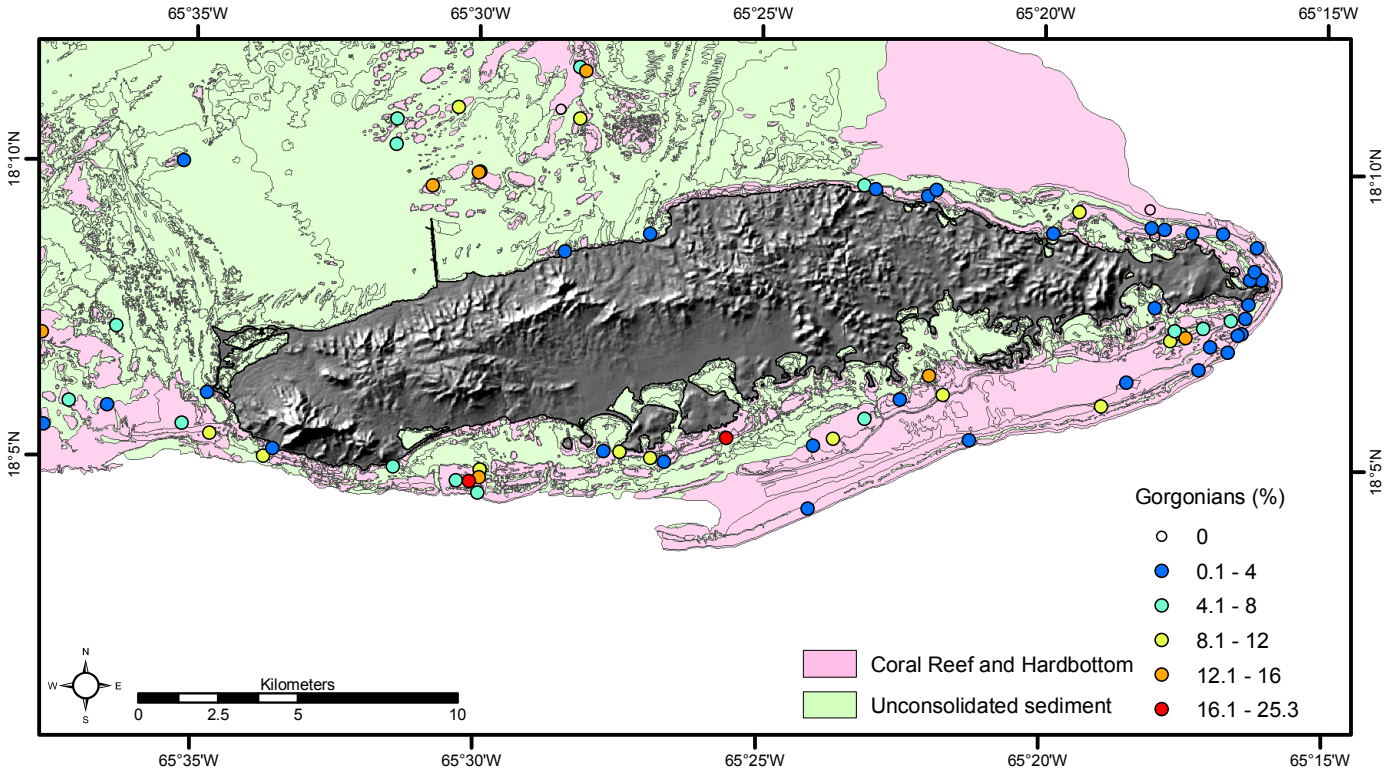


Figure 3.10. Percent gorgonian cover.

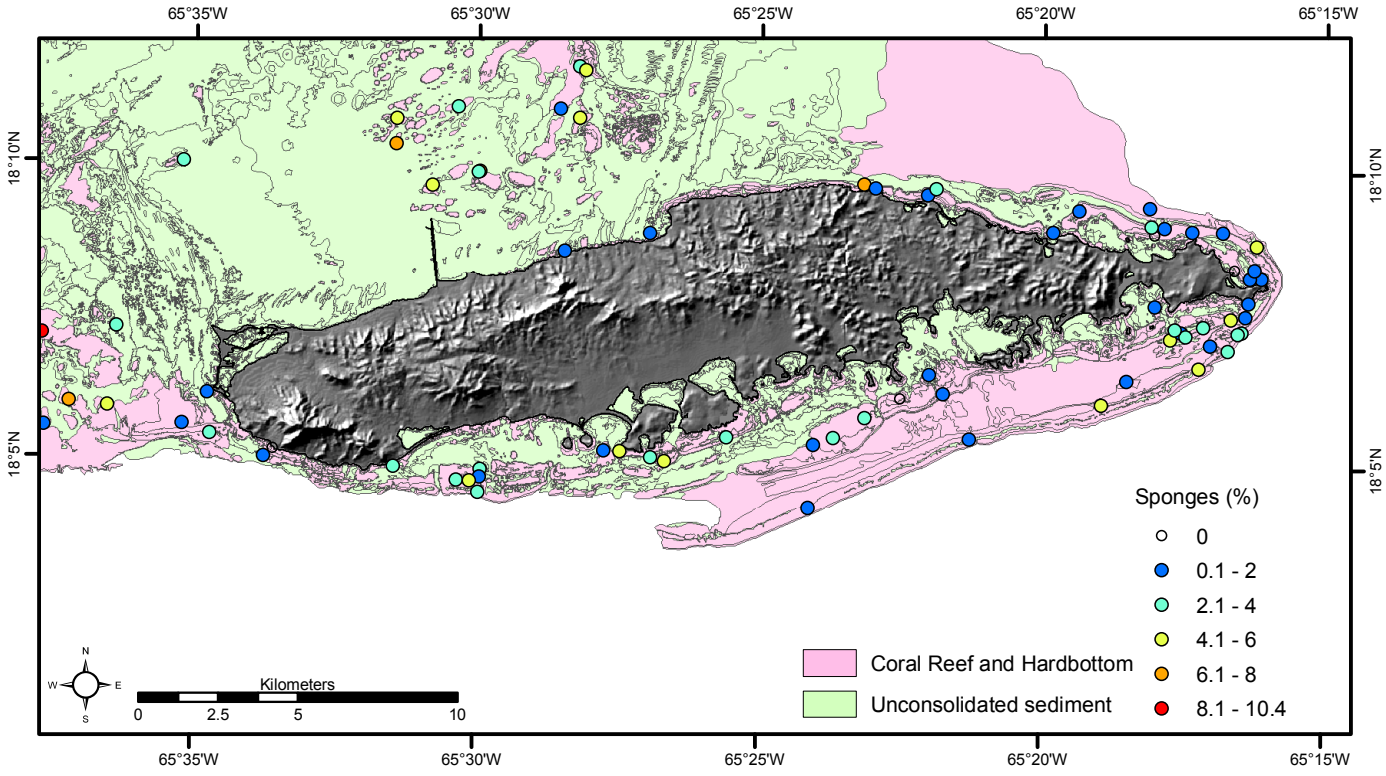


Figure 3.11. Percent sponge cover.

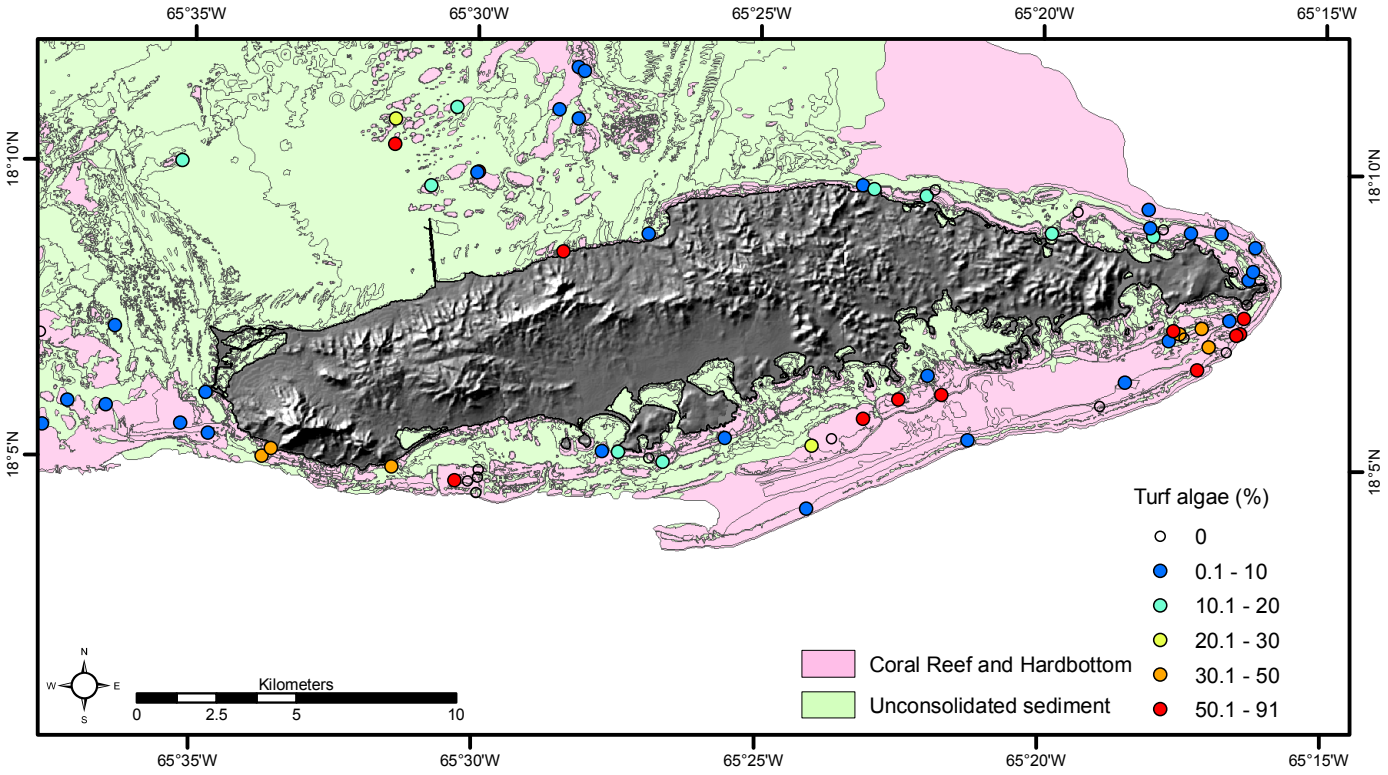


Figure 3.12. Percent turf algae cover.

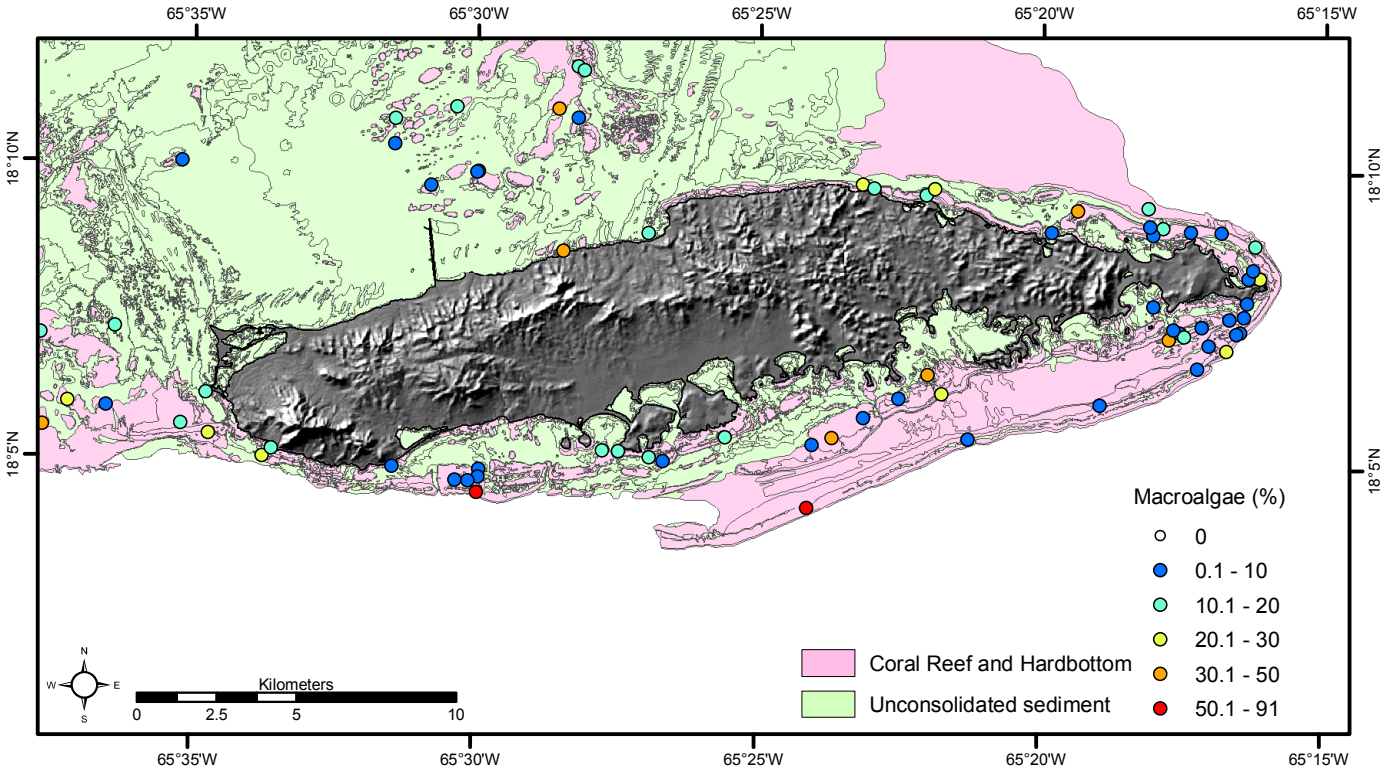


Figure 3.13. Percent macroalgae cover.

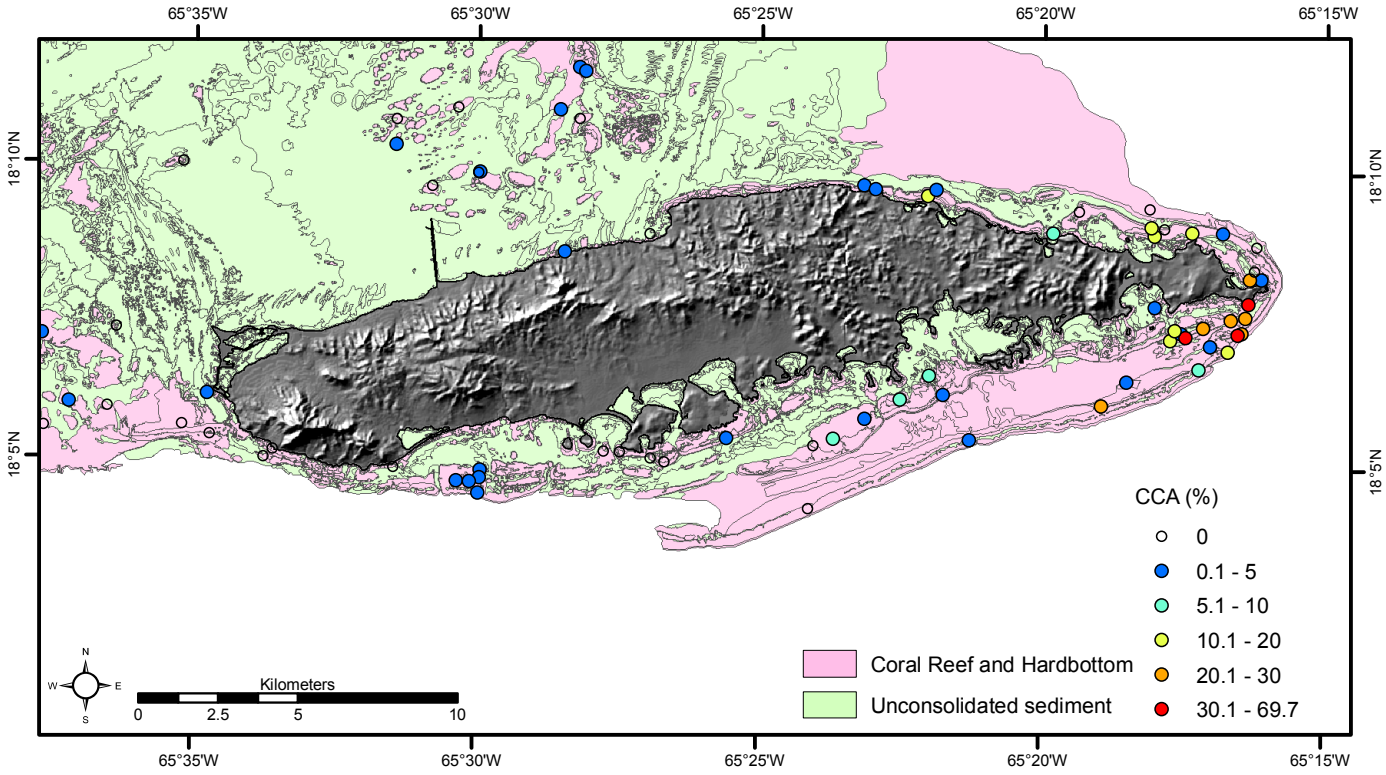


Figure 3.14. Percent crustose coralline algae (CCA) cover.

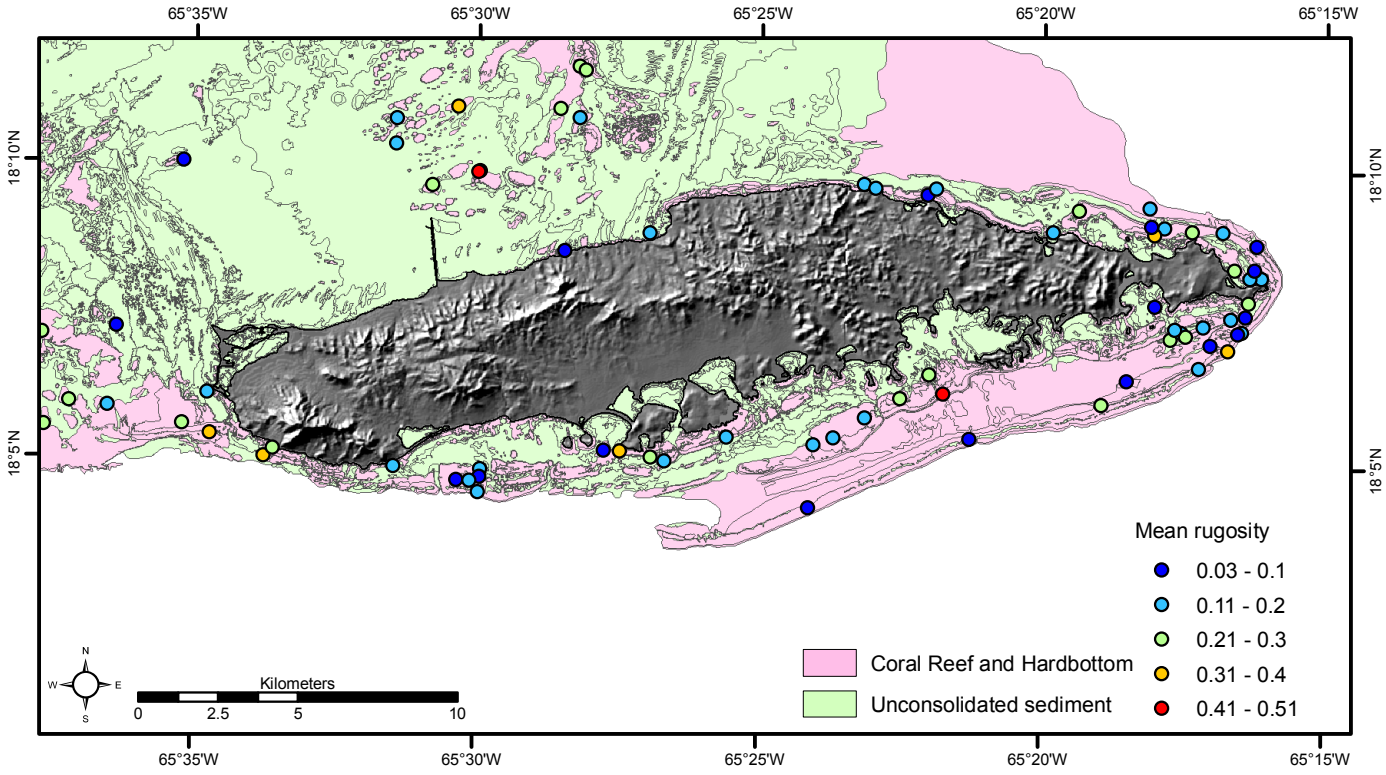


Figure 3.15. Mean rugosity.

Image 3.5. Barrel sponge. Photo: CCMA Biogeography Branch.

Turf algae was the most dominant algal type in terms of percent cover. Cover averaged 19.0 (±3.3)% and ranged from 0-91% (Figure 3.12). Sites on the south side tended to have higher cover of turf algae than those in northern strata, particularly near the east end of the island. However, there were no significant differences in mean percent cover among strata.

Macroalgal cover averaged 41.9 (±3.3)% and ranged from 0-91.2%. Although there was a large degree of variability, in general macroalgal cover tended to be lower at sites located near the east end of the island (Figures 3.5, 3.13). However, there were no significant differences in percent cover among strata. Among structure types, macroalgae cover was highest on pavement, averaging 26.5 (±6.2)%.

Mean cover of crustose (coralline) algae was 4.1 (±0.8)% and ranged from 0-69.7%. Crustose algae was rare at sites on the western half of the island, but was more prevalent at sites on the eastern end (Figure 3.14). Mean percent cover was significantly greater in 5-South and 4-South when compared to 2-North, 2-South, 1-South, and 1-North. Additionally, cover was significantly higher in 5-South than the 3-South stratum.

Mean rugosity was 0.2 (±0.01) and ranged from 0.03-0.51. There were no distinct spatial patterns in rugosity (Figure 3.15) or significant differences among survey strata. Among structure types, the highest mean rugosity was found on aggregate reef, followed by patch reefs. As expected, less complex habitats (e.g., pavement, sand w/ scattered coral and rock) generally had lower rugosity.

Since 2001, the Biogeography Branch has regularly monitored habitat and reef fish communities using the same survey methodology in other U.S. Caribbean locations, including the Buck Island National Reef Monument in St. Croix (USVI, Pittman et al. 2008), St. John (USVI) and La Parguera in southwestern Puerto Rico (http://ccma.nos.noaa.gov/ecosystems/coralreef/reef_fish.html). Summary data from 2006-2008 was generated for major benthic cover groups for each region to compare with the Vieques findings (Figure 3.16). Although the datasets extend back further, we chose to use only the recent data to be more consistent with the time period in which Vieques was surveyed. In general, levels of benthic cover in Vieques were similar to the other regions, with the exception of slightly lower, but more variable, turf algae cover, and slightly higher crustose algae cover. The higher variability is expected due to the smaller sample size in Vieques. Mean coral cover was similarly low in the other survey locations in comparison to Vieques. Likewise, Riegl et al. (2008) found similarities in the amount of coral cover and coral species assemblages between study locations in Vieques and St. Croix. In contrast to the U.S. Caribbean, mean coral cover at the Flower Garden Banks in the Gulf of Mexico is estimated at 48% (Caldow et al. 2009).

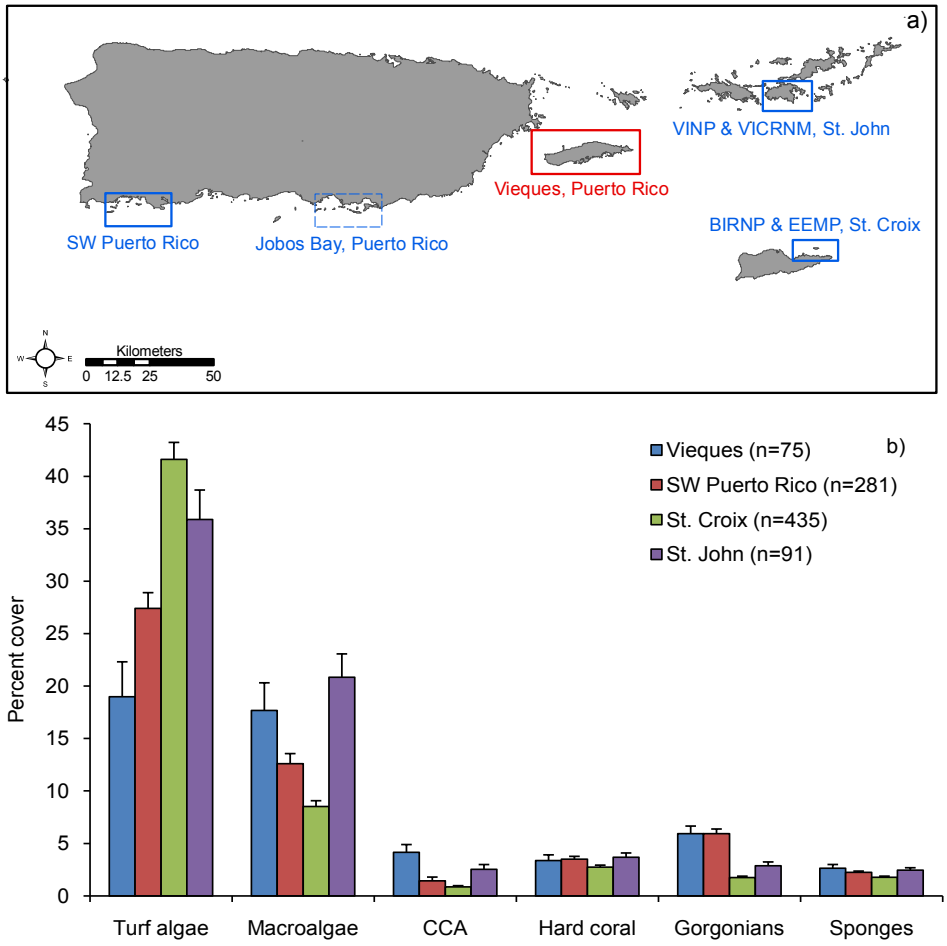


Figure 3.16. a) Locations of CCMA Biogeography Branch monitoring locations. b) Estimated mean (±SE) percent cover of major benthic groups at Vieques in 2007 and other Caribbean monitoring locations (2006-2008). Data from Jobos Bay (2009) was not analyzed at the time of publication of this report.

There have been several previous surveys of hardbottom and reef communities in Vieques that measured coral cover in conjunction with a suite of other habitat and fish variables (e.g., Garcia-Sais et al. 2001, 2004; GMI 2003, 2005; Riegl et al. 2008). These studies have been discussed more comprehensively in Bauer et al. (2008) and are referenced here for comparative purposes only. The most recent studies were primarily restricted to either the east end (GMI 2003, 2005; Riegl et al. 2008) or non-military areas (Garcia-Sais et al. 2001, 2004). These surveys were conducted with different methods (e.g., chain transects, photo transects) making direct comparisons difficult. In addition, it is important to note that all previous studies were conducted before a major bleaching event in 2005. While there are no studies to quantify the extent of the bleaching or resulting change in coral cover around Vieques, widespread bleaching was observed at nearby locations (Clark et al. 2009). At study sites in St. Croix and St. John in the USVI, it was estimated that bleaching and/or disease related mortality resulted in a 36-66% (Lundgren and Hillis-Starr 2008) and 26-48% (Miller et al. 2006) loss in regional coral cover, respectively.

Offshore of former Navy areas on the eastern portion of the island, GMI 2003/Riegl et al. 2008 estimated benthic cover using photo-transects and point count software. Coral cover (including fire coral), measured as the mean relative frequency of benthic point counts, was estimated at 5.5 (±0.9 SE)%. This low cover is consistent with our results, however within the same area (Strata 3 and 4) combined hard coral and fire coral cover did not exceed this amount at any of the sites in the present survey (Figure 3.5, 3.7). While it is unknown how much of this difference can be attributed to variation in survey design and sampling methods, it's possible that coral cover has further declined in this region.

Garcia-Sais et al. (2001, 2004) documented higher coral cover in their study (mean 24.4 ± 3.4% SE and 28.0 ± 2.0%, respectively) in the western portion of the island. The survey locations of Garcia-Sais et al. (2001, 2004) overlapped with Strata 1 and 2 in this survey, where we observed eight out of 10 sites with the highest coral cover. However, live coral cover exceeded 10% at only four of these sites, whereas Garcia-Sais et al. (2001, 2004) observed coral cover exceeding 10% at all but one survey location. It is likely that the primary reason for this large difference is due to site selection and objectives of the study. The previous monitoring locations were selected in areas of "optimal coral growth" following initial canvassing of the survey area (Garcia-Sais et al. 2001), and are permanent sites to be monitored for changes over time. In contrast, sites in the present survey were selected by a stratified-random design and hence are more reflective of average reef/hardbottom habitat throughout Vieques.

Fish Assemblages

Community metrics

The fish community observed in the study consisted of 34 taxonomic families and 110 species (Table 3.4). Fish species richness ranged from five to 34 species per site (100 m^2). Mean species richness was generally higher in the southern than northern strata, although the difference was less pronounced at the western and eastern ends of the island (Figure 3.17), and slightly higher on aggregate reef than other hardbottom types

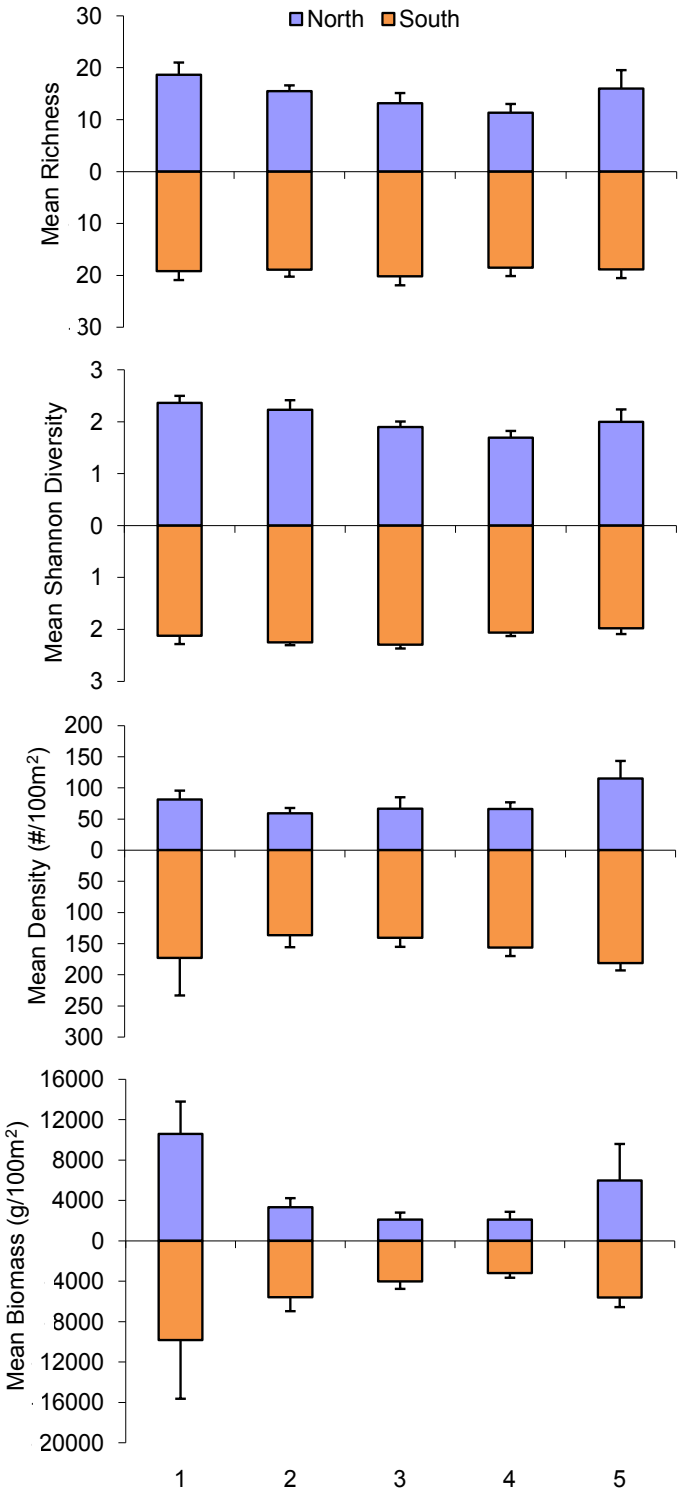


Figure 3.17. Mean (±SE) species richness, Shannon diversity, density, and biomass of fish.

Table 3.4. Mean (+/- SE) frequency, density and biomass for fish species observed at Vieques in the May 2007 survey. H=Herbivore, P=Piscivore, I=Invertivore, Z=Zooplanktivore.

Species	Common Name	Family	Trophic group	% of Surveys	Mean Density (SE)	Mean Biomass (SE)
Abudefduf saxatilis	Sergeant major	Pomacentridae	I	7%	0.20 (0.09)	8.30 (6.14)
Acanthemblemaria spp.	Blenny species	Chaenopsidae	I	7%	0.05 (0.03)	0.02 (0.01)
Acanthostracion quadricornis	Scrawled cowfish	Ostraciidae	I	1%	0.01 (0.01)	0.09 (0.09)
Acanthurus bahianus	Ocean surgeonfish	Acanthuridae	H	89%	6.73 (0.68)	434.29 (64.44)
Acanthurus chirurgus	Doctorfish	Acanthuridae	H	21%	0.44 (0.17)	33.29 (16.86)
Acanthurus coeruleus	Blue tang	Acanthuridae	H	76%	3.95 (0.51)	339.24 (61.78)
Amblycirrhitus pinos	Redspotted hawkfish	Cirrhitidae	Z	4%	0.14 (0.08)	0.02 (0.01)
Anisotremus virginicus	Porkfish	Haemulidae	I	4%	0.06 (0.03)	14.09 (8.99)
Aulostomus maculatus	Trumpetfish	Aulostomidae	P	7%	0.08 (0.04)	6.20 (2.86)
Balistes vetula	Queen triggerfish	Balistidae	I	15%	0.19 (0.09)	140.49 (53.89)
Bodianus rufus	Spanish hogfish	Labridae	I	13%	0.12 (0.04)	19.16 (7.73)
Calamus calamus	Saucereye porgy	Sparidae	I	25%	0.50 (0.19)	87.53 (44.36)
Canthidermis sufflamen	Ocean triggerfish	Balistidae	I	1%	<0.01 (<0.01)	5.51 (5.51)
Canthigaster rostrata	Sharpnose puffer	Tetraodontidae	I	23%	0.44 (0.12)	3.49 (2.34)
Carangoides ruber	Bar jack	Carangidae	P	27%	0.98 (0.57)	14.02 (3.92)
Cephalopholis cruentata	Graysby	Serranidae	P	11%	0.21 (0.09)	26.12 (10.73)
Cephalopholis fulva	Coney	Serranidae	P	23%	0.35 (0.10)	41.45 (13.21)
Chaenopsis limbaughi	Yellowface pikeblenny	Chaenopsidae	I	1%	0.01 (0.01)	0.10 (0.10)
Chaetodon capistratus	Foureye butterflyfish	Chaetodontidae	I	51%	1.30 (0.20)	34.51 (8.41)
Chaetodon ocellatus	Spotfin butterflyfish	Chaetodontidae	I	1%	0.03 (0.03)	1.83 (1.83)
Chaetodon sedentarius	Reef butterflyfish	Chaetodontidae	I	4%	0.04 (0.03)	1.04 (0.75)
Chaetodon striatus	Banded butterflyfish	Chaetodontidae	I	20%	0.28 (0.07)	5.02 (1.74)
Chromis cyanea	Blue chromis	Pomacentridae	Z	27%	4.09 (1.44)	20.74 (6.87)
Chromis multilineata	Brown chromis	Pomacentridae	Z	19%	1.59 (0.72)	3.88 (2.46)
Clepticus parrae	Creole wrasse	Labridae	Z	3%	6.57 (6.28)	515.70 (515.59)
Coryphopterus glaucofraenum	Bridled goby	Gobiidae	H	20%	1.45 (0.84)	1.42 (0.67)
Coryphopterus personatus/ hyalinus	Masked/Glass goby	Gobiidae	H	4%	1.26 (1.09)	0.82 (0.71)
Ctenogobius saepepallens	Dash goby	Gobiidae	H	1%	<0.01 (<0.01)	<0.01 (<0.01)
Decapterus macarellus	Mackerel scad	Carangidae	Z	3%	11.33 (10.96)	901.79 (891.31)
Diodon holocanthus	Balloonfish	Diodontidae	I	1%	0.02 (0.02)	5.55 (5.55)
Epinephelus adscensionis	Rock hind	Serranidae	I	1%	0.01 (0.01)	0.94 (0.94)
Epinephelus guttatus	Red hind	Serranidae	P	29%	0.40 (0.09)	129.77 (43.40)
Gerres cinereus	Yellowfin mojarra	Gerreidae	I	3%	0.04 (0.03)	1.99 (1.61)
Ginglymostoma cirratum	Nurse shark	Ginglymostomatidae	P	1%	<0.01 (<0.01)	<0.01 (<0.01)
Gnatholepis thompsoni	Goldspot goby	Gobiidae	H	15%	0.37 (0.15)	0.38 (0.30)
Gobiosoma evelynae	Sharknose goby	Gobiidae	I	15%	0.28 (0.09)	0.07 (0.02)
Gramma loreto	Fairy basslet	Grammatidae	I	8%	0.21 (0.10)	0.34 (0.21)
Gymnothorax miliaris	Goldentail moray	Muraenidae	P	1%	<0.01 (<0.01)	0.03 (0.03)
Gymnothorax moringa	Spotted moray	Muraenidae	P	1%	<0.01 (<0.01)	<0.01 (<0.01)
Haemulon aurolineatum	Tomtate	Haemulidae	I	1%	0.03 (0.03)	2.93 (2.93)
Haemulon carbonarium	Caesar grunt	Haemulidae	I	7%	0.12 (0.07)	17.05 (8.36)
Haemulon chrysargyreum	Smallmouth grunt	Haemulidae	I	1%	0.03 (0.03)	1.00 (1.00)
Haemulon flavolineatum	French grunt	Haemulidae	I	25%	0.64 (0.16)	59.99 (17.26)
Haemulon plumierii	White grunt	Haemulidae	I	20%	0.92 (0.38)	267.34 (119.39)
Haemulon sciurus	Bluestriped grunt	Haemulidae	I	4%	0.06 (0.04)	8.12 (4.73)
Haemulon spp.	Grunt species	Haemulidae	I	1%	0.03 (0.03)	0.01 (0.01)
Halichoeres bivittatus	Slippery dick	Labridae	I	48%	5.19 (1.40)	19.51 (6.19)
Halichoeres garnoti	Yellowhead wrasse	Labridae	I	64%	5.75 (0.80)	32.74 (4.49)
Halichoeres maculipinna	Clown wrasse	Labridae	I	27%	0.57 (0.16)	0.68 (0.53)
Halichoeres poeyi	Blackear wrasse	Labridae	I	11%	0.13 (0.05)	1.56 (0.89)
Halichoeres radiatus	Puddingwife	Labridae	I	25%	0.26 (0.07)	1.69 (0.71)

Table 3.4. Continued.

Species	Common Name	Family	Trophic group	% of Surveys	Mean Density (SE)	Mean Biomass (SE)
Heteropriacanthus cruentatus	Glasseye snapper	Priacanthidae	Z	1%	0.01 (0.01)	0.85 (0.85)
Holacanthus ciliaris	Queen angelfish	Pomacanthidae	I	1%	0.01 (0.01)	2.06 (2.06)
Holacanthus tricolor	Rock beauty	Pomacanthidae	I	9%	0.10 (0.04)	3.85 (1.70)
Holocentrus adscensionis	Squirrelfish	Holocentridae	I	24%	0.39 (0.11)	48.20 (15.52)
Holocentrus rufus	Longspine squirrelfish	Holocentridae	I	49%	1.38 (0.53)	114.26 (43.44)
Hypoplectrus chlorurus	Yellowtail hamlet	Serranidae	I	1%	0.02 (0.02)	0.06 (0.06)
Hypoplectrus indigo	Indigo hamlet	Serranidae	I	1%	0.02 (0.02)	0.43 (0.43)
Hypoplectrus nigricans	Black hamlet	Serranidae	P	3%	0.03 (0.03)	0.68 (0.55)
Hypoplectrus puella	Barred hamlet	Serranidae	I	7%	0.14 (0.06)	2.35 (1.52)
Hypoplectrus spp.	Hamlet species	Serranidae	I	4%	0.06 (0.04)	0.65 (0.53)
Hypoplectrus unicolor	Butter hamlet	Serranidae	P	7%	0.08 (0.04)	1.68 (0.93)
Kyphosus sectator	Chub (Bermuda/Yellow)	Kyphosidae	H	1%	0.01 (0.01)	6.68 (6.68)
Lachnolaimus maximus	Hogfish	Labridae	I	12%	0.15 (0.05)	16.23 (7.00)
Lactophrys triqueter	Smooth trunkfish	Ostraciidae	I	8%	0.08 (0.03)	10.38 (4.80)
Lutjanus analis	Mutton snapper	Lutjanidae	I	5%	0.04 (0.02)	33.85 (20.64)
Lutjanus apodus	Schoolmaster	Lutjanidae	P	12%	0.38 (0.21)	73.58 (56.82)
Lutjanus griseus	Gray snapper	Lutjanidae	P	4%	0.03 (0.01)	2.98 (1.80)
Lutjanus jocu	Dog snapper	Lutjanidae	P	1%	0.02 (0.02)	36.92 (36.93)
Lutjanus mahogoni	Mahogany snapper	Lutjanidae	P	1%	0.02 (0.02)	4.53 (4.53)
Lutjanus synagris	Lane snapper	Lutjanidae	P	3%	0.02 (0.01)	4.37 (3.44)
Malacanthus plumieri	Sand tilefish	Malacanthidae	I	8%	0.10 (0.05)	26.06 (12.75)
Malacoctenus macropus	Rosy blenny	Labrisomidae	I	7%	0.13 (0.08)	0.31 (0.23)
Malacoctenus triangulatus	Saddled blenny	Labrisomidae	I	8%	0.09 (0.04)	0.02 (0.01)
Melichthys niger	Black durgon	Balistidae	H	7%	0.19 (0.17)	68.51 (59.72)
Microspathodon chrysurus	Yellowtail damselfish	Pomacentridae	H	15%	0.47 (0.21)	27.32 (14.45)
Mulloidichthys martinicus	Yellow goatfish	Mullidae	I	5%	0.18 (0.12)	17.55 (12.51)
Mycteroperca tigris	Tiger grouper	Serranidae	P	1%	0.03 (0.03)	27.80 (27.80)
Myripristis jacobus	Blackbar soldierfish	Holocentridae	I	5%	0.06 (0.03)	10.64 (6.52)
Nes longus	Orangespotted goby	Gobiidae	I	5%	0.42 (0.29)	9.92 (9.44)
Ocyurus chrysurus	Yellowtail snapper	Lutjanidae	I	69%	2.76 (0.50)	359.77 (112.91)
Ophioblennius macclurei	Redlip blenny	Blenniidae	H	12%	0.34 (0.15)	1.09 (0.55)
Opistognathus aurifrons	Yellowhead jawfish	Opistognathidae	Z	8%	0.32 (0.16)	1.13 (0.58)
Pareques acuminatus	Highhat	Sciaenidae	I	1%	0.01 (0.01)	0.61 (0.61)
Pomacanthus arcuatus	Gray angelfish	Pomacanthidae	I	21%	0.34 (0.08)	137.66 (37.24)
Pomacanthus paru	French angelfish	Pomacanthidae	I	16%	0.45 (0.24)	174.02 (84.19)
Prognathodes aculeatus	Longsnout butterflyfish	Chaetodontidae	I	1%	0.01 (0.01)	0.10 (0.10)
Pseudupeneus maculatus	Spotted goatfish	Mullidae	I	28%	0.51 (0.13)	26.55 (7.91)
Scarus iseri	Striped parrotfish	Scaridae	H	32%	2.86 (0.89)	51.67 (19.72)
Scarus taeniopterus	Princess parrotfish	Scaridae	H	47%	3.54 (0.71)	186.92 (44.34)
Scarus vetula	Queen parrotfish	Scaridae	H	4%	0.06 (0.03)	6.64 (4.23)
Scomberomorus regalis	Cero	Scombridae	P	1%	0.03 (0.03)	16.94 (16.94)
Serranus baldwini	Lantern bass	Serranidae	I	7%	0.15 (0.08)	0.78 (0.44)
Serranus tabacarius	Tobaccofish	Serranidae	P	5%	0.12 (0.07)	2.63 (1.50)
Serranus tigrinus	Harlequin bass	Serranidae	I	28%	0.71 (0.15)	8.47 (2.01)
Serranus tortugarum	Chalk bass	Serranidae	Z	4%	0.50 (0.42)	3.20 (2.17)
Sparisoma atomarium	Greenblotch parrotfish	Scaridae	H	8%	0.31 (0.19)	0.53 (0.44)
Sparisoma aurofrenatum	Redband parrotfish	Scaridae	H	91%	8.63 (0.78)	330.17 (51.39)
Sparisoma rubripinne	Yellowtail parrotfish	Scaridae	H	11%	0.25 (0.10)	33.49 (16.53)
Sparisoma viride	Stoplight parrotfish	Scaridae	H	65%	2.19 (0.31)	348.57 (72.71)
Sphoeroides testudineus	Checkered puffer	Tetraodontidae	I	1%	0.02 (0.02)	0.86 (0.86)
Sphyraena barracuda	Great barracuda	Sphyraenidae	P	15%	0.21 (0.07)	206.75 (122.08)
Stegastes adustus	Dusky damselfish	Pomacentridae	H	17%	0.48 (0.17)	2.78 (1.18)
Stegastes diencaeus	Longfin damselfish	Pomacentridae	H	17%	0.61 (0.30)	6.13 (2.83)

Table 3.4. Continued.

Species	Common Name	Family	Trophic group	% of Surveys	Mean Density (SE)	Mean Biomass (SE)
Stegastes leucostictus	Beaugregory	Pomacentridae	H	19%	0.31 (0.10)	2.17 (0.85)
Stegastes partitus	Bicolor damselfish	Pomacentridae	H	79%	15.72 (1.50)	25.43 (4.42)
Stegastes planifrons	Threespot damselfish	Pomacentridae	H	13%	0.36 (0.13)	1.87 (1.00)
Stegastes variabilis	Cocoa damselfish	Pomacentridae	H	4%	0.03 (0.02)	0.02 (0.01)
Thalassoma bifasciatum	Bluehead	Labridae	I	83%	26.69 (2.95)	40.12 (6.17)
Xyrichtys splendens	Green razorfish	Labridae	Z	3%	0.12 (0.11)	0.47 (0.47)

(Figure 3.18). Richness in 3-South was significantly greater than 4-North ($p<0.05$); no other pairwise comparisons were significant. Of the 31 sites on the north side of the island, richness only exceeded 20 at three locations (10%), while >20 species were documented at 16 of the 44 locations on the south side (36%) (Figure 3.19).

Shannon diversity (H') ranged from 1.04-2.88. Similar to the richness metric, diversity was significantly lower in 4-North when compared to 3-South ($p<0.05$); no other pairwise comparisons were significant. Although there were no distinct spatial patterns, diversity "hotspots" included patch reefs on the northwestern side of the island and aggregate reef in the southwest region (Figure 3.20).

Overall, total fish density tended to differ on a north-south rather than east-west gradient (Figure 3.17, 3.21). In general, fish density was lower on the north side of the island compared to the south side. Density in 4-South and 5-South were significantly greater compared to all northern strata with the exception of 5-north. In addition, density was significantly greater in 3-South compared to 2-, 3-, and 4-North, and in 2-South compared to 2-North. The large standard error of mean density in 1-South was primarily due to a large school of mackerel scad (*Decapterus macarellus*) at one site.

Although biomass also tended to be higher on the south side and at the eastern and western ends of the island, there was a high degree of variability in some strata (Figure 3.17, 3.22). A Kruskal-Wallis test indicated that biomass was not significantly different among strata ($p = 0.068$). Again, the high mean and standard error in 1-South was partly due to the school of *D. marcarellus*. Similarly, individual sites in 1-North and 5-North with high biomass influenced the high variability in those strata.

Results of the nMDS and ANOSIM analysis indicate that fish assemblages differed among strata (Figure 3.23). In particular, there was a strong north-south effect. Southern sites on the

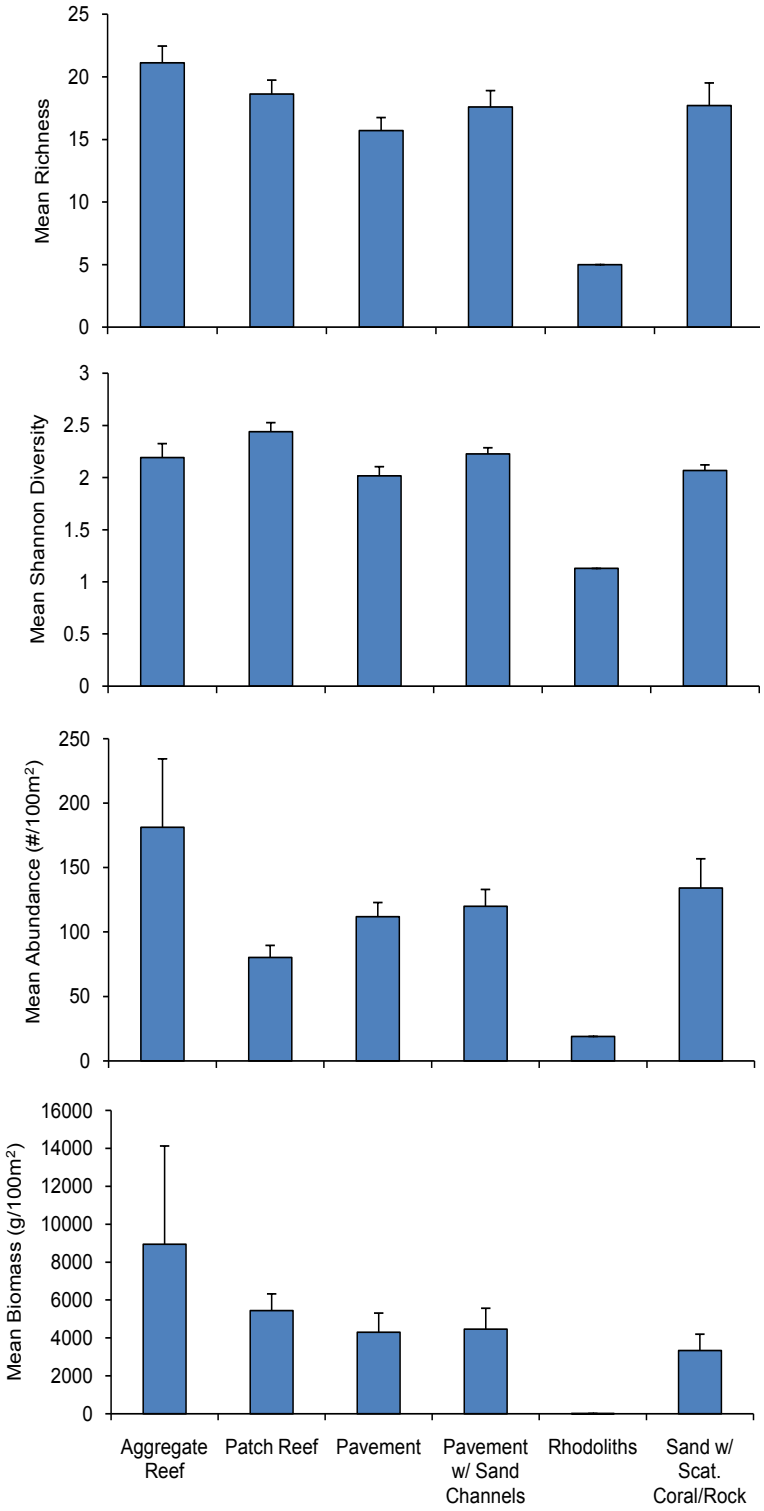


Figure 3.18. Mean (±SE) species richness, Shannon diversity, density, and biomass across hardbottom habitat type in the Vieques 2007 survey.

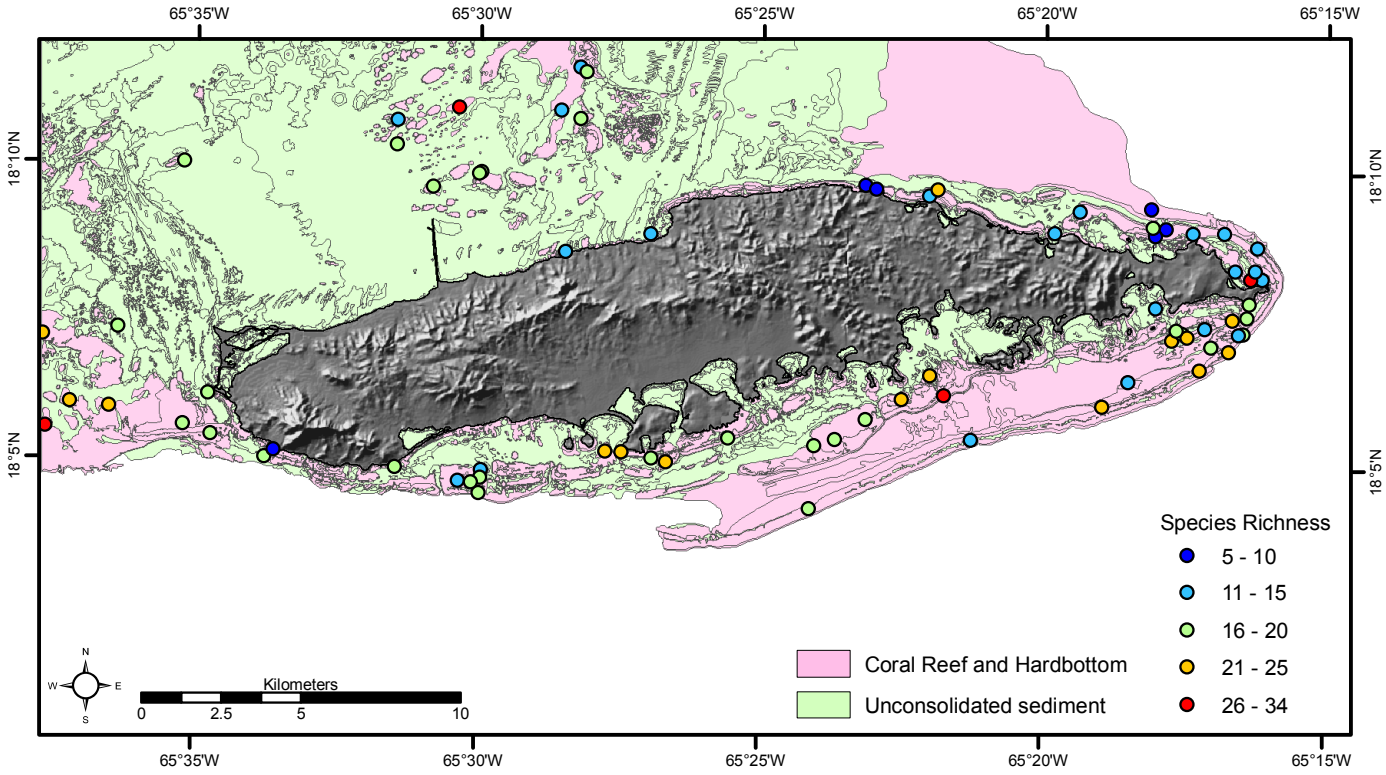


Figure 3.19. Fish species richness.

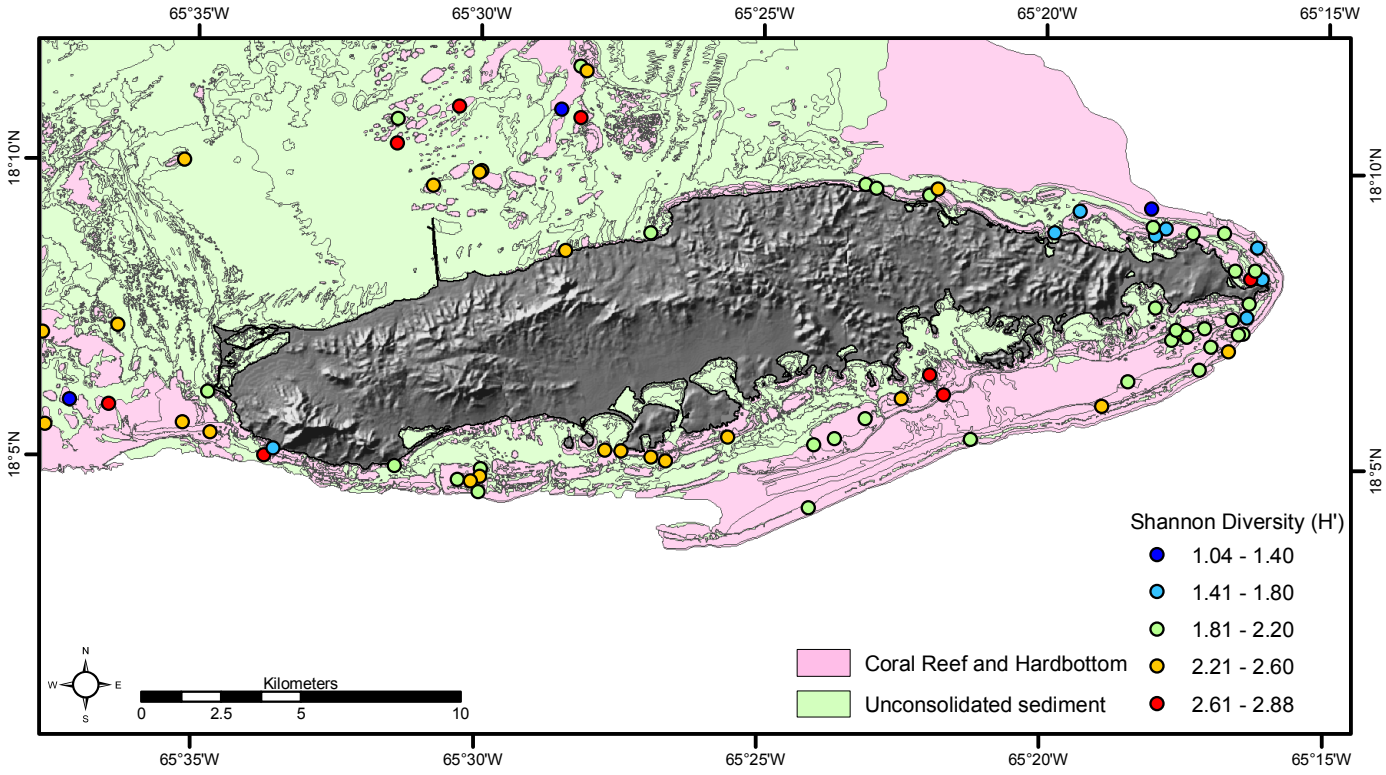


Figure 3.20. Fish species diversity.

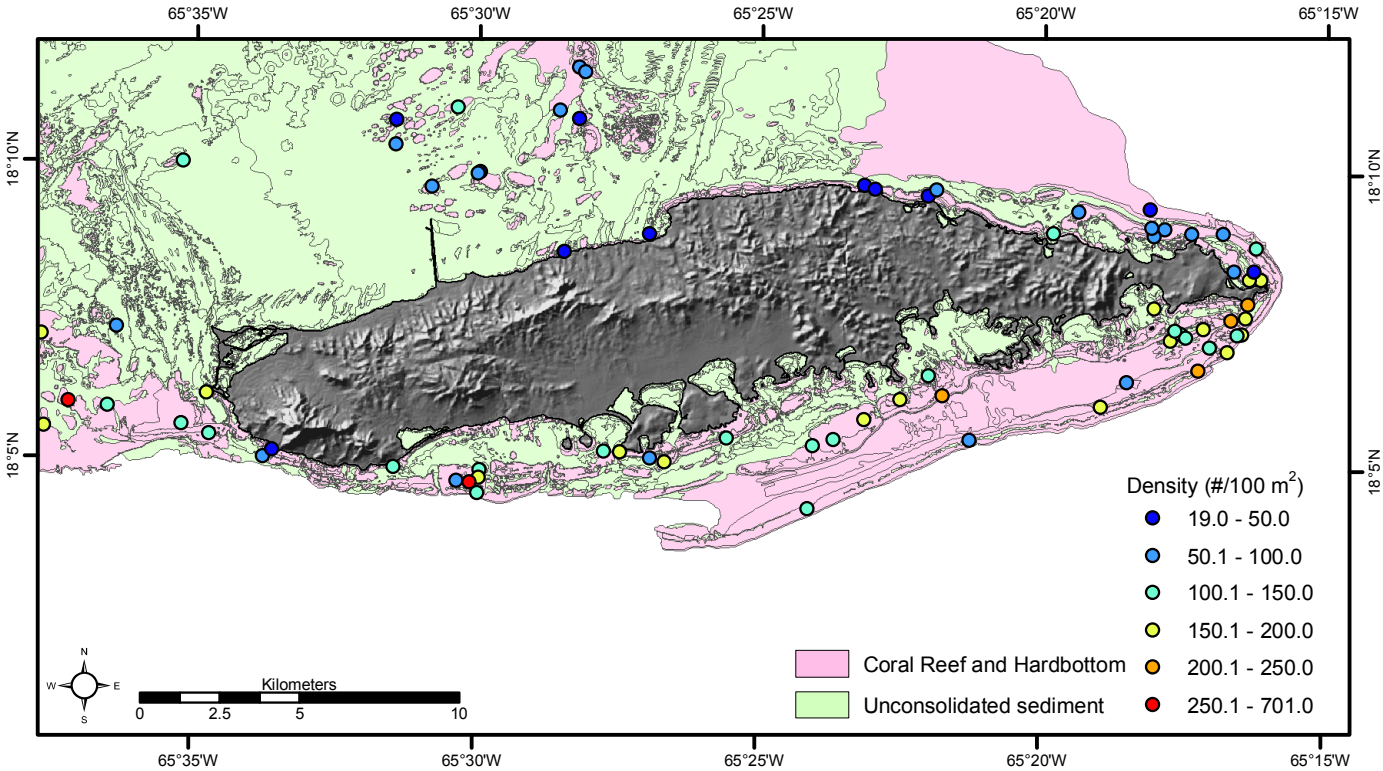


Figure 3.21. Total fish density.

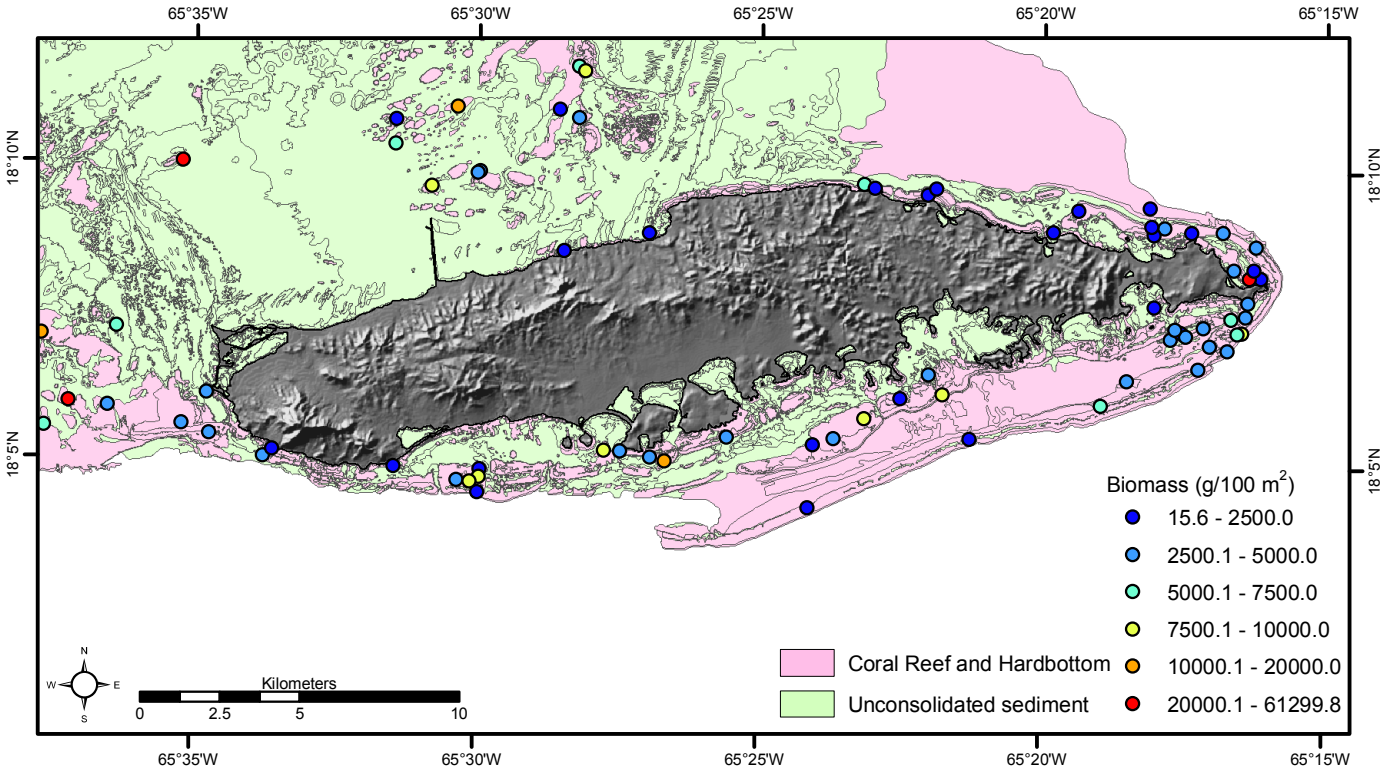


Figure 3.22. Total fish biomass.

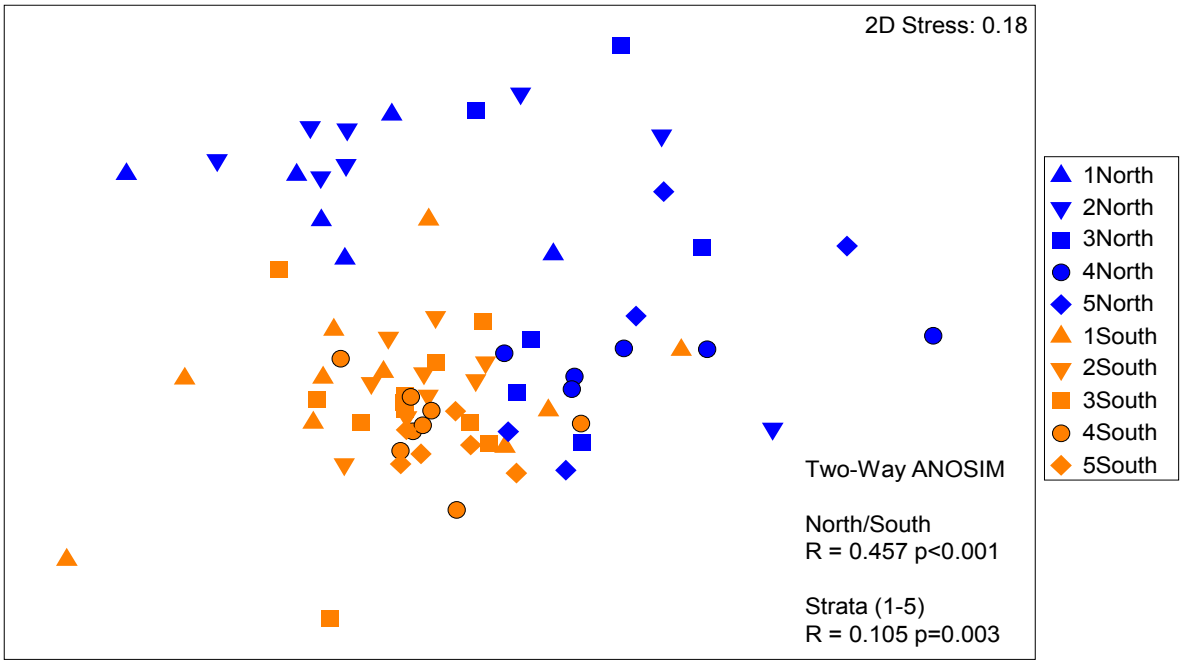


Figure 3.23. Non-metric multidimensional scaling ordination based on between site similarity in fish community composition using fish abundance data. Sites are color-coded by north/south proximity.

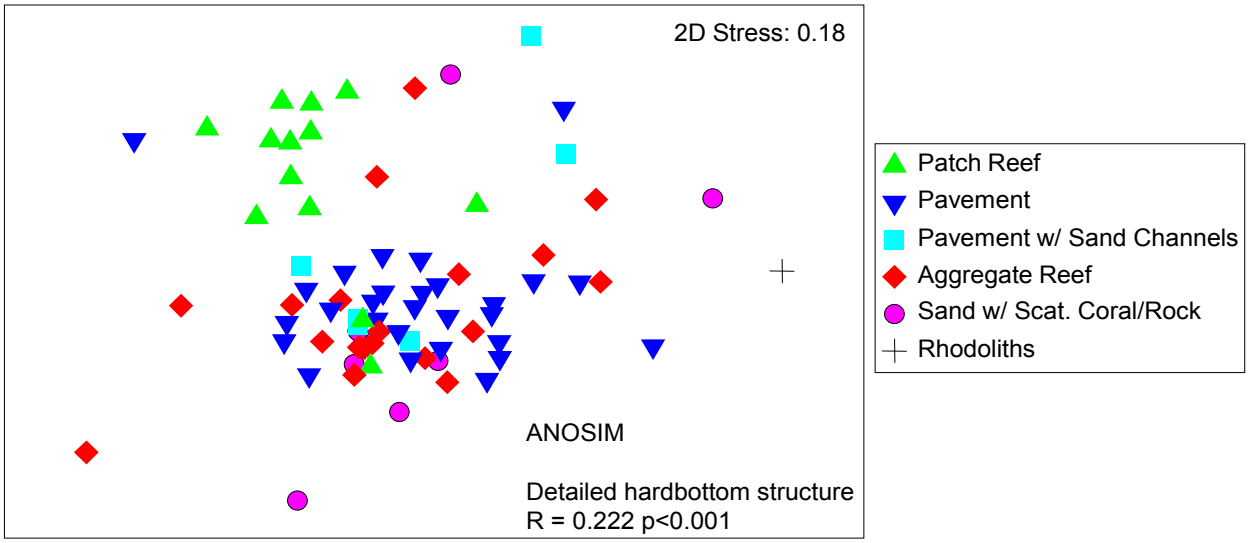


Figure 3.24. Non-metric multidimensional scaling ordination based on between site similarity in fish community composition using fish abundance data. Sites are color-coded by hardbottom habitat type.

nMDS plot formed a more compact group of similar sites. In contrast, northern sites tended to be more dispersed, although sites within strata 1- and 2-North were more similar to each other. Results of the ANOSIM analysis indicated that both the north/south and east-west (i.e., 1-5) strata factors were statistically significant, but the higher R value for the north/south factor (0.457, vs. 0.105 for the 1-5 strata effect) indicates that this factor is more evident. Pairwise tests for differences between strata 1-5 indicated that there were significant differences between communities in strata 1 vs. 3 and 4, and strata 2 vs. 4 and 5.

At least part of the differences in fish community structure among strata, particularly on the north vs. the south side of the island, appears to be associated with hardbottom structure (Figure 3.24). The spatial distribution of benthic habitats around Vieques is heterogeneous; as a result, the distribution of survey sites according to their detailed hardbottom type is also uneven around the island. For example, 14 surveys were conducted on higher complexity aggregate reef on the south side, compared to 5 on the north side. In contrast, patch reef structure is more prevalent on the north side, and 10 of the 13 patch reef survey sites were located in the five northern strata. The nMDS plot revealed some separation by habitat type, particularly for patch reefs and pavement. Aggregate reef sites tended to be more scattered but many shared high similarity with each other and the pavement group. Pavement communities tended to cluster together regardless of whether they were located

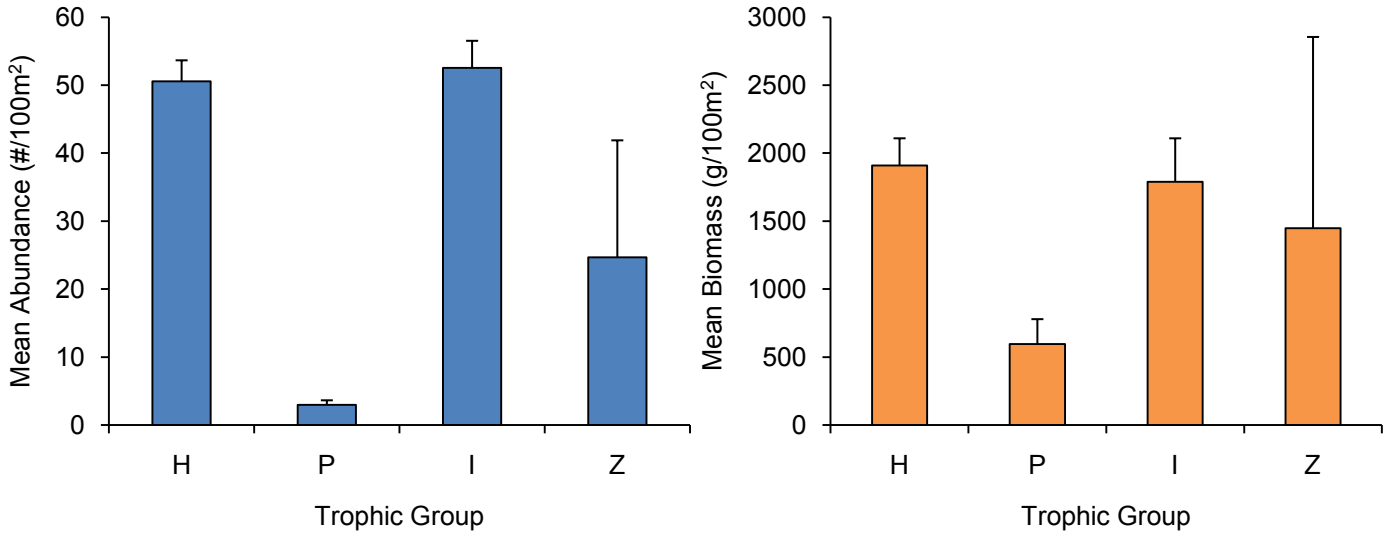


Figure 3.25. Mean (±SE) density (a) and biomass (b) of major trophic groups across surveys. H=Herbivore, P=Piscivore, I=Invertivore, Z=Zooplanktivore.

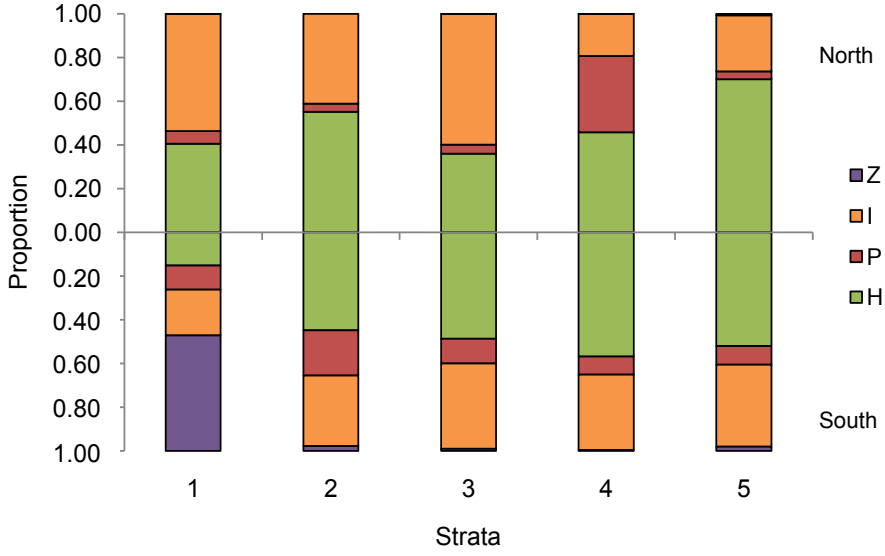


Figure 3.26. Proportional biomass of trophic groups across survey strata.

Image 3.6. Gray angelfish (*Pomacanthus arcuatus*). Photo: CCMA Biogeography Branch.

on the north or south shore. However, within pavement sites, there was still a clear split between the northern and southern pavement sites, indicating that a factor other than habitat type is driving some of the dissimilarity between the north and south shores. Other potential factors that could account for this pattern include differences in depth, exposure to currents, wave action, and hydrodynamics between the north and south sides of the island. For example, depth was positively correlated with several fish metrics, including total density (Spearman's Rho=0.25).

Similarity percentages were calculated to examine which species accounted for similarities/dissimilarities among and between groups. In general, the most abundant species appear to contribute to the largest similarities among groups and dissimilarities between groups. For example, although *Thalassoma bifasciatum* was abundant across all strata and hardbottom types, the mean abundance of this species was nearly twice as high in the southern strata compared to the north, and nearly three times higher on pavement and aggregate reef compared to patch reef. Several outliers are apparent on the nMDS plots. These survey points included sites with both the lowest and highest total fish abundance (4N01 and 1S10, respectively) and those with the highest abundance of particular species.

Trophic Groups, Families, and Species

Biomass and abundance were distributed unevenly throughout trophic and taxonomic groups. The most abundant trophic groups in terms of biomass and abundance were herbivores (H, e.g., parrotfish, damselfish) and invertivores (I, e.g., grunts, butterflyfishes), while piscivores (P, e.g., snappers, groupers) constituted a

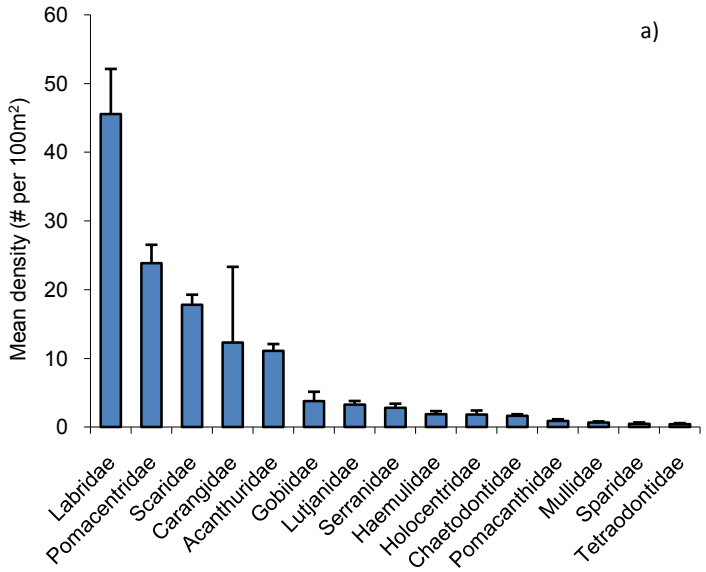


Figure 3.27. Mean (± SE) a) density and b) biomass of fish families observed in Vieques survey.

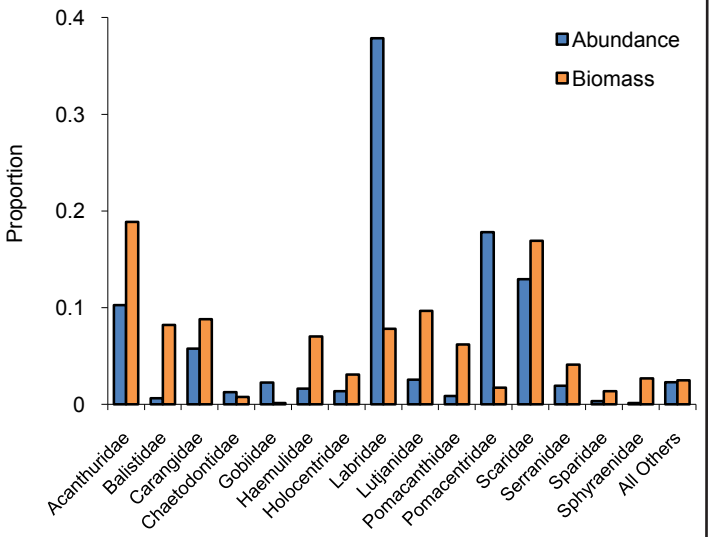


Figure 3.28. Proportional distribution of abundance and biomass of major fish families.

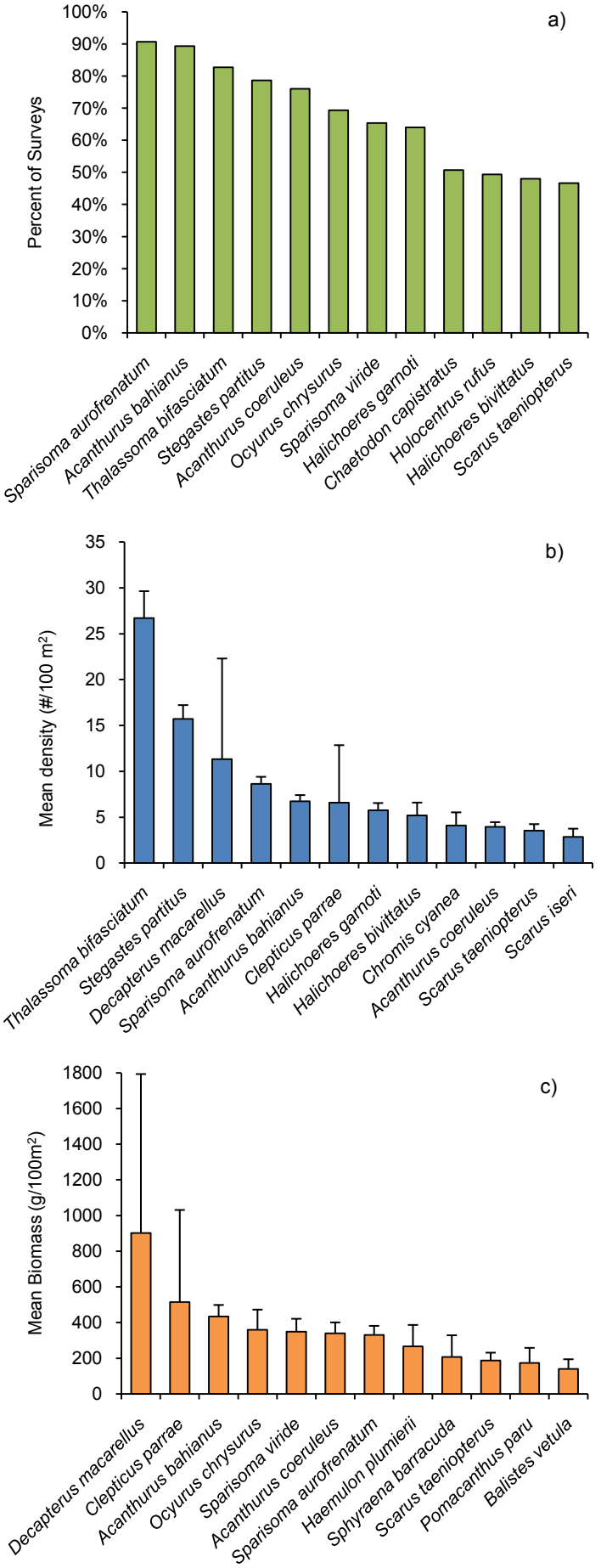


Figure 3.29. Top twelve fish species by a) survey frequency, b) mean (± SE) density, and c) mean (± SE) biomass.

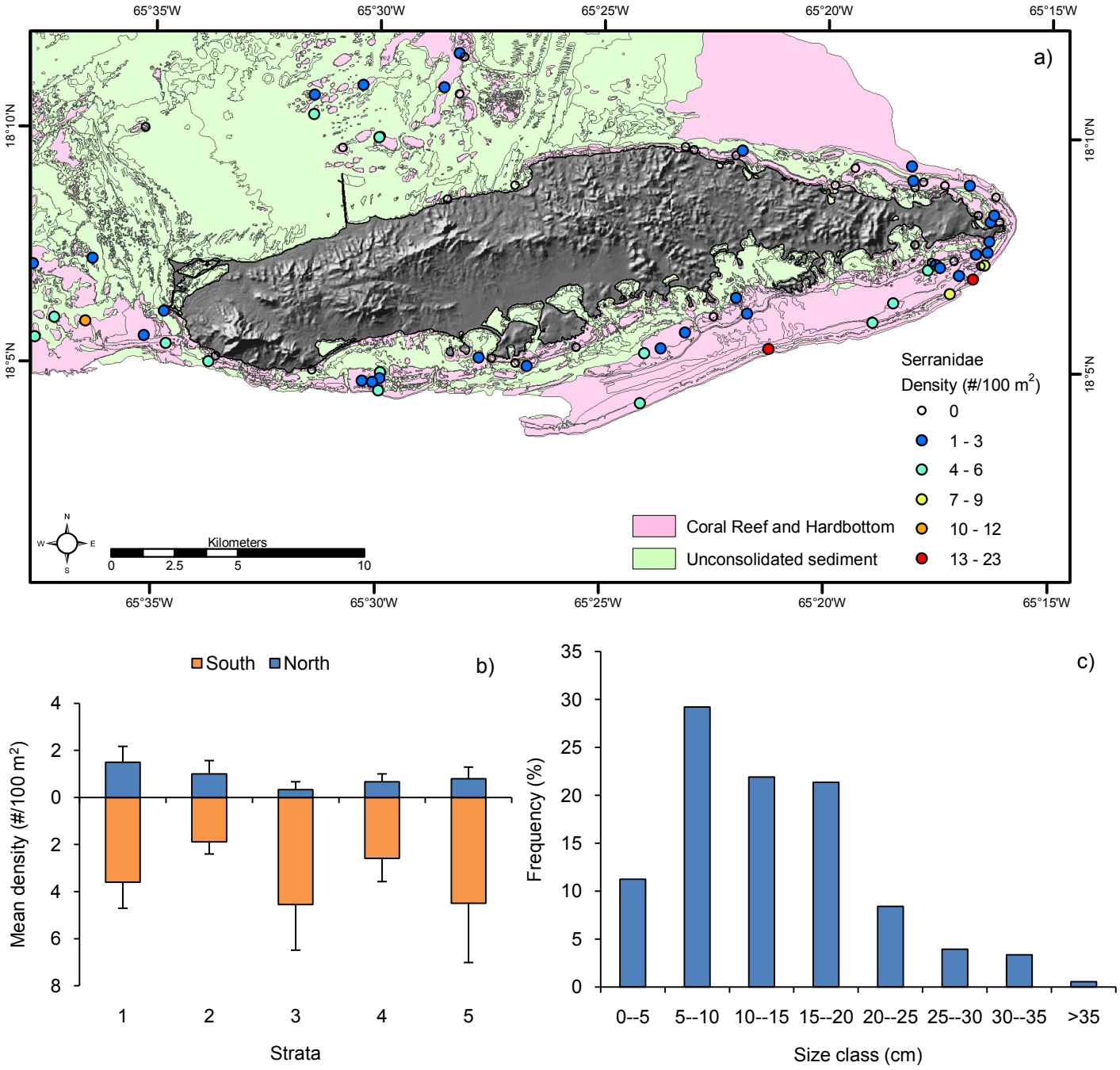


Figure 3.30. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of groupers, hamlets and seabasses (Family Serranidae).

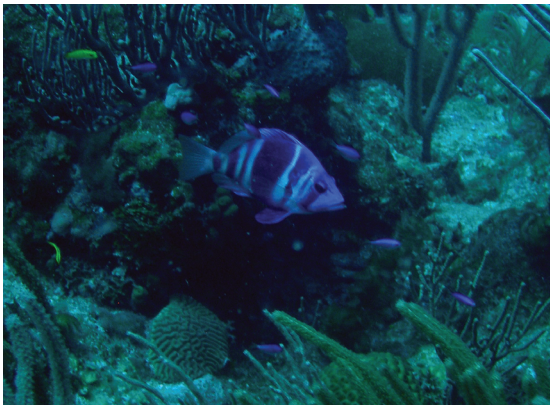


Image 3.7. Indigo hamlet (*Hypoplectrus indigo*). Photo: CCMA Biogeography Branch.

smaller percentage (Figure 3.25). The proportional biomass of each trophic group was generally similar across strata, with the exception of 1-South, where the zooplanktivore (Z) *D. marcarellus* accounted for a high proportion of the total biomass (Figure 3.26) due to the one large school. In addition, herbivores tended to constitute a slightly greater proportion of the total biomass in the easternmost strata in comparison to the western counterparts. Piscivores accounted for approximately one-third of the biomass in 4-North, but this was primarily due to one nurse shark (*Ginglymostoma cirratum*) present in one survey.

Families with the highest mean abundance and biomass are ranked in Figure 3.27a-b and by their proportional abundance/biomass in Figure 3.28. Approximately 90% of individuals and biomass came from 7 and 10 families, respectively. While individuals

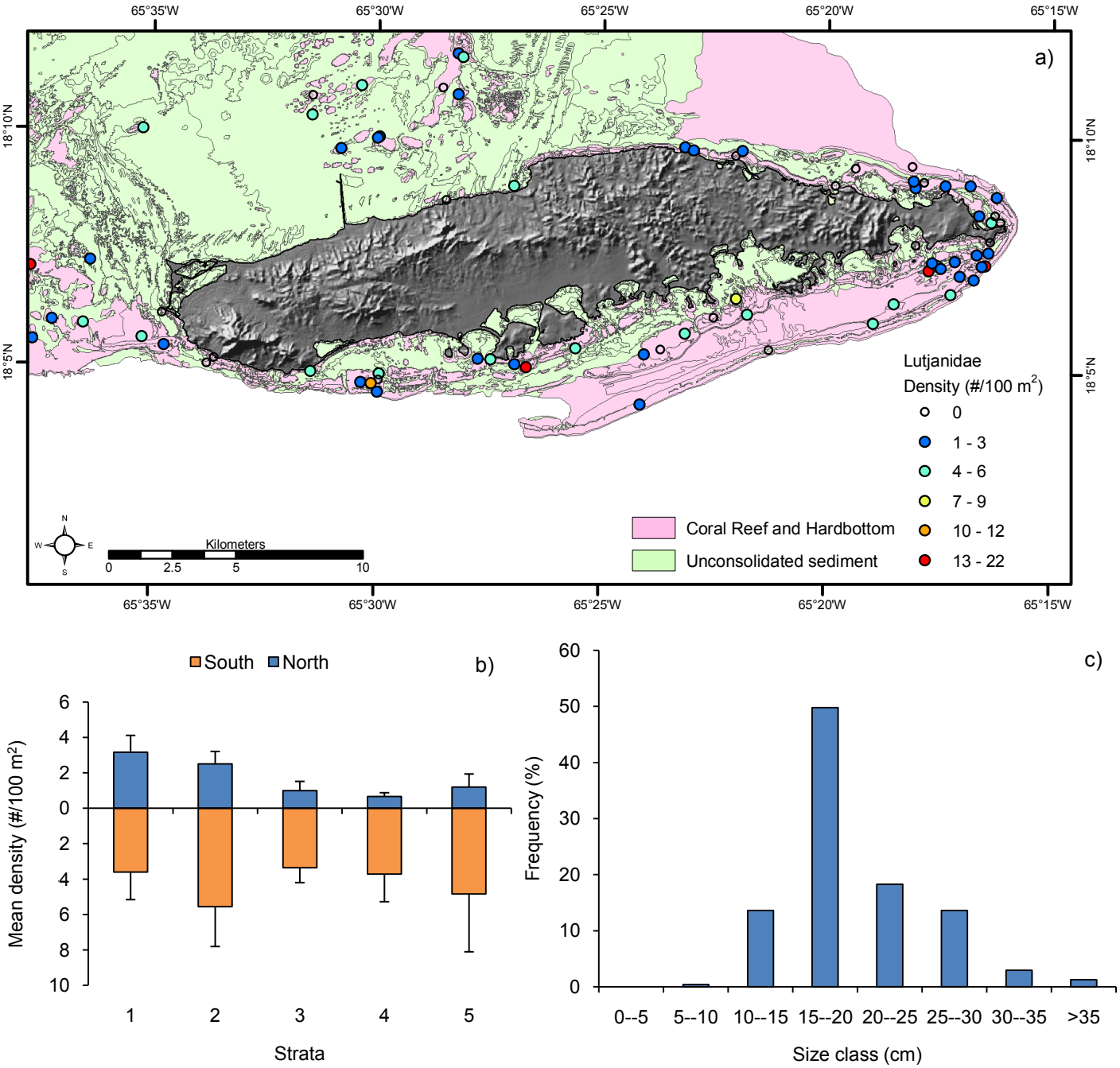


Figure 3.31. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of snappers (Family Lutjanidae).

from the families Labridae (wrasses) and Pomacentridae (damselfishes) were the most numerically abundant, surgeonfishes (Family Acanthuridae) and parrotfishes (Family Scaridae) accounted for the highest proportion of biomass (Figure 2.28).

The most frequently observed fish species include the redband parrotfish (*Sparisoma aurofrenatum*), ocean surgeonfish (*Acanthurus bahianus*), bluehead (*Thalassia bifasciatum*), bicolor damselfish (*Stegastes partitus*), and blue tang (*Acanthurus coeruleus*), which were all sighted at over 70% of the transects (Figure 3.29a). These species also ranked high in terms of mean abundance, and with the exception of the small bodied *S. partitus*, biomass (Figure 3.29b-c). Other species such as *D. marcarellus* and *Clepticus parrae* (creole wrasse) were not frequently sighted, but were patchily abundant when found. Aside from the one *G. cirratum*, no other sharks were observed in any of the transects.

Summary information on the spatial distribution, mean density by strata, and size frequency for select families and species are displayed in Figures 3.30-3.33 and Figures 3.34-3.43, respectively.

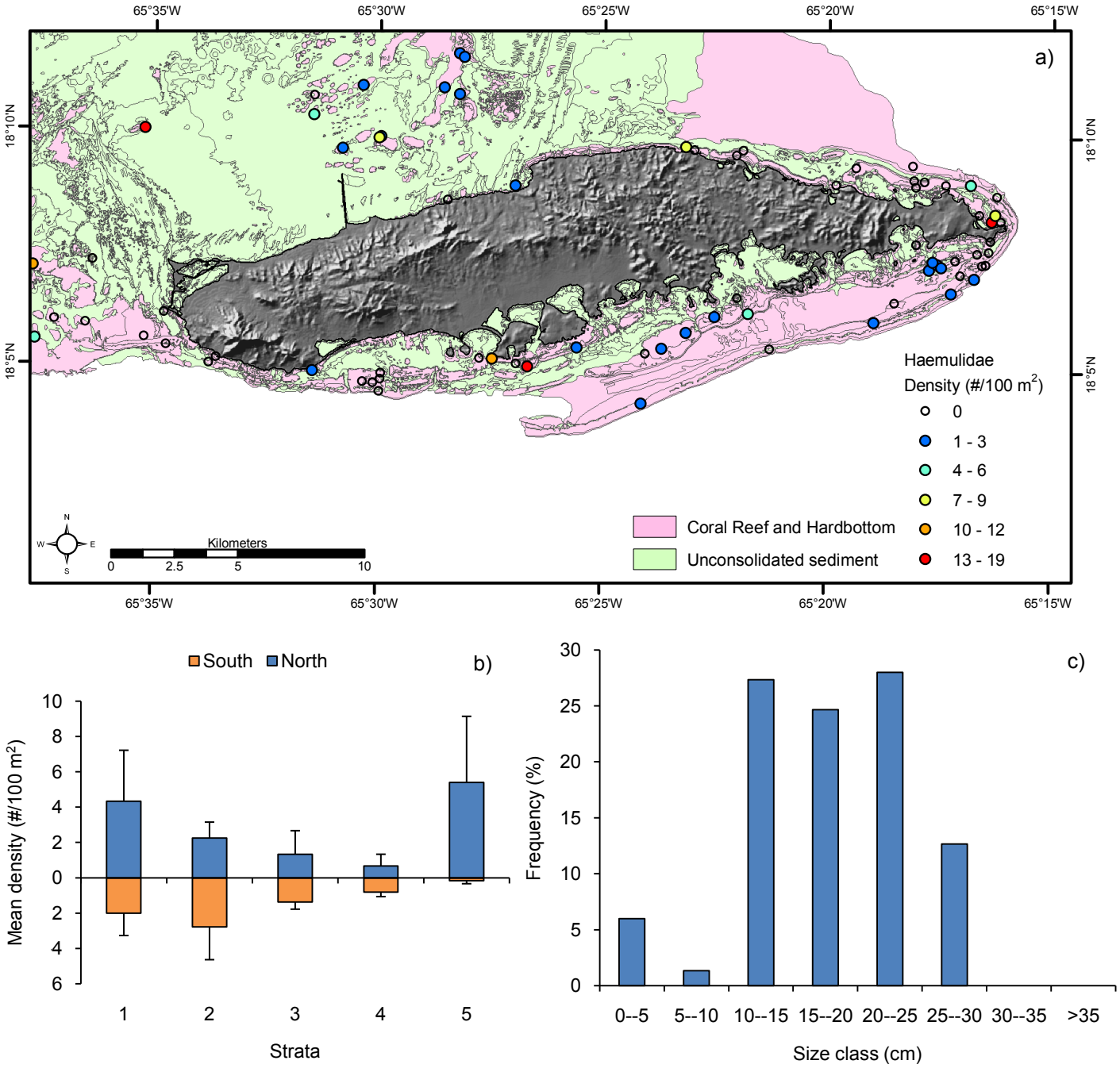


Figure 3.32. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of grunts (Family Haemulidae).

Serranids (groupers, hamlets and seabasses) were observed in 63% of the survey transects, with higher densities on the south side of the island (Figure 3.30). The family was represented by 15 species, with red hind (*Epinephelus guttatus*), harlequin bass (*Serranus tigrinus*), and coney (*Cephalopholis fulva*) most frequently sighted. Size frequency was skewed towards the smaller size classes, with few large adults observed. The commercially important tiger grouper was only observed at one survey location in the southwestern portion of the study area.

Fishes of the family Lutjanidae (snappers) were observed at 75% of the survey locations. Again, sighting frequency and density tended to be higher in the southern strata (Figure 3.31). Seven Lutjanid species were documented, with the yellowtail snapper (*Ocyurus chrysurus*) accounting for the majority of the sightings, followed by schoolmaster (*Lutjanus apodus*). The remaining species were infrequently observed.

Grunts (Family Haemulidae) were present within 44% of survey transects. Distribution tended to be patchy and at most sites only a few individuals were observed (Figure 3.32). Sites with higher densities were located on

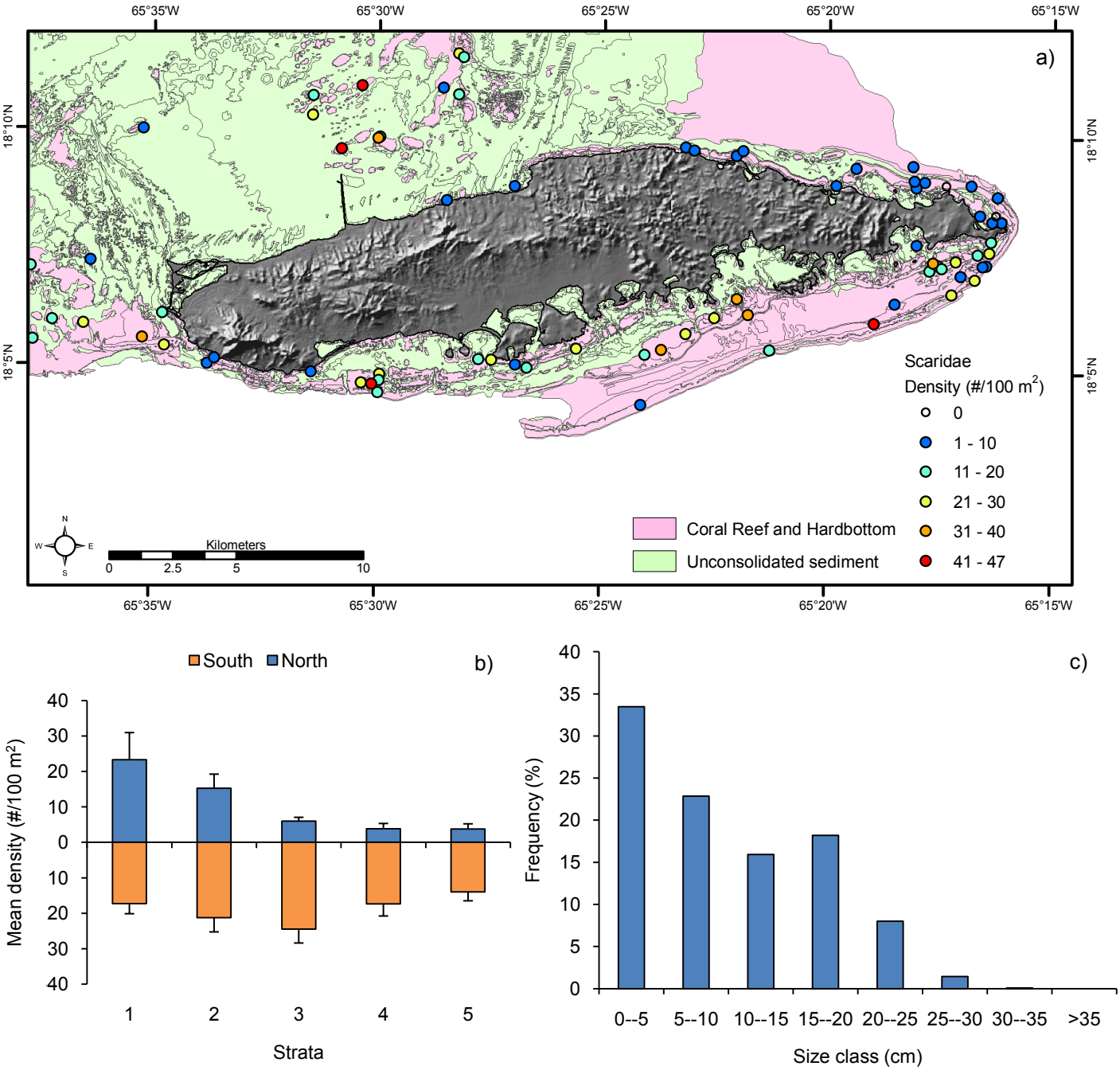


Figure 3.33. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of parrotfishes (Family Scaridae).

the northeast tip, on patch reefs in the northwest area, and south of Ensenada Sombe and Puerto Mosquito. Of the eight species observed, French grunt (*Haemulon flavolineatum*) and white grunt (*Haemulon plumierii*) were most frequently sighted and had the highest mean abundance and biomass.

Parrotfishes (Family Scaridae) were common members of the Vieques reef community, occurring in all but two of the survey transects. However, they were less abundant in the northeastern strata compared to the rest of the island (Figure 3.33). Of the seven species, the redband parrotfish (*Sparisoma aurofrenatum*) and princess parrotfish (*Scarus taeniopterus*) were most abundant, while the stoplight parrotfish (*Sparisoma viride*) had the highest mean biomass.

Coney (*C. fulva*) demonstrated one of the most distinct spatial patterns of any species considered and were located almost exclusively on the south side of Vieques, with the highest densities in the southeastern strata (Figure 3.34). Fish were most frequently associated with aggregate reef and pavement structure types, and to a lesser extent sand w/ scattered coral and rock. The majority of observed individuals were small adults, with fewer juveniles or large adults.

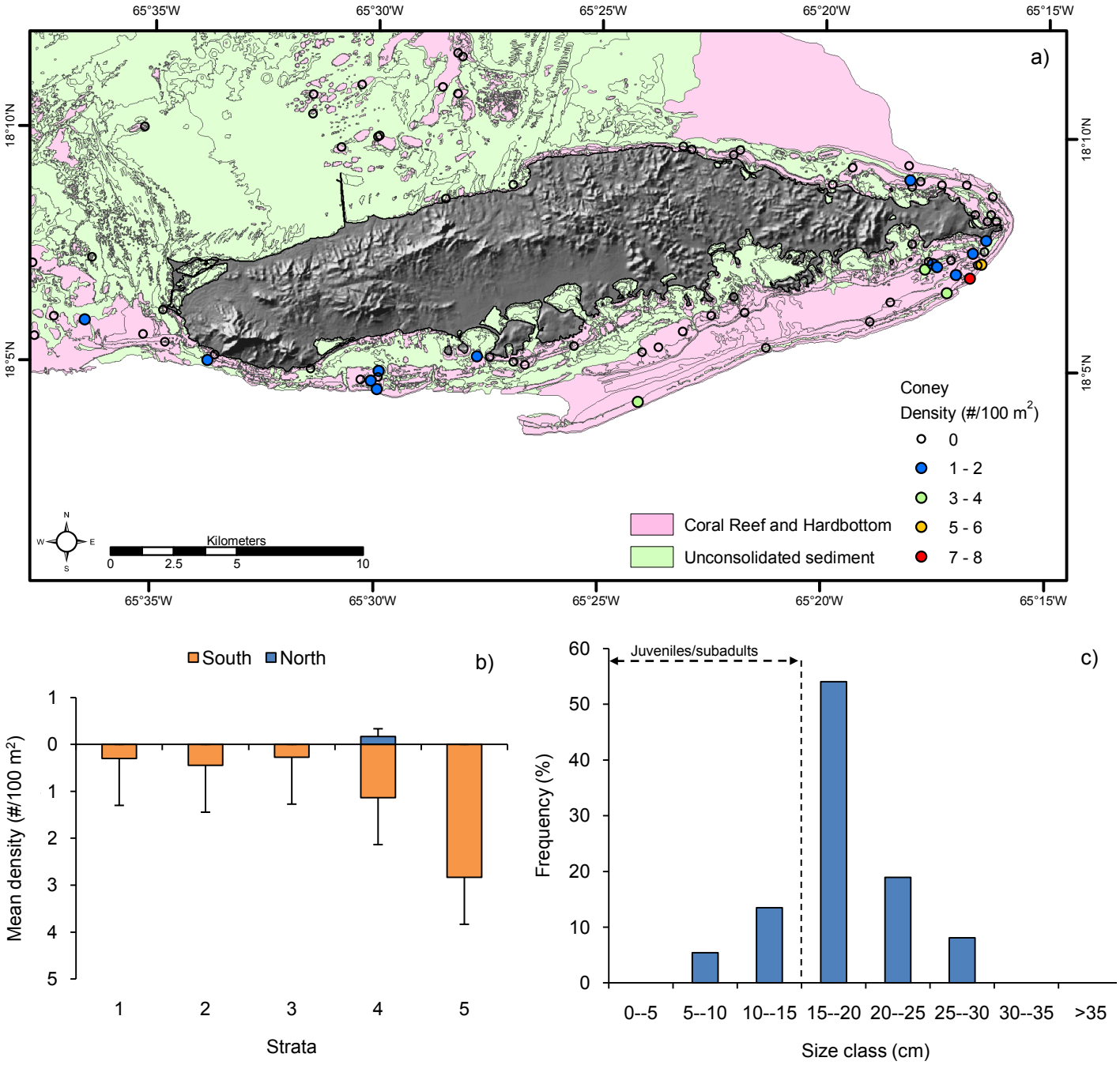


Figure 3.34. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of coney (*Cephalopholis fulva*).

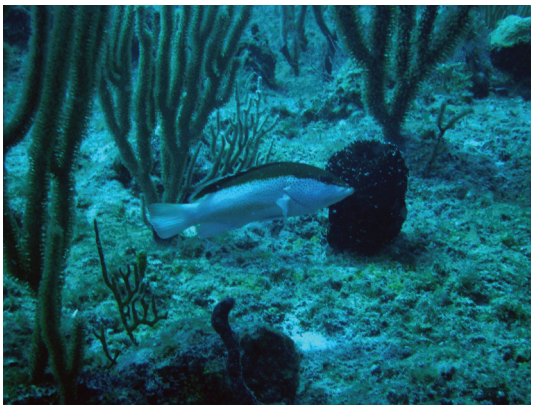


Image 3.8. Coney (*Cephalopholis fulva*). Photo: CCMA Biogeography Branch.

Red hind (*E. guttatus*) were sighted in 29% of survey transects, more frequently in southern strata and generally in low densities (Figure 3.35). Individuals were found across all hardbottom types. The majority of individuals were juveniles/subadults and small adults. The largest red hind observed were within the 30-35 cm size class, whereas the maximum known size for this species is 76 cm total length (Fishbase, Freose and Pauly 2008).

Schoolmaster (*L. apodus*) were infrequently observed (12 of survey transects) and generally in low densities (Figure 3.36). The large mean abundance in 2-South was due to one location where 20 individuals were recorded. This site with large schoolmaster density was found on pavement habitat type, but the species was found across all hardbottom types. The majority of individuals were juveniles/subadults and small adults.

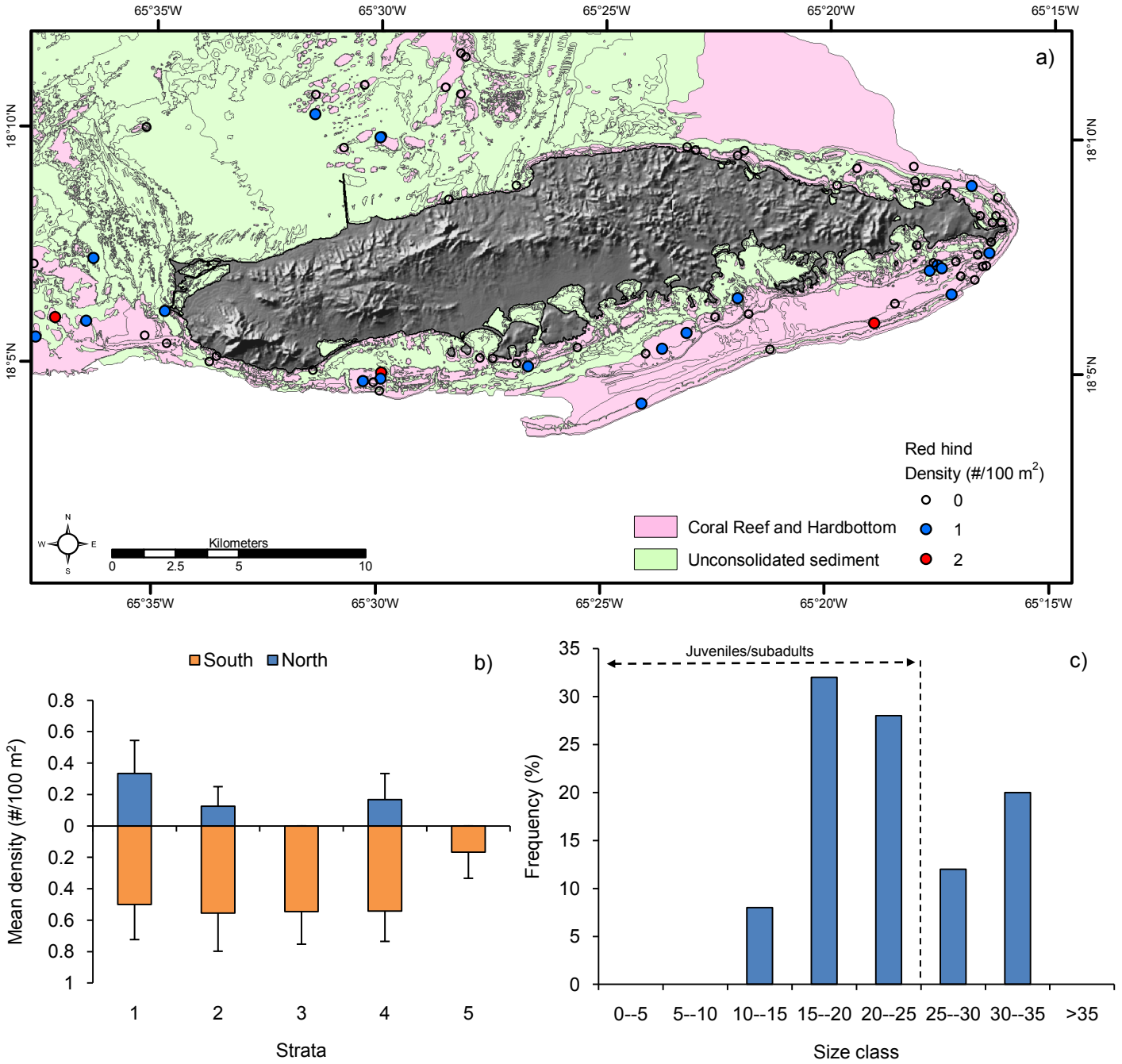


Figure 3.35. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of red hind (*Epinephelus guttatus*).

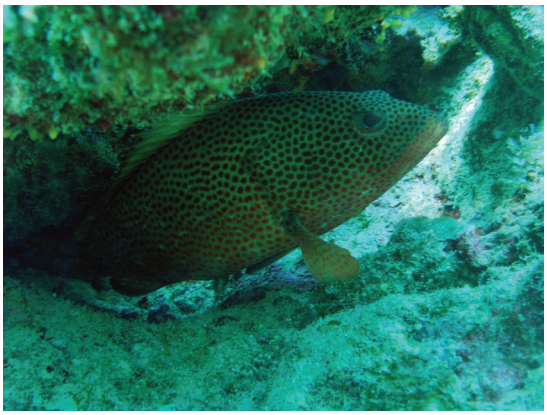


Image 3.9. Red hind (*Epinephelus guttatus*). Photo: CCMA Biogeography Branch.

The most abundant lutjanid species, yellowtail snapper (*O.chrysurus*) were observed in 69% of the survey transects (Figure 3.37). The species was found all around the island and across all hardbottom types, but higher densities generally occurred on the south side. The two sites with the highest density occurred at the far eastern and western edges of the survey area. The majority of the individuals were in the juvenile/subadult size classes; only a small percentage of yellowtail snapper were adult-sized.

French grunt (*H. flavolineatum*) were present at 25% of the survey sites and were largely absent from sites on the northwestern portion of the island (Figure 3.38). Sites with the highest densities were located on the northeastern tip and in strata 2-South. The majority of the individuals were larger juveniles/subadults and small adults, whereas few small juveniles or large adults were ob-

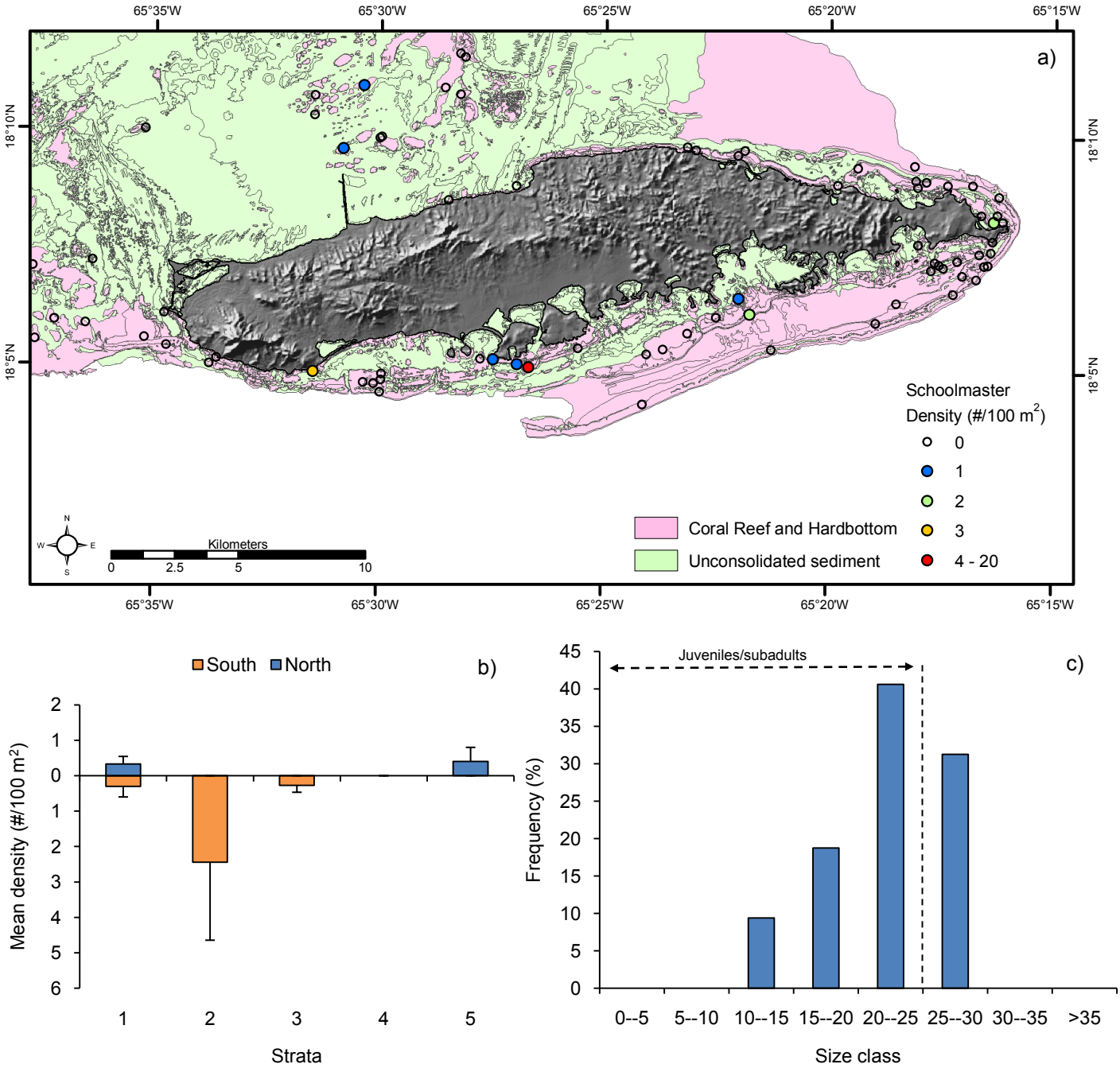


Figure 3.36. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of schoolmaster (*Lutjanus apodus*).

served. The species was found most frequently on aggregate reef, pavement, and pavement with sand channels habitat.

Hogfish (*L. maximus*) were present in only 12% of the survey transects but exhibited a very spatially distinct distribution pattern. The species were largely associated with patch reefs on the north/northwest portion of the survey area (Figure 3.39). Only one individual was observed in survey transects on the south side of the island. Individuals were primarily juveniles/subadults and small adults. Two large hoghfish of 55 cm were also observed.

Ocean surgeonfish (*A. bahianus*) were sighted in 89% of the surveys and were present in all areas on all hardbottom types (Figure 3.40). Mean density was highest in 5-South and lowest in 1-South. Subadults and small adults were most frequent, while small juveniles comprised a smaller percentage of the sightings.

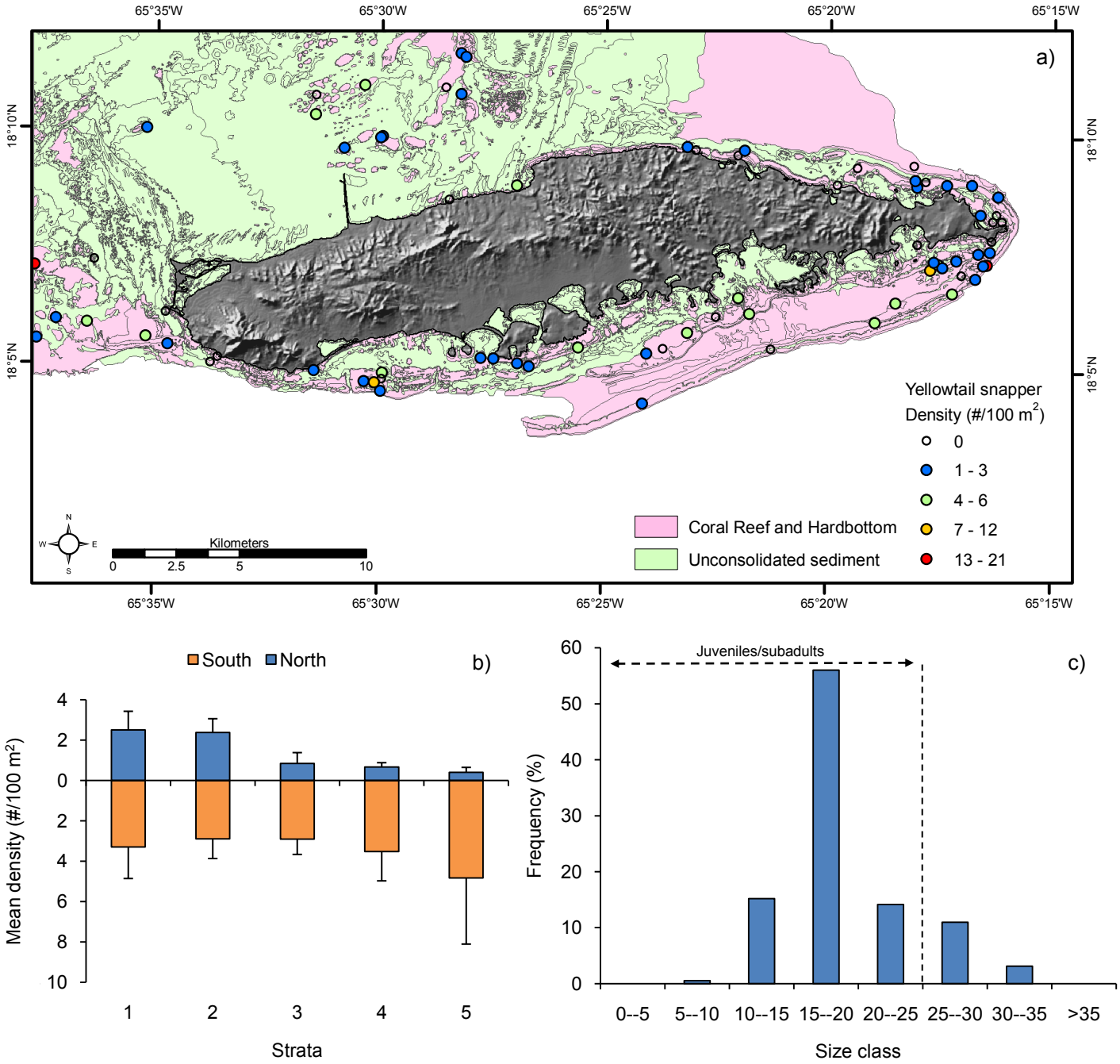


Figure 3.37. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of yellowtail snapper (*Ocyurus chrysurus*).

Blue tang (*A. coeruleus*) were present in 76% of survey transects and were associated with all hardbottom types (Figure 3.41). While there were no clear spatial patterns, density tended to be higher at patch reefs on the north shore, on the eastern tip, and on fringing reefs on the south shore. The species exhibited a peak in frequency for small adults.

Redband parrotfish (*S. aurofrenatum*) was the most frequently sighted fish and was present in 91% of the transects (Figure 3.42). With the exception of 1-North, mean density was higher in all southern strata compared to the north. Sites from which the species was absent were all located in strata 3-, 4-, and 5-North. Approximately two-thirds of all observed individuals were juveniles/subadults.

Stoplight parrotfish (*S. viride*) were sighted in 65% of the survey transects (Figure 3.43). Although the species was associated with all hardbottom types, many of the sites with the highest densities were located in structure types of higher complexity (e.g., patch reefs, aggregate reef, pavement w/ sand channels). In particular, mean density in 1- and 2-North was high due to large densities on several patch reefs.

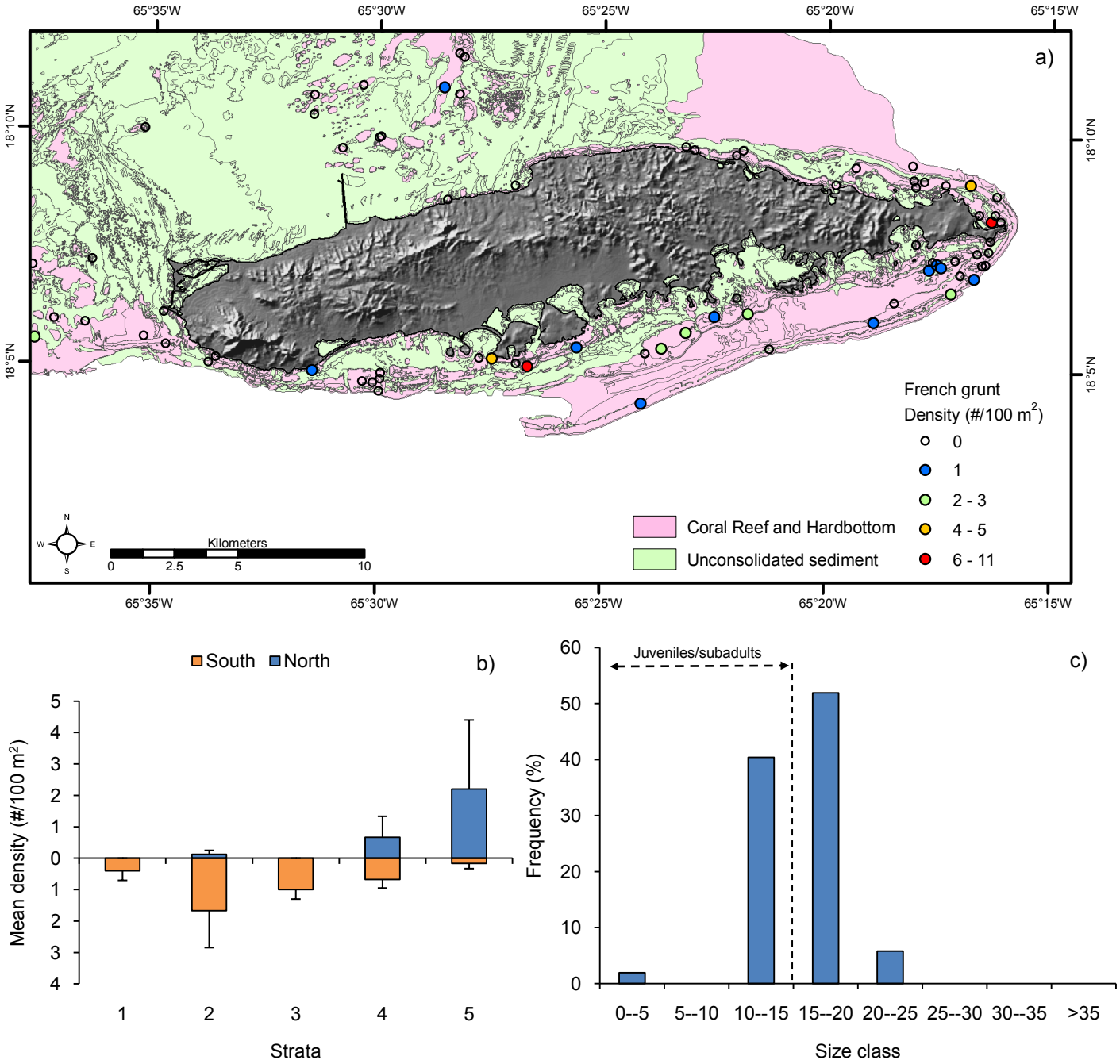


Figure 3.38. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of french grunt (*Haemulon flavolineatum*).

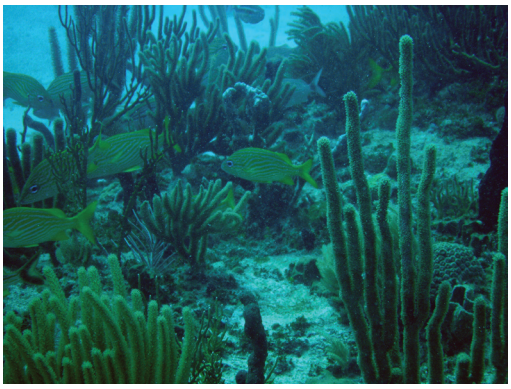


Image 3.10. French grunt (*Haemulon flavolineatum*). Photo: CCMA Biogeography Branch.

Due to differences in site selection, location and survey methods, it is not possible to make direct comparisons in metrics from this survey with those from previous studies. However, in terms of relative abundance, the fish species composition observed here was comparable with rankings from several earlier assessments (Table 3.5). *T. bifasciatum* was the most abundant species in two other surveys (DON 1979; GMI 2003) and ranked among the top five most abundant in the remaining studies. Of the ten most abundant species in this study, six were also shared with GMI (2003). The masked goby (*Coryphopterus personatus*) was the most abundant species in Garcia-Sais et al. (2001, 2004) but was only the 19th most abundant here and occurred in only 4% of transects. However, this species tends to occur in aggregations, and hence can be locally abundant when present.

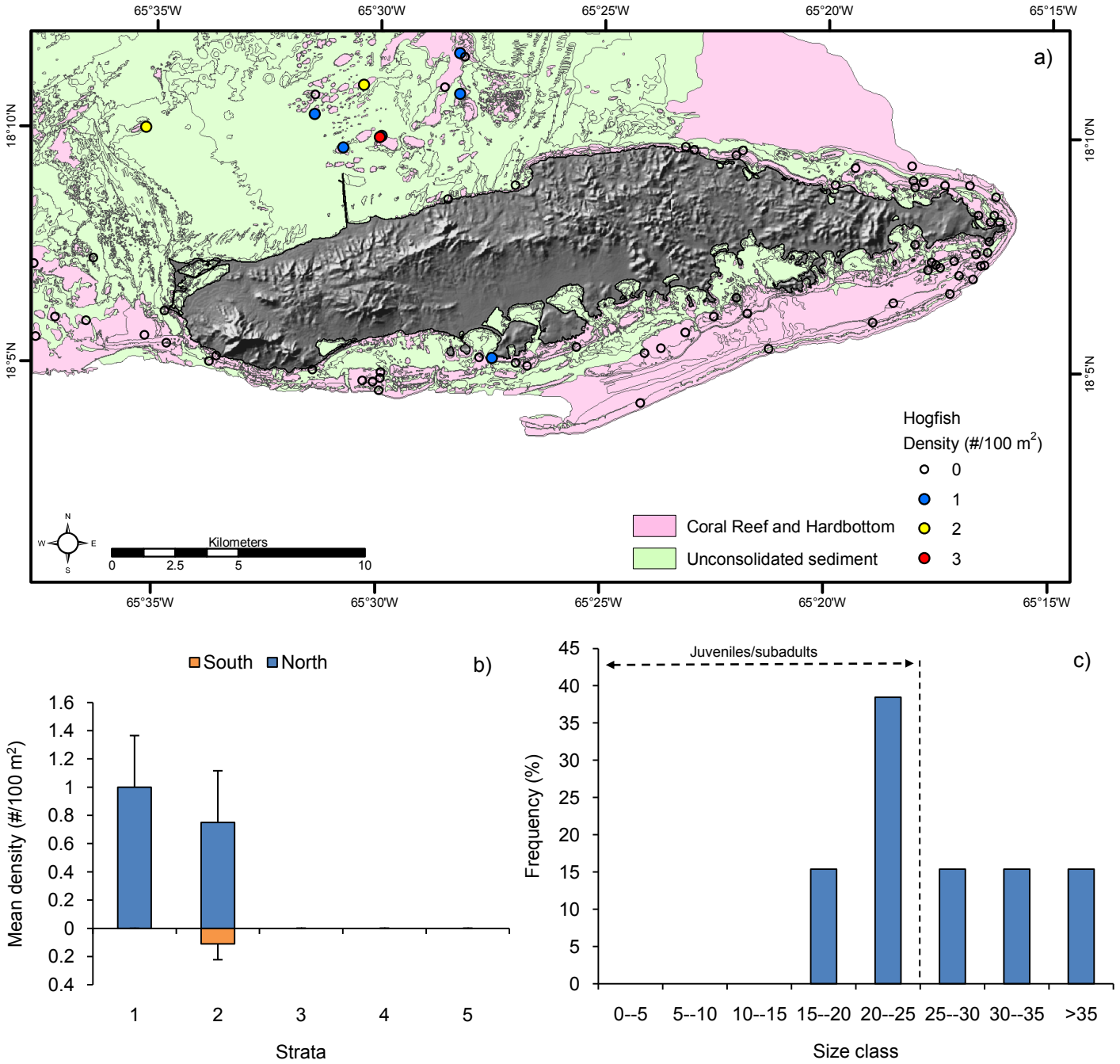


Figure 3.39. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of hogfish (*Lachnolaimus maximus*).

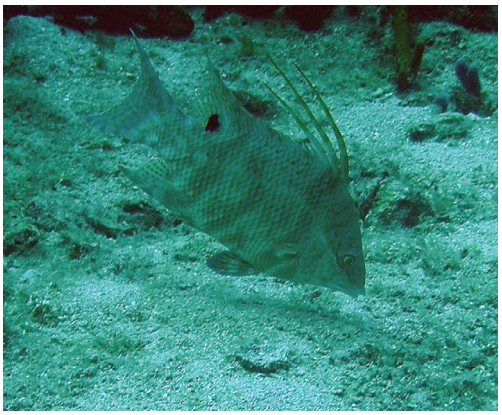


Image 3.11. Hogfish (*Lachnolaimus maximus*).
Photo: CCMA Biogeography Branch.

These studies also reported heterogeneity in fish communities within/among benthic habitat types and at regional scales, although findings among studies were inconsistent. While DON (1986) reported communities to be similar across locations, GMI (2003) also detected a difference in fish communities between sites located north and south of the island using MDS analysis. Although their study area was restricted to the eastern military area (i.e., overlapped with Strata 3 and 4 of this study area), the MDS results were similar in that southern sites tended to be more clustered together, while the northern samples were more dissimilar.

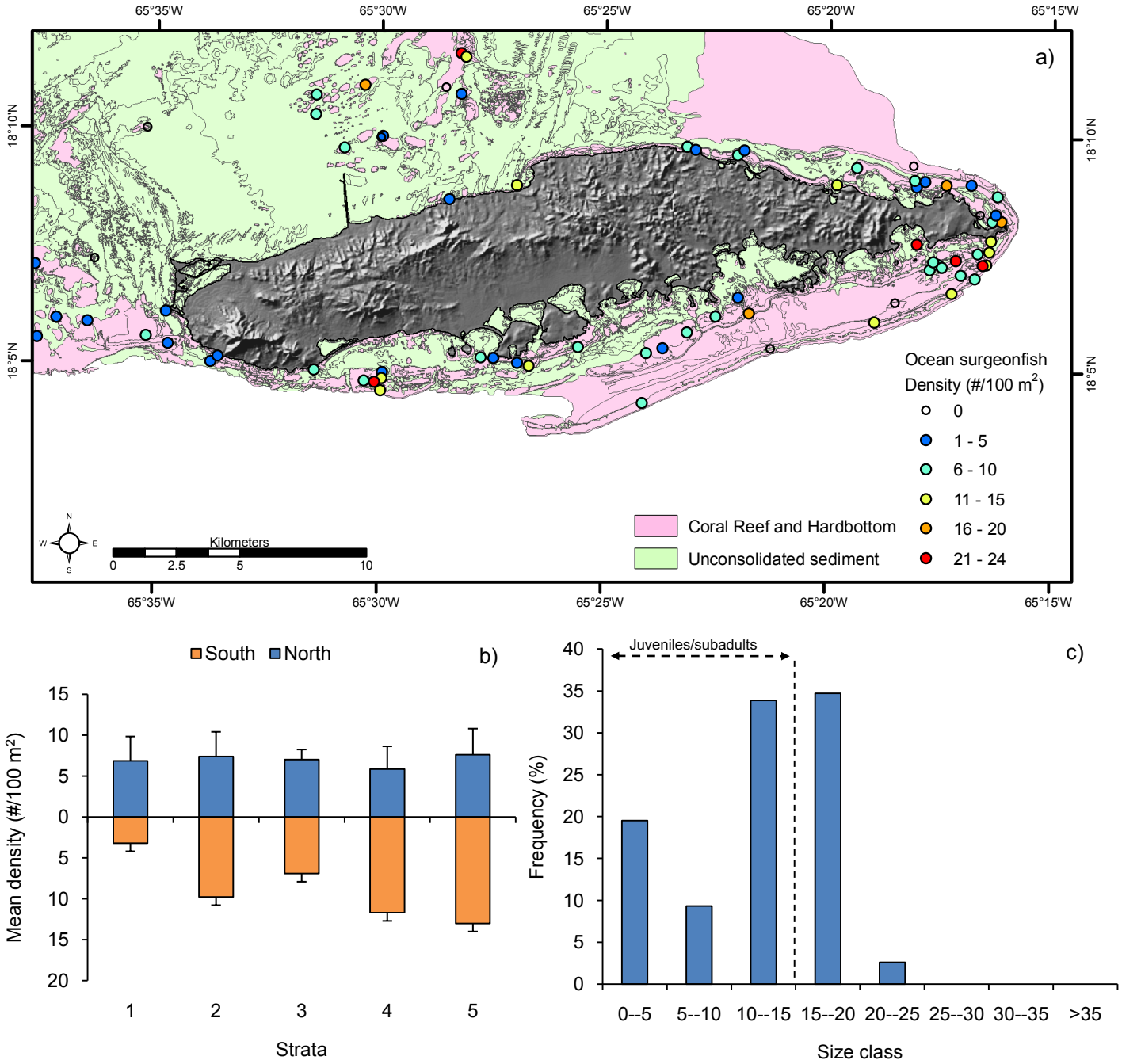


Figure 3.40. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of ocean surgeonfish (*Acanthurus bahianus*).

Image 3.12. Ocean surgeonfish (*Acanthurus bahianus*). Photo: CCMA Biogeography Branch.

Comparison with other U.S. Caribbean monitoring locations

To put our results in context with nearby study areas in the U.S. Caribbean, fish data from the 2007 Vieques survey were compared with three locations (La Parguera in southwestern Puerto Rico, St. Croix and St. John, USVI) that have been monitored by the Biogeography Branch using identical methods. Data were summarized for the three locations from 2003-2007. Only hardbottom sites were included for a total number of sites from each location as follows: SW Puerto Rico (450), St. Croix (714), and St. John (617).

Several fish community metrics (species richness, density, biomass) were compared among the four locations. Density and biomass data were not normally distributed and richness data did not meet the assumption of homogeneity of variances, therefore non-parametric Wil-

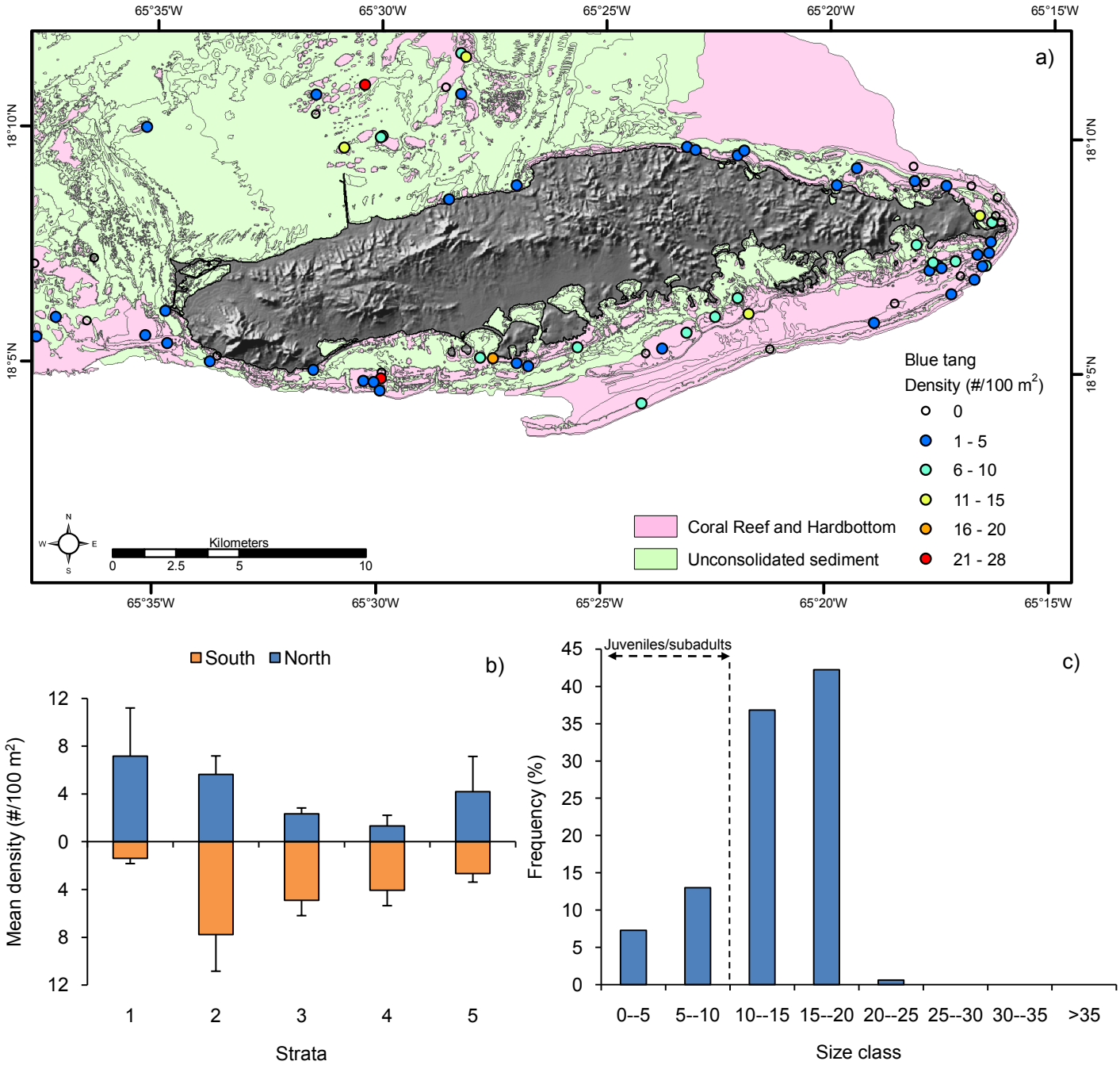


Figure 3.41. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of blue tang (*Acanthurus coeruleus*).

coxon tests and the corresponding non-parametric Dunn's test (Zar 1999) were used to test for differences among regions.

Species richness, density, and biomass were significantly greater in St. John ($p<0.05$) than each of the three other study locations (Figure 3.44a-c). Richness was similar among Vieques, SW Puerto Rico, and St. Croix and averaged 18-19 species/100 m^2). Fish density was also significantly greater in St. Croix in comparison to Vieques and SW Puerto Rico, and in Vieques compared to SW Puerto Rico. While biomass was significantly greater in St. Croix than SW Puerto Rico, there were no differences between Vieques and either St. Croix or SW Puerto Rico.

Abundance and biomass of key families were not always consistent across regions (Figure 3.45). Both abundance and biomass of snappers (Lutjanidae) were significantly greater in Vieques compared to each of the other study regions ($p<0.001$). In contrast, scarid abundance was significantly lower in Vieques compared to St. John and SW Puerto Rico, and biomass was significantly lower than in St. John. Serranid abundance and

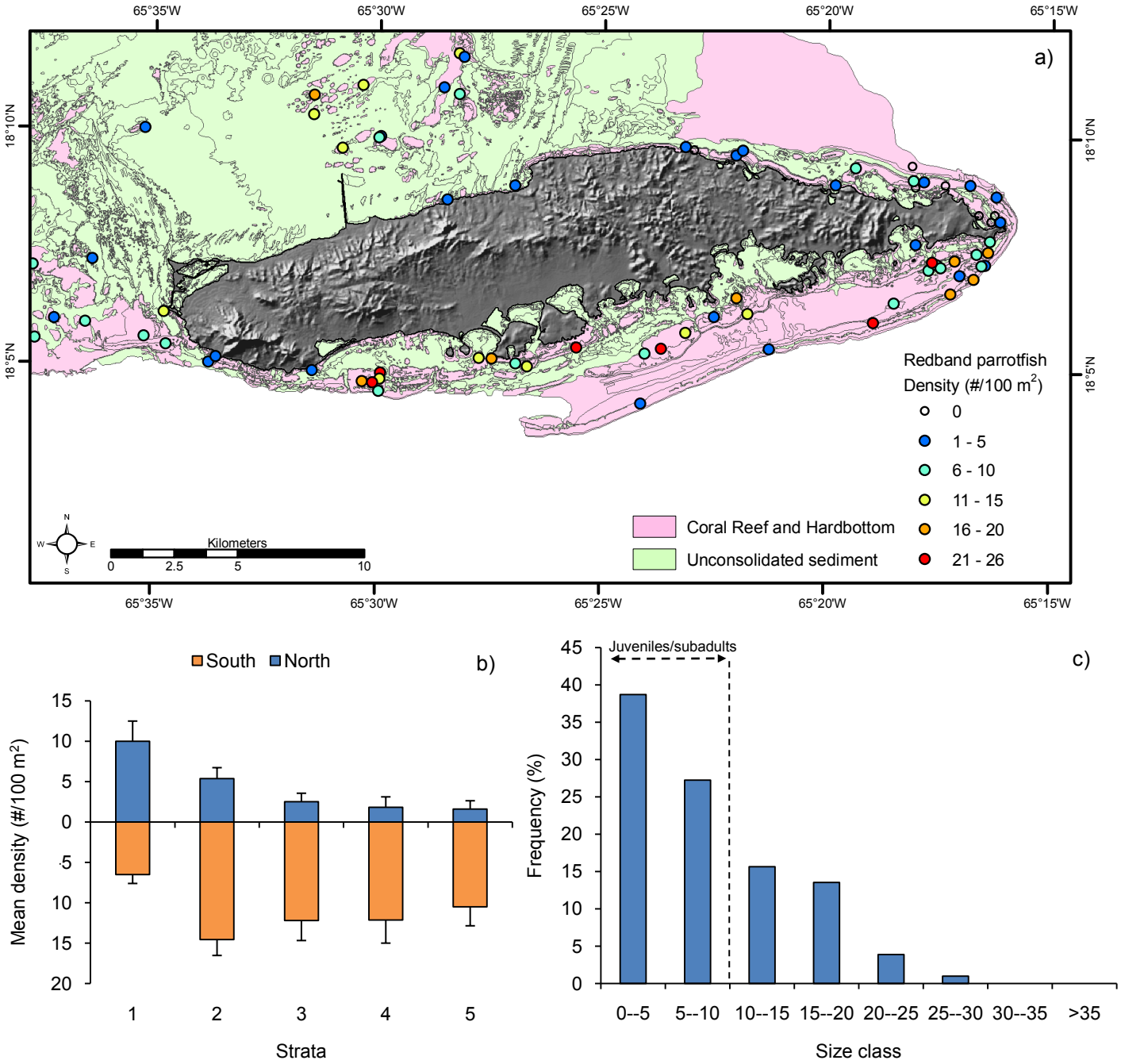


Figure 3.42. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of redband parrotfish (*Sparisoma aurofrenatum*).

biomass were significantly lower in Vieques than St. Croix and St. John, but biomass was significantly greater than in SW Puerto Rico. There were no significant differences in abundance or biomass of grunts (Haemulidae) across regions.

Macroinvertebrates

Diadema antillarum was observed at seven of 75 sites for a total of 106 individuals. Five out of seven sites were located on the north side, while the site with the highest observed density (54 urchins/100 m^2), was located in 4-South (Figure 3.46).

One immature *S. gigas* was observed in a survey transect on sand w/ scattered coral and rock habitat. The absence of queen conch in this survey is expected as they are typically associated with softbottom.

No spiny lobster (*P. argus*) were recorded during the survey, despite surveying 7500 m^2 of hardbottom.

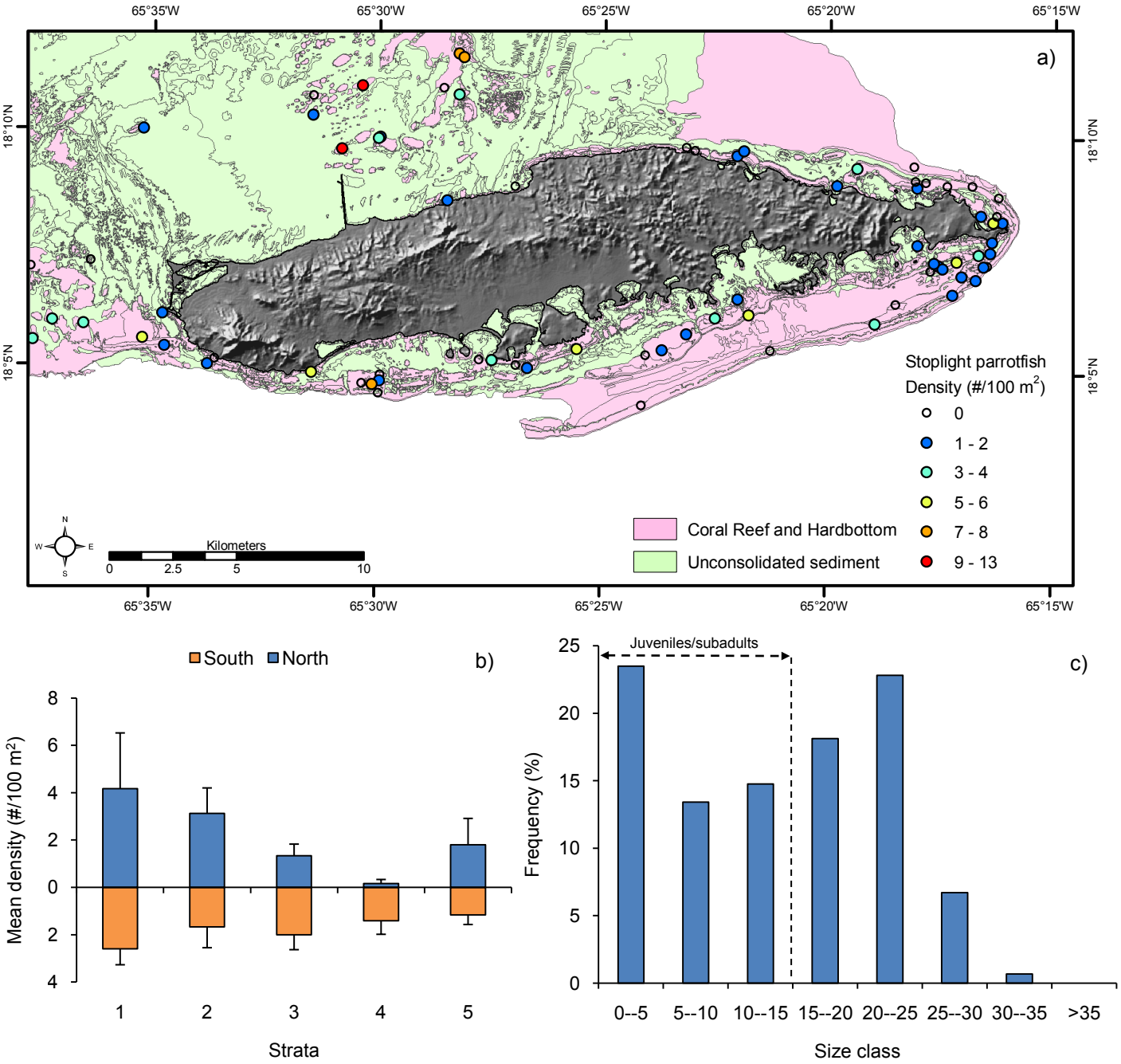


Figure 3.43. a) Spatial distribution, b) mean (±SE) density across strata, and c) size class frequency histogram of stoplight parrotfish (*Sparisoma viride*).

Marine Debris

A total of sixteen debris items, all unexploded ordnance, were found within the survey transect at three locations (Figure 3.47). All three sites were located on the north side of the island offshore of former Navy areas. The largest observed munition was an MK-81 250 lb bomb of approximately 150 cm in length. The site with the highest density of ordnance (13 items/100m^2) was located west of the Live Impact Area, but was still located within the area of special concern. Four of the items appeared to be intact ordnance (~40x8 cm) while the remaining items were smaller and may have been fragments of larger items. Munitions were observed outside survey transects at five additional locations. Although no obvious impacts to the habitat were observed, ordnance was often integrated into the surrounding substrate and colonized by organisms such as turf algae, macroalgae, crustose algae, and encrusting sponge. Preliminary identification of items was made when possible (Dave Green, PIKA, personal communication) and provided to the Navy for their records.

Table 3.5. Abundance ranks of the ten most abundant reef fish species among reef/hardbottom in the present study and five previous studies.

Ranking	Present study	DON 1979	DON 1986	Garcia-Sais et al. 2001	GMI 2003	Garcia-Sais et al. 2004
1	*Thalassoma bifasciatum*	*Thalassoma bifasciatum*	*Acanthurus coeruleus*	*Coryphopterus personatus*	*Thalassoma bifasciatum*	*Coryphopterus personatus*
2	*Stegastes partitus*	*Acanthurus coeruleus*	*Sparisoma viride*	*Stegastes partitus*	*Stegastes partitus*	*Clepticus parrae*
3	*Decapterus macarellus*	*Acanthurus chirurgus*	*Sparisoma rubripinne*	*Stegastes planifrons*	*Chromis multilineata*	*Chromis cyanea*
4	*Sparisoma aurofrenatum*	*Ophioblennius atlanticus*	*Thalassoma bifasciatum*	*Scarus iseri*	*Acanthurus bahianus*	*Thalassoma bifasciatum*
5	*Acanthurus bahianus*	*Acanthurus bahianus*	*Acanthurus chirurgus*	*Thalassoma bifasciatum*	*Acanthurus coeruleus*	*Inermia vittata*
6	*Clepticus parrae*	*Abudefduf saxatilis*	*Scarus iseri*	*Chromis multilineata*	*Halichoeres bivittatus*	*Scarus iseri*
7	*Halichoeres garnoti*	*Stegastes adustus*	*Scarus taeniopterus*	*Stegastes adustus*	*Sparisoma aurofrenatum*	*Stegastes adustus*
8	*Halichoeres bivittatus*	*Chromis multilineata*	*Haemulon flavolineatum*	*Decapterus macarellus*	*Halichoeres maculipinna*	*Stegastes partitus*
9	*Chromis cyanea*	*Scarus iseri*	*Holocentrus adscensionis*	*Chromis cyanea*	*Scarus iseri*	*Gobiosoma evelynae*
10	*Acanthurus coeruleus*	*Scarus taeniopterus*	*Sparisoma aurofrenatum*	*Haemulon flavolineatum*	*Stegastes adustus*	*Sparisoma viride*

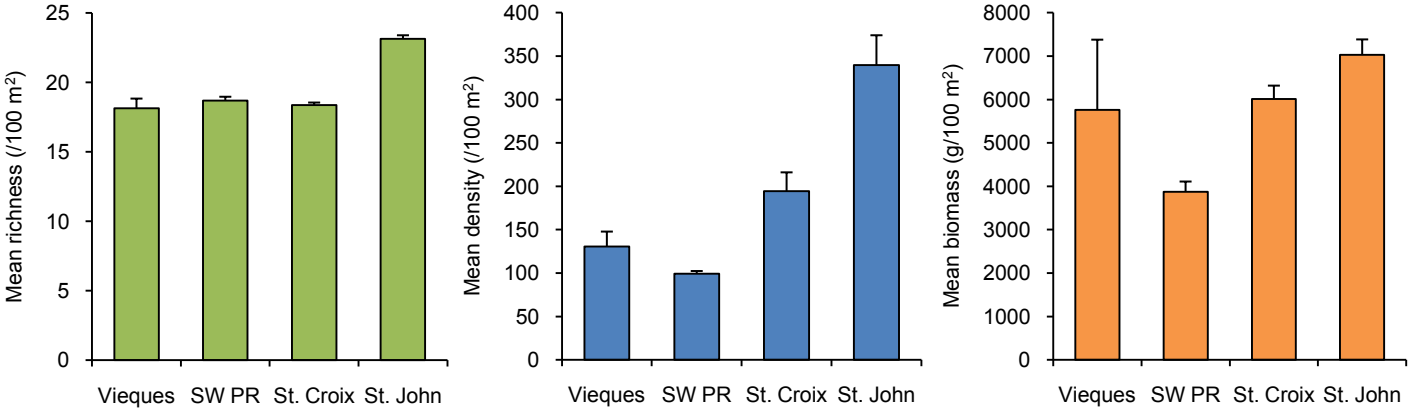


Figure 3.44. Estimated mean (±SE) fish species richness, density, and biomass at Vieques in May 2007 and other CCMA Biogeography Branch Caribbean monitoring locations (2003-2007): La Parguera in SW Puerto Rico (n=450), St. Croix (n=714) and St. John (n=617). See Figure 3.16a for map of the study areas.

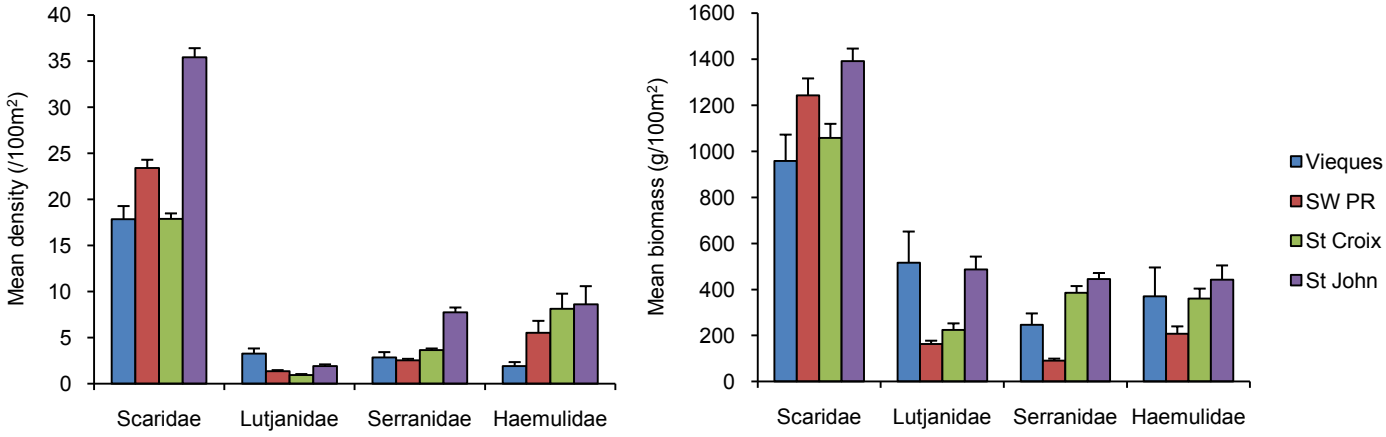


Figure 3.45. Estimated mean (±SE) density and biomass of key fish families in Vieques compared to other CCMA Biogeography Branch monitoring locations (2003-2007): La Parguera in SW Puerto Rico (n=450), St. Croix (n=714) and St. John (n=617).

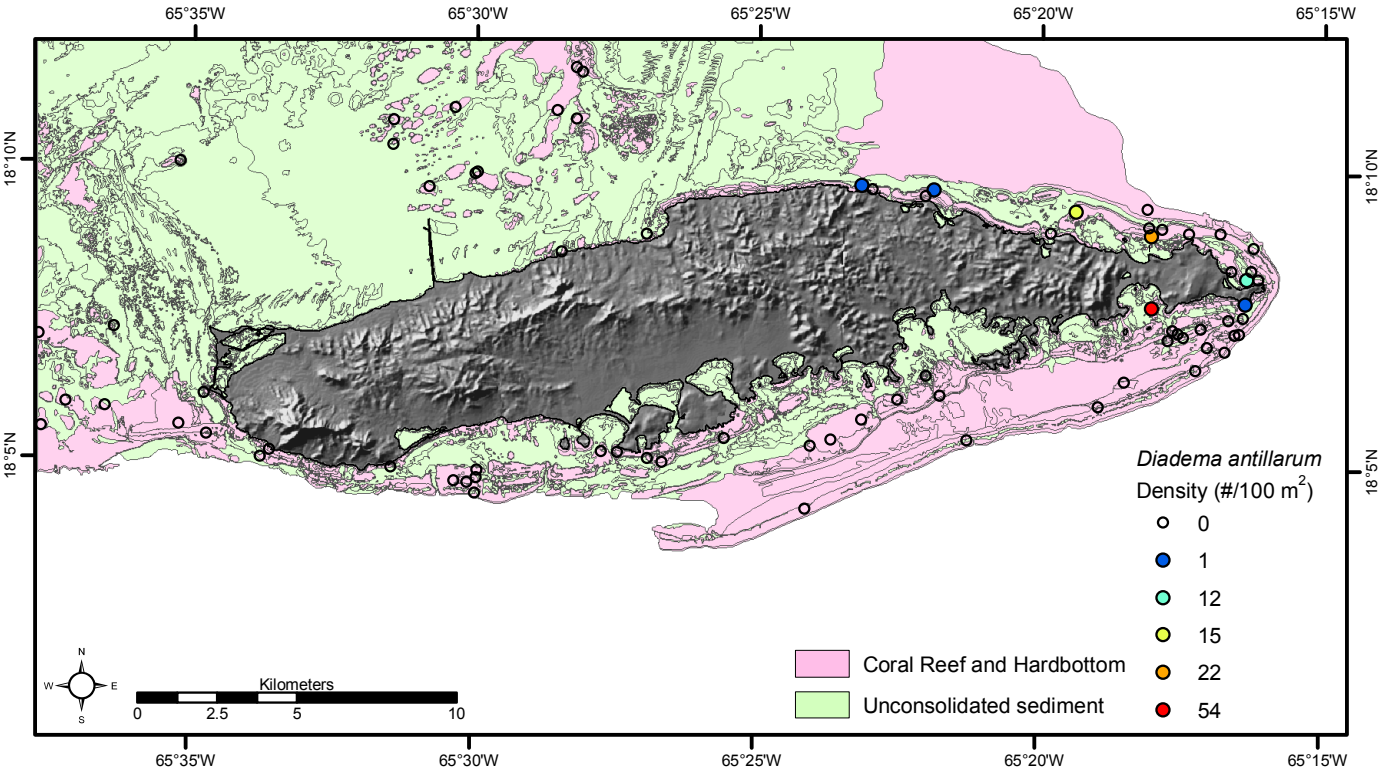


Figure 3.46. Spatial distribution of the long-spined urchin (*Diadema antillarum*).

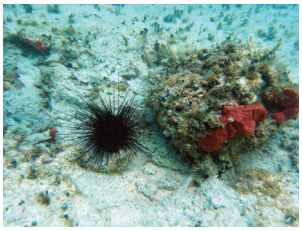
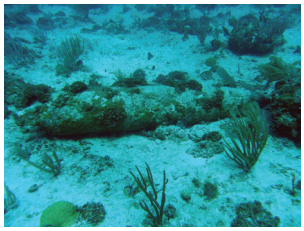


Image 3.12. *Diadema antillarum*.
Photo: CCMA Biogeography Branch.

Image 3.13. Unexploded ordnance.
Photo: CCMA Biogeography Branch.



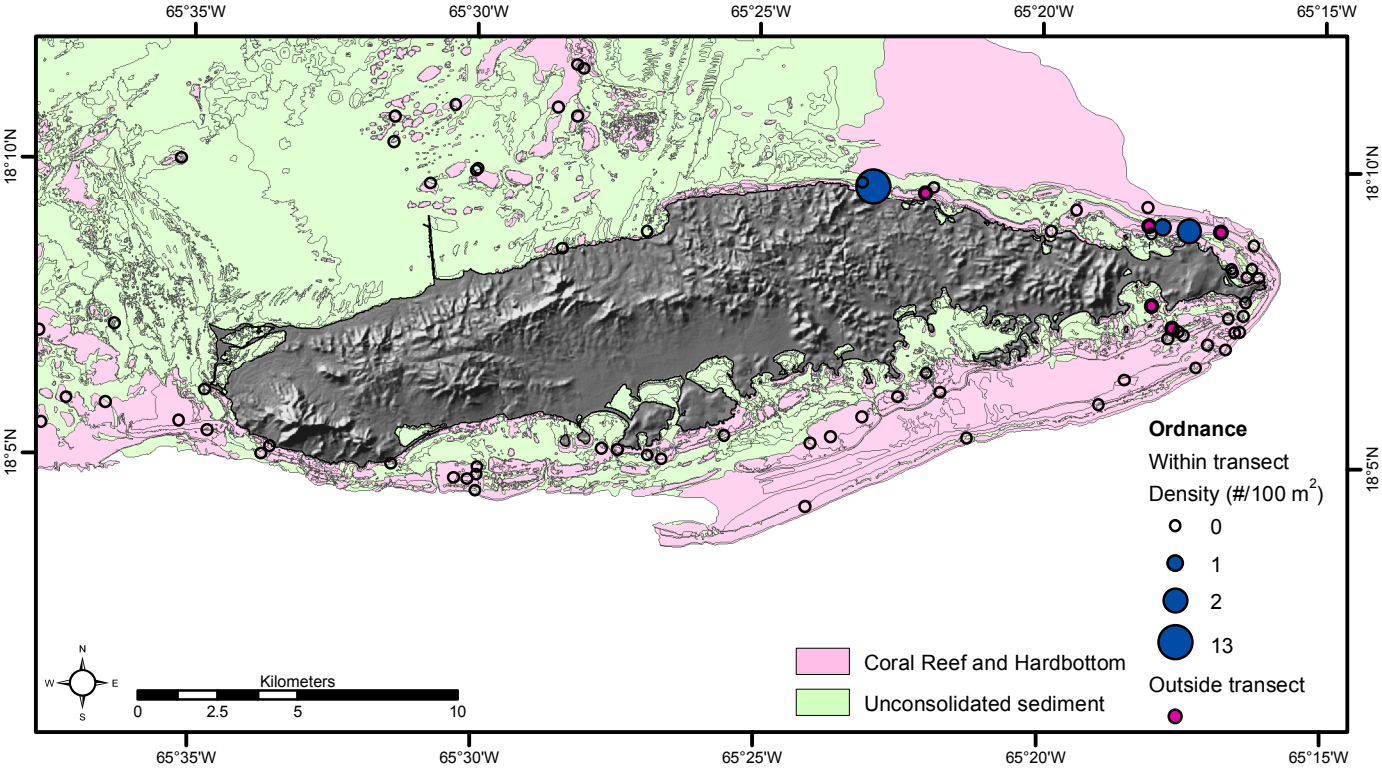


Figure 3.47. Spatial distribution of unexploded ordnance observed both within and outside survey transects.

3.4 SUMMARY AND CONCLUSIONS

Regular monitoring of the habitat and fish community in Vieques would allow potential changes to be followed over time, as well as to strengthen statistical comparisons between strata. In addition to local changes in land use and marine zoning, other regional factors are known to have affected benthic and fish communities in the greater Caribbean in recent decades. These include a widespread die-off of *D. antillarum* in the 1980s, mass mortality of Acroporids due to white-band disease, coral bleaching events, overfishing, and tropical cyclones. Due to the lack of consistent monitoring, there was a large gap in published reports quantifying fish abundance and benthic cover from the late 1980s-early 2000s. As such, the likely succession in Vieques reefs must be inferred from nearby regions, although a recent mapping analysis illustrated the progressive decline in *Acropora* in Bahia Salina del Sur from 1975-1985 (Hernandez-Cruz et al. 2006). Riegl et al. (2008) suggested that the primary cause of death of *Acropora* in Vieques was likely disease, while subsequent hurricanes aided in breaking up the dead stands into reef rubble. Benthic habitat composition on reef/hardbottom habitats in Vieques appears to be similar to other monitoring locations in the U.S. Caribbean, despite differences in management, land use and marine zoning between the various study areas. This supports the idea that present conditions on Vieques have been primarily shaped by regional-scale factors.

As this characterization was limited to one sampling period and a relatively small number of survey sites, it is difficult to make conclusive statements about fish and benthic cover metrics in relation to habitat and geographic location. For many habitat and fish metrics, there was often a large degree of variation within strata, resulting in a relatively large coefficient of variation (CV) of estimates of the mean (e.g., >20%). Despite the limitations, several interesting patterns emerged along the north vs. south shore of Vieques and also adjacent to the various land use strata from east to west. Many of the benthic and fish variables showed a gradual shift in abundance along one or both of these axes. These patterns are likely influenced by differences in reef morphology, habitat composition, bathymetry, hydrodynamics, and sedimentation. As demonstrated in Chapter 2, the composition and extent of benthic habitat structure around Vieques varies over space. For example, there is a higher amount of aggregated reef and pavement on the south shore of Vieques compared to the north side of the island. The southern coast is also marked by the presence of numerous bays and lagoons, many of which are lined by mangroves, which likely serve as nursery habitat and recruitment sources for many species (see Chapter 4). In contrast to the generally more topographically complex south shore, where the location of the shelf edge ranges approximately 1-4 km from shore, the area north of Vieques extending up towards Culebra is relatively uniform and shallow (<30 m) (Bauer et al. 2008).

Twentieth-century land use in Vieques is unique compared to other neighboring Caribbean islands due to the presence of the U.S. Navy from the 1940s-2003. There has been speculation that Naval activities, particularly firing exercises, have had a negative impact on marine biota. Conversely, one might expect that the lack of residential and commercial development on two-thirds of the island offered a degree of protection from anthropogenic activities (i.e., a de-facto marine protected area). Although there were some differences in fish and benthic communities across survey strata, our results do not support either of these hypotheses. Although coral cover was lowest in the strata north of the LIA (4-North), cover was only significantly lower when compared with the strata with the highest amount of cover (1-South). For most fish metrics, there was a stronger north-south trend than east-west. Although fisheries data for Vieques is inconsistent across years (see Bauer et al. 2008), interviews with fishermen indicated that primary fishing areas include the northern, eastern, and southeastern coasts of Vieques (Shivlani 2007; DON 1986).

A recent report summarizing data from the first five years of data collection in St. Croix illustrates the utility of regular monitoring in detecting changes over time and for informing marine spatial planning (Pittman et al. 2008). The transfer of lands from the U.S. Navy to the municipality and US. Fish and Wildlife are likely to result in a potential shift in development, runoff patterns, population demographics, and maritime activities such as fishing/diving. The results presented here are intended both to inform the current management decision-making process, as well as serve as a baseline for regular monitoring efforts. A spatially comprehensive assessment of softbottom habitat types (e.g., seagrass, mangrove) is also needed to fully characterize benthic and fish communities around Vieques. Regular monitoring of all habitats and associated communities are essential for conservation and management of Vieques' marine resources.

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LITERATURE CITED

Ault, J.S., S.G. Smith, J. Luo, M.E. Monaco, and R.S. Appeldoorn. 2008. Length-based assessment of sustainability benchmarks for several coral reef fishes in Puerto Rico. Environmental Conservation 35(3): 221-231.

Bauer, L.J., C. Menza, K.A. Foley, and M.S. Kendall. 2008. An ecological characterization of the marine resources of Vieques, Puerto Rico. Part I: Historical data synthesis. Prepared by National Centers for Coastal Ocean Science (NCCOS) Biogeography Branch in cooperation with the Office of Response and Restoration. Silver, Spring, MD. NOAA Technical Memorandum NOS NCCOS 86. 121 pp.

Beyer, H.L. 2004. Hawth's Analysis Tools for ArcGIS. Available at http://www.spatialecology.com/htools.

Caldow, C., R.Clark, K. Edwards, S.D. Hile, C. Menza, E. Hickerson and G.P. Schmahl. 2009. Biogeographic characterization of fish communities and associated benthic habitats within the Flower Garden Banks National Marine Sanctuary: Sampling design and implementation of SCUBA surveys on the coral caps. NOAA Technical Memorandum NOS NCCOS 81. Silver Spring, MD. 134 pp.

Clark, R., C. Jeffrey, K. Woody, Z. Hillis-Starr, and M. Monaco. 2009. Spatial and temporal patterns of coral bleaching around Buck Island Reef National Monument, St. Croix, US Virgin Islands. Bulletin of Marine Science 84(2): 167-182.

Clarke, K.R. and R.M. Warwick. 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd Edition. PRIMER-E, Plymouth.

Cochran, W.G. 1977. Sampling Techniques. John Wiley and Sons, Inc., New York. 413 pp.

DON (Department of the Navy). 1979. Draft environmental impact statement for the continued use of the Atlantic Fleet Weapons Training Facility Inner Range (Vieques). Prepared by TAMS (Tippetts, Abbett, McCarthy, Stratton) and Ecology and Environment, Inc.

DON (Department of the Navy). 1986. Environmental assessment of continued use of the Atlantic Fleet Weapons Training Facility Inner Range, Vieques, Puerto Rico. Prepared by Ecology and Environment, Inc.

Froese, R. and D. Pauly (eds.). 2008. FishBase. World Wide Web electronic publication. www.fishbase.org, version (06/2008).

García-Cagide, A., R. Claro, and B.V. Koshelev. 1994. Reproducción. pp. 187-262. In: R. Claro (ed.) Ecología de los peces marinos de Cuba. Inst. Oceanol. Acad. Cienc. Cuba. and Cen. Invest. Quintana Roo (CIQRO) México.

Garcia-Sais, J.R., R.L. Castro, J.S. Clavell and M. Carlo. 2001. Baseline characterization of coral reef and seagrass communities from Isla de Vieques, Puerto Rico. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 108 pp.

Garcia-Sais, J.R., R.L. Castro, J.S. Clavell and M. Carlo. 2004. Monitoring of coral reef communities from Isla de Vieques, Puerto Rico, 2004. Department of Marine Sciences, University of Puerto Rico, Mayaguez. 122 pp.

GMI (Geo-Marine, Inc.). 2003. Reef ecosystem baseline assessment survey and monitoring, Vieques Island, Naval Station Roosevelt Roads, Puerto Rico. Prepared for Atlantic Division, Naval Facilities Engineering Command, Norfolk, Virginia.

GMI (Geo-Marine Inc.). 2005. An assessment of the condition of coral reefs off the former Navy bombing ranges at Isla de Culebra and Isla de Vieques, Puerto Rico. Prepared for the Department of Defense, Legacy Resource Management Program, Arlington, Virginia, and US Army Corps of Engineers, Huntsville, Alabama.

Hernandez-Cruz, L.R., S.J. Purkis, and B.M. Riegl. 2006. Documenting decadal spatial changes in seagrass and *Acropora palmata* cover by aerial photography analysis in Vieques, Puerto Rico: 1937-2000. Bulletin of Marine Science 79(2): 401-414.

Kendall, M.S., C.R. Kruer, K.R. Buja, J.D. Christensen, M. Finkbeiner, R.A. Warner and M.E. Monaco. 2001. Methods used to map the benthic habitats of Puerto Rico and the U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS CCMA 152. Silver Spring, MD. 45 pp.

Lundgren, I. and Z. Hillis-Starr. 2008. Variation in *Acropora palmata* bleaching across benthic habitats at Buck Island National Reef Monument (St. Croix, USVI) during the 2005 bleaching event. Bulletin of Marine Science 83: 441-451.

Miller, J.R., R. Waara, E. Muller and C.S. Rogers. 2006. Coral bleaching and disease combine to cause extensive mortality on reefs in U.S. Virgin Islands. Coral Reefs 25:418.

Pittman, S.J., S.D. Hile, C.F.G. Jeffrey, C. Caldow, M.S. Kendall, M.E. Monaco, and Z. Hillis-Starr. 2008. Fish assemblages and benthic habitats of Buck Island Reef National Monument (St. Croix, U.S. Virgin Islands) and the surrounding seascape: A characterization of spatial and temporal patterns. NOAA Technical Memorandum NOS NCCOS 71. Silver Spring, MD. 96 pp.

Riegl, B.M., R.P. Moyer, B. Walker, K. Kohler, D. Gilliam and R.E. Dodge. 2008. A tale of germs, storms, and bombs: geomorphology and coral assemblage structure at Vieques (Puerto Rico) compared to St. Croix (US Virgin Islands). Journal of Coastal Research 24(4): 1008-1021.

Shivlani, M. 2007. Community studies to determine the feasibility and expectations of marine protected area (MPA) management in Vieques, Puerto Rico. Unpublished report. 38 pp.

Zar, J.H. 1999. Biostatistical Analysis. Prentice Hall, New Jersey. 663 pp.