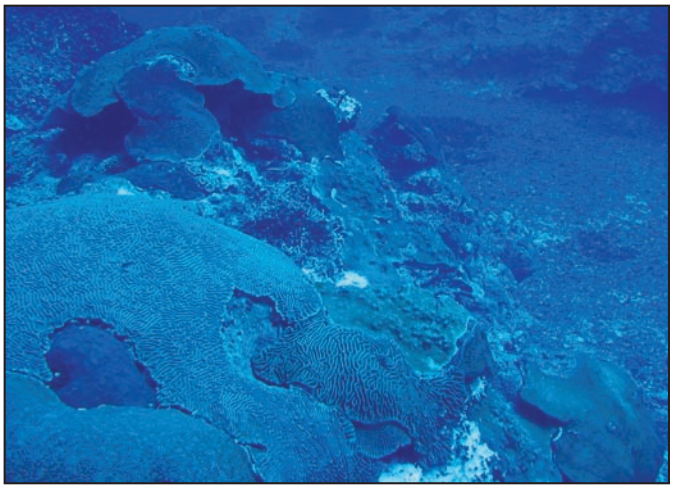
Chapter 3: Benthic Composition

3.1 INTRODUCTION

The coral caps are dominated by reef building corals, which have been estimated to cover nearly 50% of the shallower portions of the reef (Gittings, 1998; Aronson et al., 2005) and up to 82% in deeper waters (32-40 m; Precht et al., 2008a). Coral colonies over 2 m in height are commonly encountered and provide shelter for a thriving reef fish community (see Chapter 4: Fish Communities).



Montastraea, Diploria and *Madracis* corals (CCMA)

Scientific research has been conducted on the banks for more than 30 years (Gittings and Hickerson, 1998). Past studies evaluating potential impacts from the oil and gas industry have provided valuable information on the benthic communities (Bright and Pequegnat, 1974; Viada, 1980; Gittings, 1998). In the late 1980s permanent stations for long-term monitoring were established on the banks and continue to be surveyed annually (Precht et al., 2008a). This monitoring effort has focused on relatively small portions of the coral cap environments and thus provides a spatially limited scope of inference.

The research presented here complements these prior studies with the development of a spatial framework and sampling design that includes 90% of the coral cap community. The data, analysis and results presented here provide a spatially-explicit characterization of the benthic community at depths shallower than 33.5 m (100 ft). For comparative purposes, analyses are presented contrasting the benthic communities of the Shallow Coral Cap (SCC) to coral reef systems in St. Croix and St. John in the U.S. Virgin Islands (USVI) as well as southwestern Puerto Rico.

3.2 METHODS

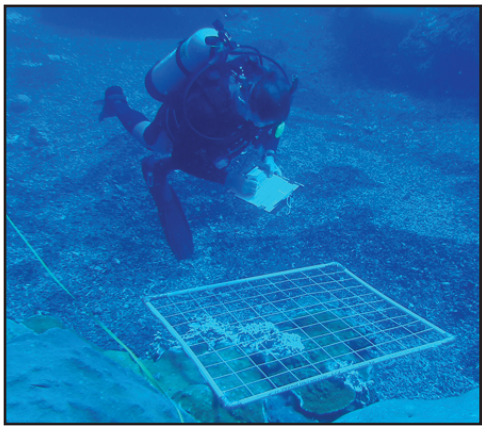
3.2.1 Survey Data

Benthic data were collected using underwater visual surveys of the East Bank (EB) and West Bank (WB) coral caps in 2006 (73 sites) and 2007 (32 sites). As detailed in Chapter 2, the 2007 sampling mission was concluded early due to Hurricane Humberto. Each sampling mission consisted of a randomly selected set of sample sites from which benthic and fish community data were gathered simultaneously. During each survey, data on benthic composition were collected from four 1 m^2 quadrats which were randomly placed along a 25 m belt transect used to census fish. In each quadrat abiotic and biotic components of the benthic habitat were measured (Table 3.1) and the mean for that survey location calculated. Abiotic data included: percent cover of hardbottom, sand and rubble components, and marine debris. Cover estimates included the bottom directly beneath living organisms such that an area recorded as 100% live coral would also receive a value of 100% hardbottom. Biotic data included: percent cover of coral species, algae classes, sponge morphotypes and coral bleaching. Data on each abiotic and biotic variable were averaged from the four quadrats to obtain synoptic representative

Table 3.1. Benthic variables measured to characterize the benthic community of the Flower Garden Banks National Marine Sanctuary (FGBNMS).

	Measurements		
Benthic Biota	**Percent cover**	**Height (cm)**	**Abundance (#)**
Abiotic			
Hardbottom	X	X	
Sand	X		
Rubble	X		
Fine Sediment	X		
Biotic			
Corals (by species)	X		
Macroalgae	X	X	
Seagrasses (by species)			
Sponges			
Barrel, tube, vase morphology	X	X	X
Encrusting morphology	X		
Other benthic macrofauna			
Anemones and hydroids	X		X
Tunicates and zooanthids	X		
Macroinvertebrates			
Queen conch			X
Spiny lobster			X
Long-spined urchin			X
Marine debris (type, area of debris, area affected, colonized by)			

estimates of the variables at each site. Coral colonies were reported as entirely bleached if they contained any portion of white, blotchy, mottled or pale tissue. This protocol assumes stress throughout the colony and estimates maximum bleaching impact. To determine susceptibility of the banks as a whole or individual species to coral bleaching, percent bleaching was standardized by the total coral cover or total percent cover of the particular species respectively. The average from the four quadrats represents a spatial average and was used as an independent replicate to derive domain-wide and strata specific means and standard errors. In addition to the data obtained from quadrat surveys key macroinvertebrates (queen conch [*Strombus gigas*], Caribbean spiny lobster [*Panulirus argus*], long-spined sea urchin [*Diadema antillarum*]) and marine debris observed within the 25 x 4 m transect were recorded. See Chapter 2 for more information on sampling designs and Appendix B for measurement protocols.



Diver collecting benthic data. (CCMA)

3.2.2 Data analysis

A series of analyses were conducted to provide an overall characterization of the benthic composition for the banks. Unbiased, domain-wide estimates of percent cover are provided for the SCC. Following this, comparative and correlative techniques were utilized to identify differences among strata and explore relationships between variables. Through the development of interpolated surfaces and through the technique of clustering, spatial patterning of key variables was observed. A quantification of marine debris is provided as one measure of anthropogenic stress. Finally, the data collected were compared with data from the U.S. Caribbean to determine how this system compares with other systems similar in species composition.

Domain-wide Population Estimates

Domain-wide estimates were computed employing methods described by Cochran (1977) for a stratified sampling design using 2006 data, strata and corresponding sampling weights. Measurements collected in 2007 were not included because the incomplete field mission imposed spatial bias (see Chapter 2 for details regarding sampling design). Mean percent cover and standard error were calculated for each major taxonomic group (coral, macroalgae and sponges) as well as for abiotic data categories (hardbottom, rubble and sand).

Strata Comparisons

For comparative analyses, the 73 sample sites surveyed in 2006 were classified into three different strata: East Bank High relief (EBH), East Bank Low relief (EBL) and West Bank High relief (WBH) depending on benthic relief and geographic location. There were no low relief habitat sites surveyed on the WB, and therefore no West Bank Low relief stratum was used in the analyses or presented in results. Benthic relief was derived from a benthic habitat map developed for this study (see Appendix C).

These strata are different from those actually used for the 2006 sampling design. It must be noted therefore, that estimates of means and variances are not technically valid; however since a random proportional-to-area design was used, the difference between the valid and computed estimates are assumed to be negligible. As with the domain-wide calculations, data from the 2007 mission were not included because the incomplete field mission imposed spatial bias.

Data analysis included mean percent cover of each major taxonomic group (coral, macroalgae and sponges), individual coral species data and abiotic data (hardbottom, rubble and sand). Shannon's diversity (H', log_{10}) and Pielou's evenness (J') indices were calculated on the coral data using MVSP® (Kovach Computing Systems, 1985). Shannon's diversity index (H') is represented as:

$$H' = - \Sigma_i \, p_i \, (\ln p_i)$$

where H' is a weighted combination of: total number of species (richness) and the extent to which the total abundance is spread equally amongst the observed species (evenness) p_i is the proportion of the total count arising from the i th species.

Pielou's evenness (*J'*) index is represented as:

$$J' = H' / \ln S$$

where *S* is the total number of species.

As data did not conform to assumptions of normality due to high frequency of zero values, a non-parametric Kruskal-Wallis test was run on ranked data in JMP© (SAS Institute Inc., 2000) to identify differences among strata (EBH, EBL and WBH). While sample sizes among strata were not equal, impacts on the tests were assumed negligible because data dispersion was similar. Pairwise comparisons were performed using the Nemenyi test (Zar, 1999).

Correlative Analyses

Correlations were investigated among percent cover of corals, macroalgae, and sponges as well as depth using non-parameteric Spearman's analysis on percent cover. Data collected during both the 2006 and 2007 field missions were utilized for these analyses. Results are reported as Spearman's ρ (Rho).

Interpolations

Percent cover data were interpolated and mapped using inverse distance weighting (IDW) to guide interpretation of spatial patterns. These interpolations were created without separating data by strata; therefore, where observed patterns cross strata they must be interpreted with consideration given to strata differences (e.g., a site containing high percent cover in the EBH strata near the border of EBL may result in the adjacent area in EBL appearing high as well which may not reflect reality). Interpolated surfaces were generated for each bank with ArcGIS spatial analyst (ESRI, 2006) using all data from 2006 and 2007. By combining the years we increase our coverage of sample points on EB; however, this assumes no differences between years. EB was further segregated into two portions: the main portion of the bank and a smaller mound that is approximately 470 m northeast of the main portion. Only three surveys were conducted on this smaller portion of EB, thus an interpolated surface for this region was not generated.

Clustering

Cluster analysis was conducted to further understand the spatial distributions of coral species within the SCC. Cluster analysis is an analytical method used to summarize information into groups based on similarities among variables (Sokal and Rohlf, 1995). This was accomplished using the Bray-Curtis proximity coefficient, hierarchical cluster analyses of the species and sites, and a nodal analysis of the species and site cluster analyses. The nodal analysis, the intersection of the species clusters and the site clusters, was used to identify the species assemblages defining the site groupings. Analysis included data from both 2006 and 2007. *Montastraea annularis* complex (composed of *Mo. franksi*, *Mo. faveolata* and *Mo. annularis*) was removed from this analysis; however the unique *Montastraea* species were kept. Additionally, rare coral species (species that occurred in three or fewer samples) were omitted from the analysis, resulting in 18 species for all sample sites.

Prior to calculating the Bray-Curtis coefficient, the coral species percentages were converted to integers by multiplying the coral species cover percentages by 100. A matrix of Bray-Curtis dissimilarity coefficients were calculated for the species and site data. These matrices were processed by the Cluster Procedure in the SAS/STAT© software (SAS Institute Inc., 2006). Scree plots of cluster distances were examined to determine where breaks in the dissimilarity level among the clusters occurred. Nodal analysis was then used to relate coral assemblages with site groups.

Marine Debris

A map depicting the distribution of marine debris was created allowing spatial patterns to be interpreted.

Comparison with U.S. Caribbean

Spatial patterns in benthic composition and diversity were examined across three U.S. Caribbean reef ecosystems that have been monitored using the same methods since 2001 (Menza et al., 2006; Pittman et al., 2007). Methods are further detailed in Section 3.4.1.

3.3 RESULTS AND DISCUSSION

3.3.1 Abiotic Cover

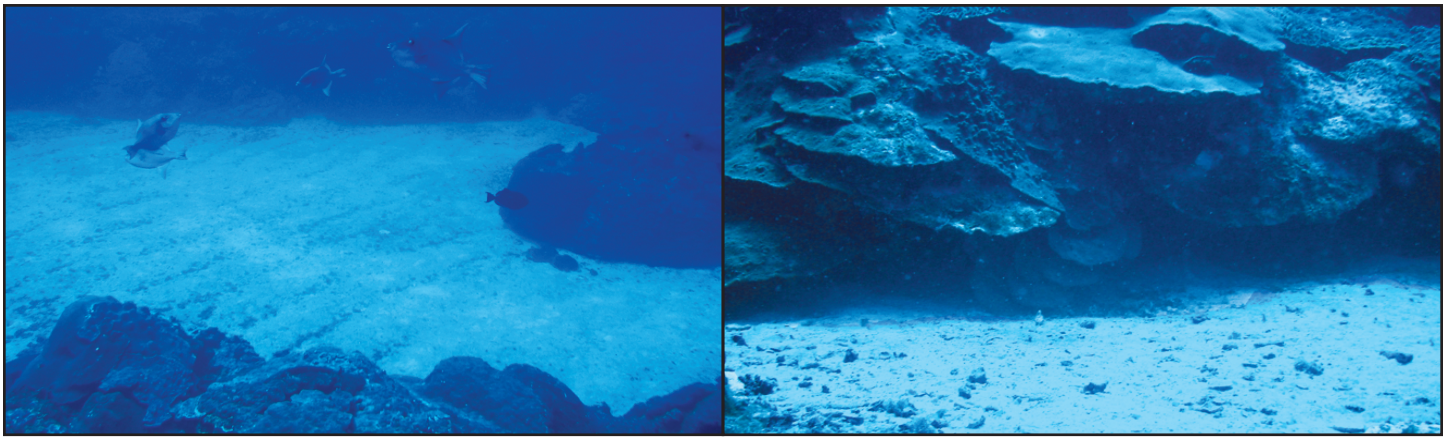
Total hardbottom cover of the SCC was estimated at 89% (Table 3.2). This estimate is consistent with observations by Rezak et al. (1985) who used photo transect surveys to derive a value of 85% hardbottom on the coral caps. Significant differences were found between strata (p=0.0009) with nearly double the coverage in high relief areas (EBH at 92%, WBH at 94%) compared to low relief (EBL at 53.8%).

Table 3.2. Mean percent cover (± SE) for abiotic categories among strata and for the sanctuary.

Strata	N Rows	Hard (± SE)	Rubble (± SE)	Sand (± SE)
EBH	39	93 (2.3)	2 (0.9)	4 (1.6)
EBL	10	54 (12.6)	46 (12.6)	0 (0)
WBH	24	95 (3.0)	2 (1.9)	2 (1.9)
FGB	73	89 (1.6)	8 (1.4)	3 (0.7)

The difference in hardbottom coverage between strata is in part due to a relatively recent large-scale mortality event in the EBL which converted substantial portions of the *Madracis mirabilis* fields to rubble. It is hypothesized that the observed mortality is the result of damage from Hurricane Rita which came within 83 km of the sanctuary in 2005 (Hickerson et al., 2008; Precht et al., 2008b). On average 8% of the SCC was rubble, with significantly more observed in the low relief strata (46%; p<0.0001; Table 3.2). Rubble made up significantly less of the benthic habitat than hardbottom and was completely absent in nearly 75% of transects.

Sand comprised a relatively small proportion of benthic cover (3%). While there are a few large sand patches and sand channels present on the coral caps the majority of sand habitat is restricted to areas under coral plate edges or in between coral colonies. It should be noted that substantial volumes of sand and sediment (up to 1 m deep) were displaced as a result of Hurricane Rita in 2005 and values obtained during the current study may be lower than they were even one year prior as a result (Hickerson et al., 2008; Precht et al., 2008b). No significant differences were detected between the two high relief habitats and no sand was observed on the low relief stratum.



Sand channels between coral colonies (left) and sand patch under coral plate edges (right). (E. Hickerson, CCMA)

3.3.2 Coral Cover

Stony corals dominated the benthic community structure comprising 48% of the benthos (Table 3.3). During 2006 and 2007, a total of 20 corals were identified to the species level among 14 genera. The most dominant in terms of cover were *Montastraea*, *Diploria* and *Madracis*. Gittings (1998) analyzed research studies spanning 20 years and obtained a value of nearly 50% comparing favorably with the current study and emphasizing the stability of the coral community.

Table 3.3. Mean percent cover (± SE) for biotic categories surveyed by strata and for the sanctuary.

Strata	N Rows	Corals (± SE)	Macroalgae (± SE)	Sponges (± SE)
EBH	39	58 (3.3)	14 (2.2)	0.7 (0.2)
EBL	10	32 (6.4)	23 (6.6)	0.7 (0.2)
WBH	24	59 (4.3)	8 (1.6)	0.7 (0.2)
FGB	73	48 (2.0)	13 (1.0)	0.7 (0.1)

The highest coral cover was observed in the high relief strata (EBH=58% and WBH=59%; Figure 3.1) and was almost twice as high as the coral cover found in the low relief stratum (EBL=32%; p=0.0001). Coral cover within each stratum was generally homogenous, showing no consistent spatial pattern. *Montastraea franksi* was the most dominant species on the high relief strata, whereas the most abundant coral in the low relief stratum was *Ma. mirabilis* (Table 3.4). Among these strata both evenness and diversity were lowest on low relief habitats

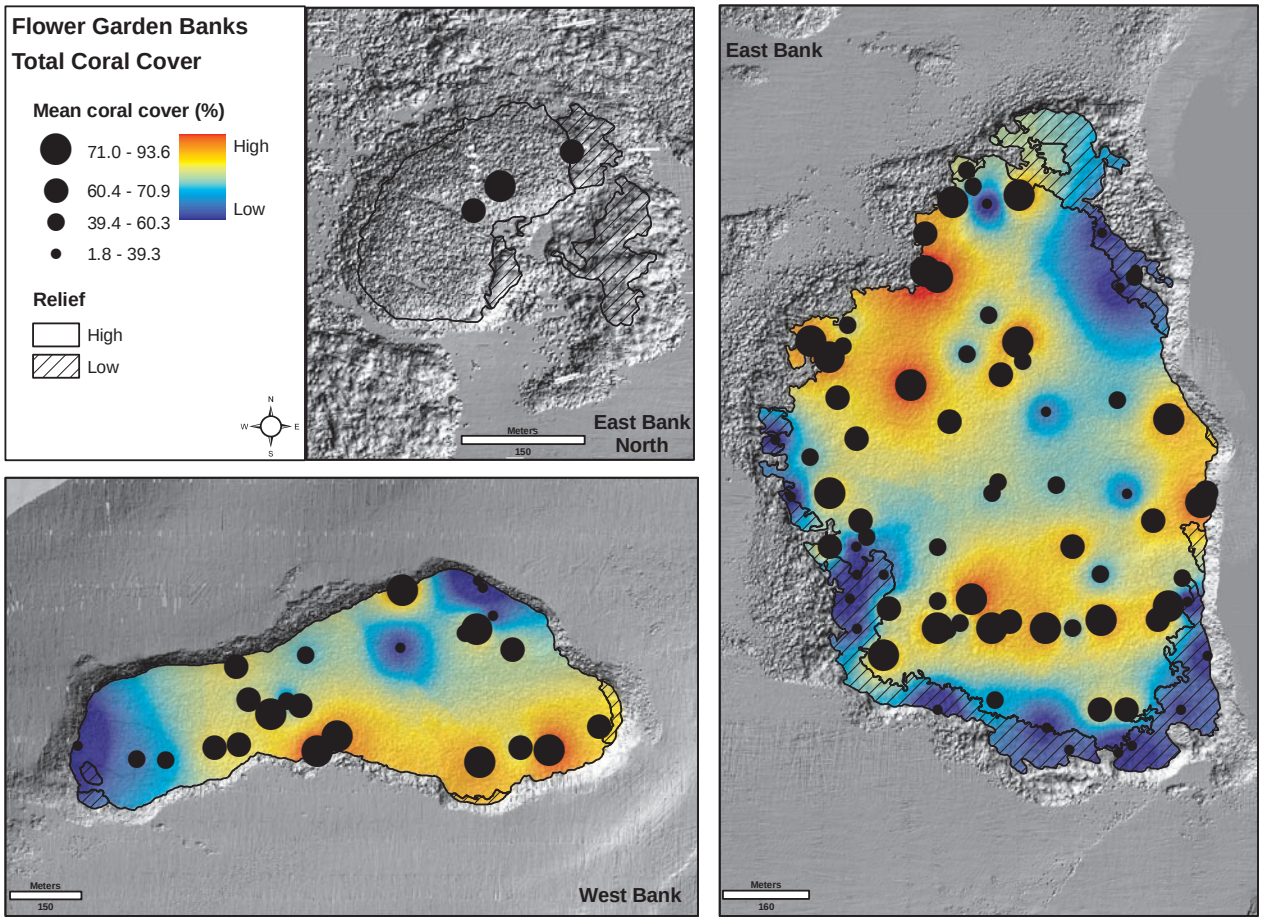


Figure 3.1. Spatial interpolation of mean coral cover among sample sites within FGBNMS.

Table 3.4. Mean percent cover (± SE) of coral species sampled in 2006 among strata.

Coral species	EBH (± SE)	EBL (± SE)	WBH (± SE)
Agaricia agaricites	0.1 (0.03)	<0.1 (<0.1)	0.1 (0.04)
Agaricia fragilis	<0.1 (<0.1)	0	<0.1 (<0.1)
Agaricia spp	<0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)
Colpophyllia natans	3.3 (1.0)	2.8 (2.6)	1.6 (0.7)
Diploria spp	0.2 (0.2)	0	<0.1 (<0.1)
Diploria strigosa	4.5 (0.8)	3.6 (2.4)	5.6 (2.0)
Madracis decactis	0.4 (0.1)	<0.1 (<0.1)	0.3 (0.1)
Madracis mirabilis	0.5 (0.5)	13.0 (5.0)	<0.1 (<0.1)
Madracis spp	0	0	0.1 (0.1)
Millepora alcicornis	1.0 (0.5)	0.9 (0.5)	0.7 (0.2)
Millepora spp	<0.1 (<0.1)	0	0.4 (0.2)
Montastraea annularis	1.6 (1.0)	0.9 (0.9)	4.6 (2.7)
Montastraea annularis complex	0.8 (0.8)	0	7.9 (4.6)
Montastraea cavernosa	3.7 (1.0)	2.8 (2.4)	3.7 (1.3)
Montastraea faveolata	5.7 (1.7)	0	2.1 (1.0)
Montastraea franksi	32.2 (3.2)	4.1 (2.6)	28.3 (3.9)
Mussa angulosa	0.2 (0.05)	<0.1 (<0.1)	<0.1 (<0.1)
Porites astreoides	3.2 (0.5)	3.8 (1.9)	2.0 (0.3)
Porites spp	0	0	<0.1 (<0.1)
Scolymia cubensis	<0.1 (<0.1)	<0.1 (<0.1)	<0.1 (<0.1)
Scolymia spp	<0.1 (<0.1)	0	<0.1 (<0.1)
Siderastrea siderea	0.4 (0.2)	0	0
Stephanocoenia intercepta	0.4 (0.1)	0.2 (0.1)	1.4 (0.5)

however these differences were not significant (Figure 3.2). A strong, negative relationship was found between total coral cover and both macroalgae (ρ = -0.71) and sponges (ρ = -0.56) and a weak correlation was observed with depth (ρ = -0.16).

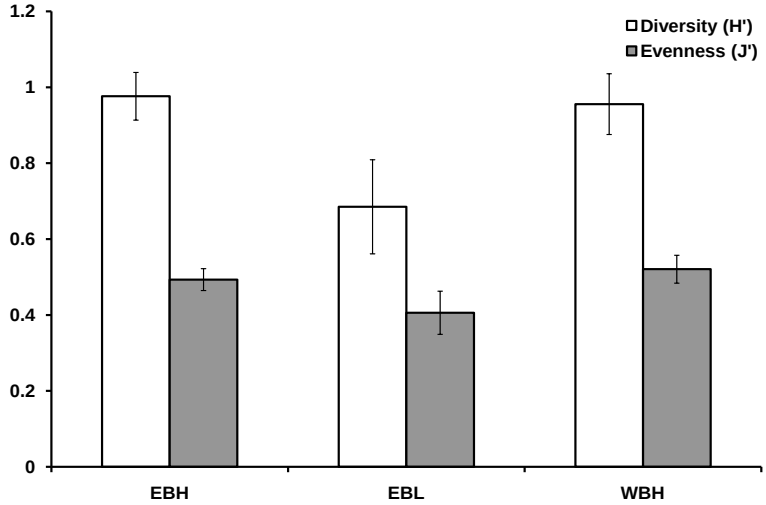
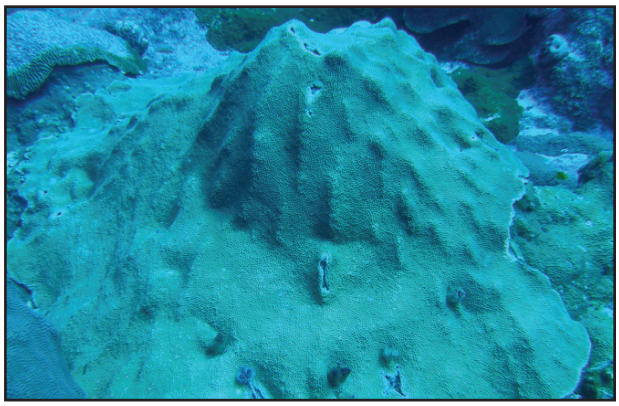


Figure 3.2. Shannon-Weiner diversity indices (H') and evenness (J') for corals surveyed by strata. Error bars represent standard error.

3.3.2.1 Montastraea *species*

The genus *Montastraea* contains four species in the Caribbean, all of which occur within the FGBNMS. They account for over three quarters of the total coral coverage on high relief strata (Table 3.4). These observations concur with those of Rezak et al. (1985) who found *Montastraea* to be the most dominant hermatypic coral on the banks. On the top of the coral caps these species form mounding boulder colonies often taller in size than a diver; however on the edges of the caps in deeper water, plating morphotypes become more prevalent. *Montastraea* colonies typically contain numerous cracks and crevices that provide shelter for smaller fish species while also providing large overhangs and holes suitable for the many large species of grouper residing on the banks.



Montastraea faveolata (CCMA)

It must be noted that the following species specific analyses may be confounded by the occasional recording of *Mo. annularis* complex *in lieu* of other species of *Montastraea* with the exception of *Montastraea cavernosa*. This classification was utilized six times in 2006 and once in 2007.

3.3.2.1.1 <u>*Montastraea franksi*</u>

Mo. franksi made up the largest proportion of cover among all corals in high relief strata (EBH=32.2% and WBH=28.3%; Table 3.4). Although it was significantly less common in the low relief stratum (p=0.0006), it was the second most dominant coral species (4.1%) in that area and its distribution was very similar to the distribution of total coral cover (Figure 3.3). *Mo. franksi* also displayed strong moderate relationships with both macroalgae (ρ = -0.40) and sponges (ρ = -0.35) and a weak relationship with depth (ρ = -0.15).

3.3.2.1.2 <u>*Montastraea faveolata*</u>

Mo. faveolata was present in fewer than half of the sites surveyed and completely absent from surveys on the EBL stratum. Overall cover in the high relief strata was not significantly different with 5.7% in EBH and 2.1% in WBH. *Mo. faveolata* was generally more common along the eastern half of the EB, with a relatively low representation within the WB (Figure 3.4). *Mo. faveolata* showed a strong negative relationship with depth (ρ = -0.32) but no relationship with either macroalgae or sponges.

3.3.2.1.3 <u>*Montastraea cavernosa*</u>

Mo. cavernosa cover was relatively low (approximately 4%) and patchily distributed (Figure 3.5). Unlike the other *Montastraea* species, *Mo. cavernosa* cover estimates were similar among the varying relief strata, exhibiting no relationship with depth or presence of either macroalgae or sponges.

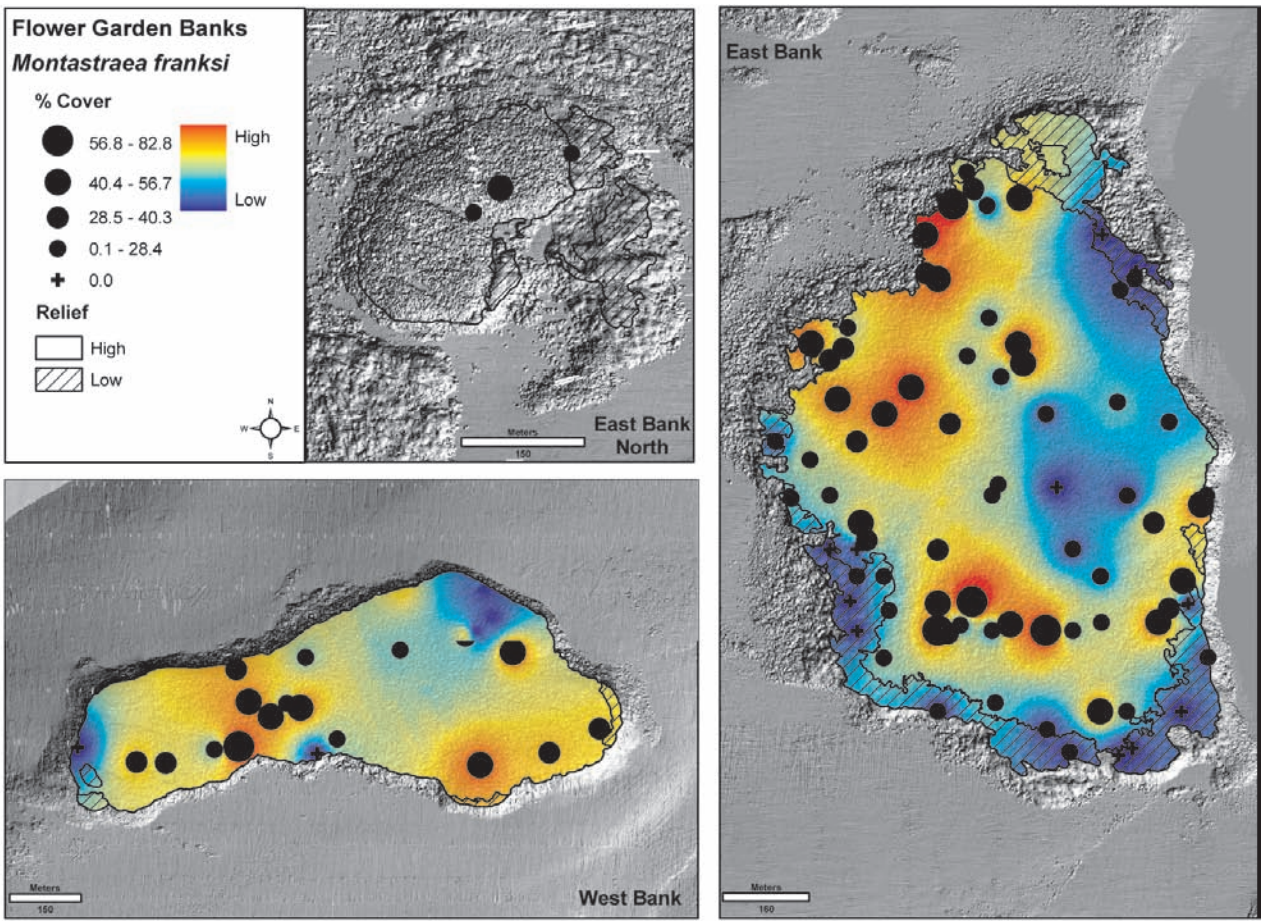


Figure 3.3. Spatial interpolation of Montastraea franksi *among sample sites within FGBNMS.*

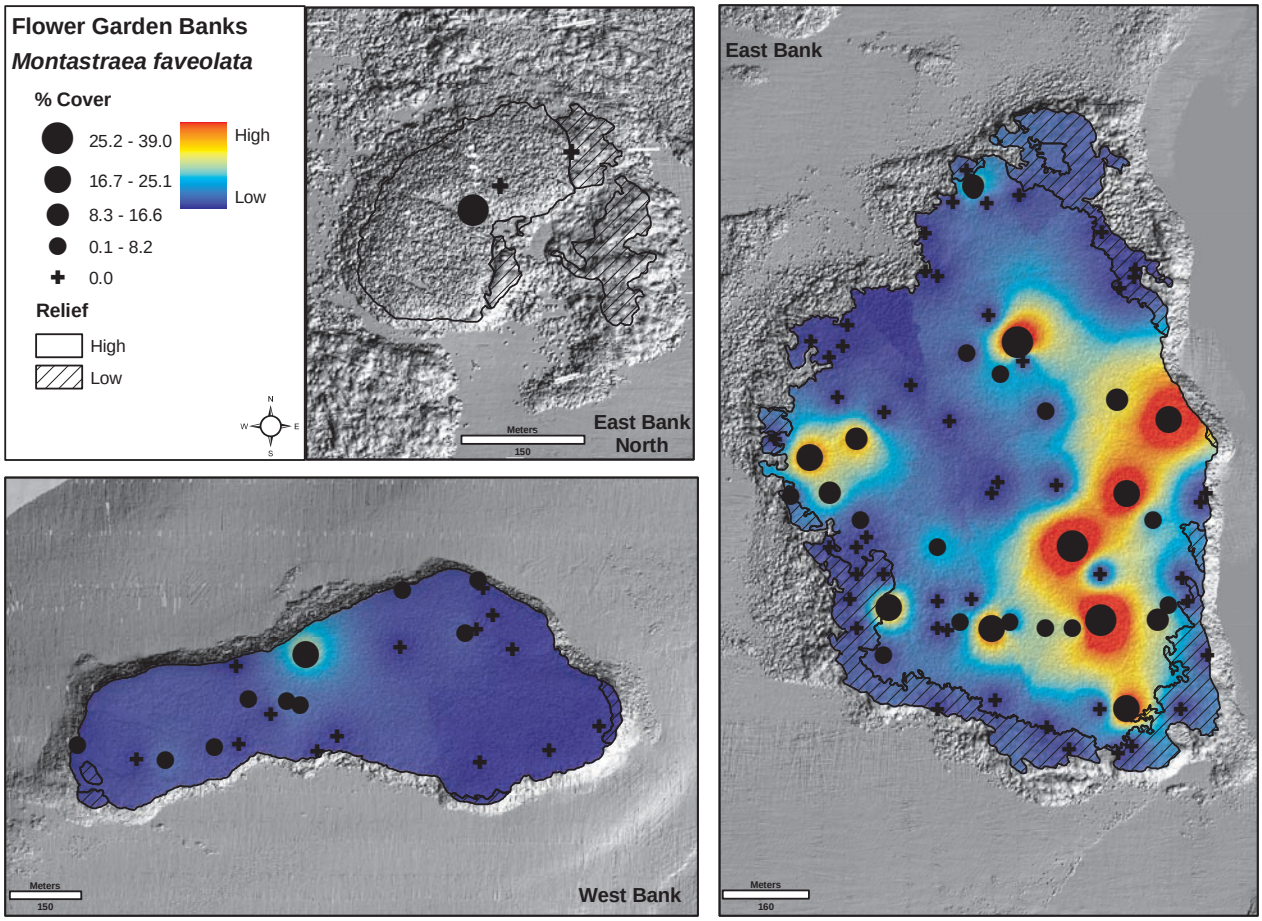


Figure 3.4. Spatial interpolation of Montastraea faveolata *among sample sites within FGBNMS.*

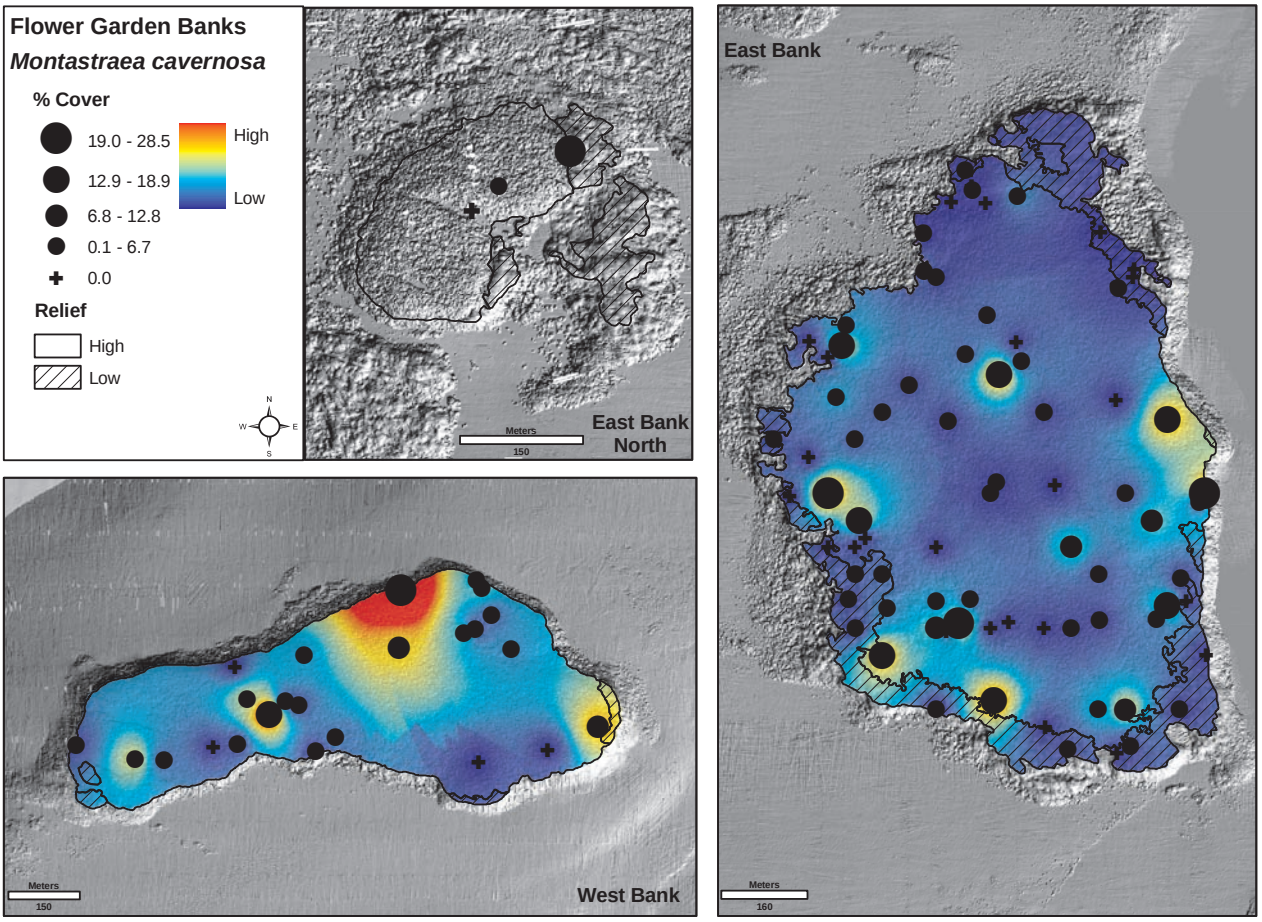


Figure 3.5. Spatial interpolation of Montastraea cavernosa *among sample sites within FGBNMS.*

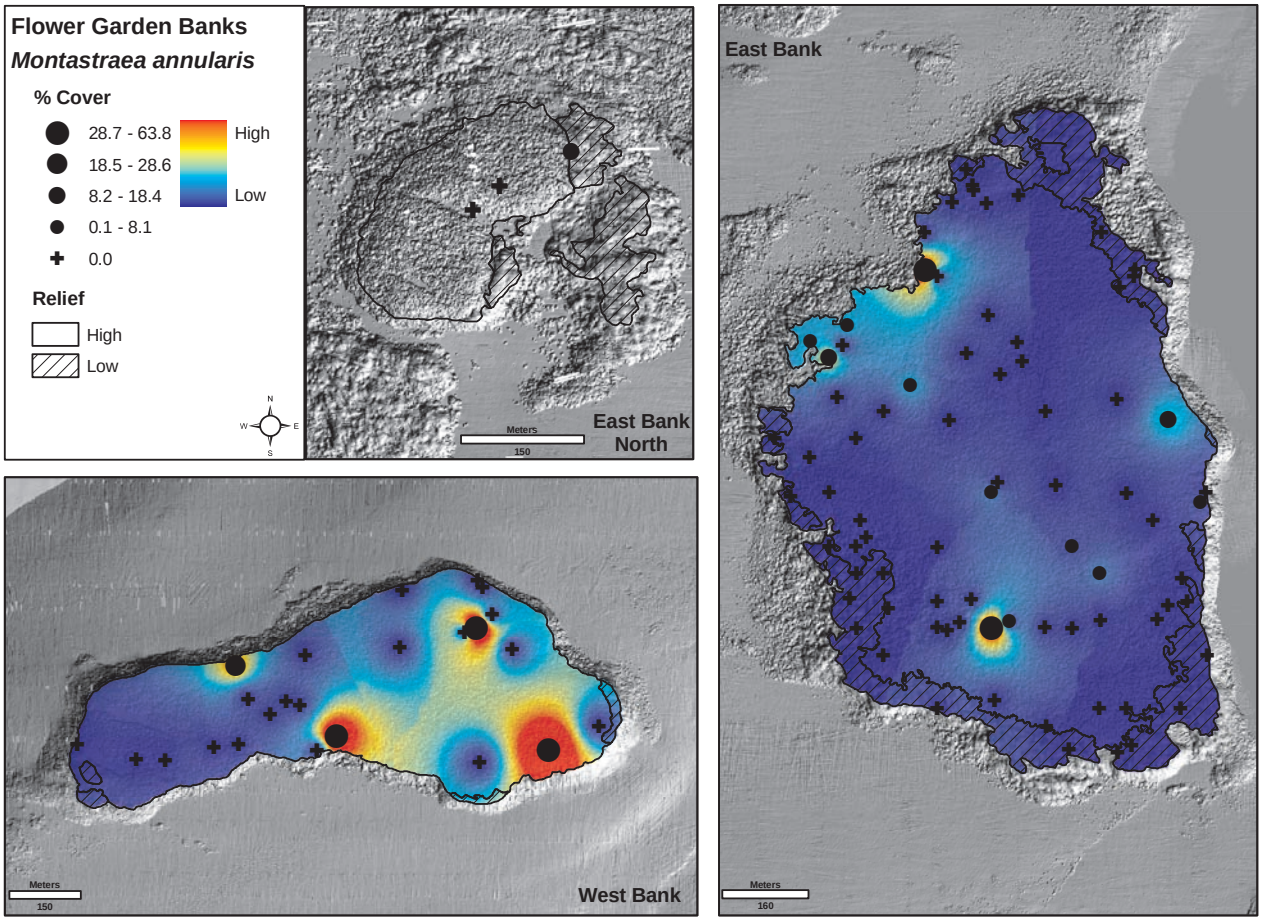


Figure 3.6. Spatial interpolation of Montastraea annularis *among sample sites within FGBNMS.*

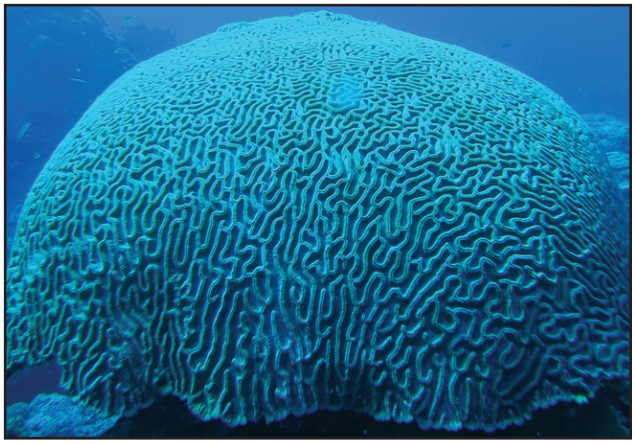
3.3.2.1.4 Montastraea annularis

Only ten surveys in 2006 contained recorded instances of *Mo. annularis* and only one of those was from the EBL. No significant differences were detected among strata. *Mo. annularis* cover among strata ranged from <1% in EBL to 2% in EBH and 5% in WBH (Table 3.4). Similar to *Mo. cavernosa*, *Mo. annularis* showed a patchy distribution with no discernible spatial patterning (Figure 3.6). In spite of the low frequency of occurrence, moderately negative relationships were observed with depth (ρ = -0.21), macroalgae (ρ = -0.36) and sponges (ρ = -0.26).

3.3.2.2 Diploria *species*

The genus *Diploria* contains members of the larger group commonly referred to as the brain corals. Similar to members of the genus *Montastraea*, colonies of *Diploria* take boulder form in shallower waters and tend to plate out at deeper depths. Only one species, *Diploria strigosa*, was observed during the course of the surveys on the coral caps. As a result of its size (up to 2 m) and its relative abundance, *D. strigosa* contributes substantially to the habitat complexity of the coral cap floor.

It should be noted that in 2006 there is one instance of a *Diploria* colony that was not identified to the species level.



Diploria strigosa colony (CCMA)

3.3.2.2.1 Diploria strigosa

D. strigosa was the second most dominant coral species in terms of coral cover on the SCC and was relatively evenly distributed among strata (Table 3.4). While no significant differences were detected, the highest coverage was observed within the interior portions of the EB and along the edges of the WB (Figure 3.7). This contrast in distribution between the banks merits further investigation. There was a moderately negative correlation between this species and depth (ρ = -0.31) as well as macroalgae (ρ = -0.27); however no relationship was observed between *D. strigosa* and sponges.

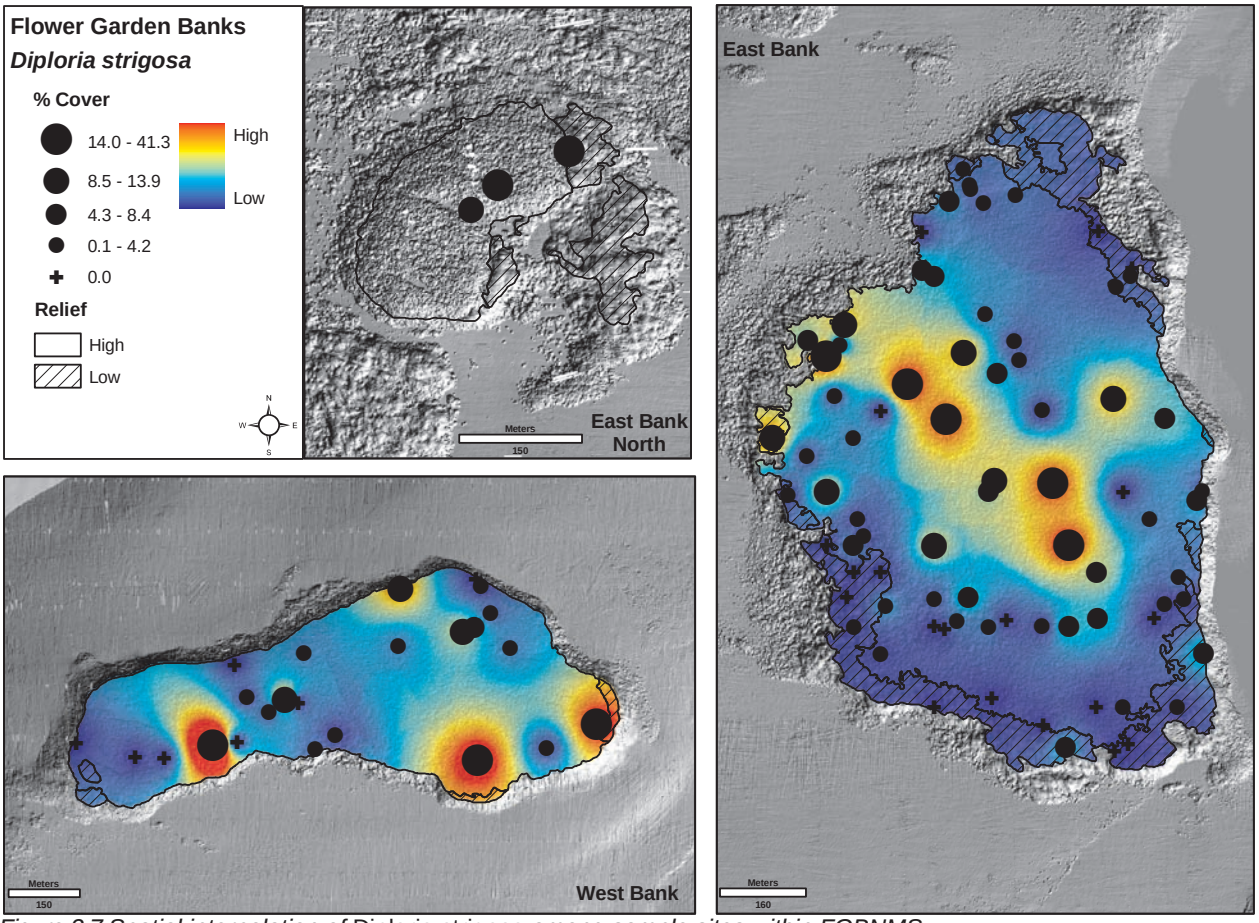
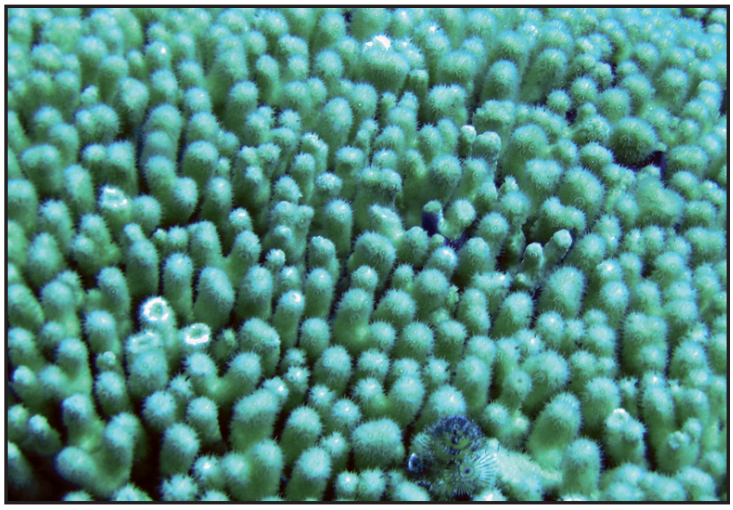


Figure 3.7.Spatial interpolation of Diploria strigosa *among sample sites within FGBNMS.*

3.3.2.3 Madracis *species*

Corals of the genus *Madracis* are most commonly encountered in deeper waters around the Caribbean. In morphology *Madracis* species can be knobbed, lobed, encrusting, branching or a combination adding additional complexity to the benthos resident on the banks and providing additional structure for a variety of reef fish species. At the FGBNMS, seven species have been recorded, the majority during submersible surveys in waters greater than 45 m. Two of the shallower water species in the genus were observed during the course of this study, *Ma. mirabilis* and *Madracis decactis*; however, the latter contributed less than 0.4% coverage in any of the strata.



Madracis mirabilis (CCMA)

3.3.2.3.1 <u>*Madracis mirabilis*</u>

Ma. mirabilis was the most dominant coral within the EBL stratum (13%) where it blanketed large areas at depths below the more complex *Montastraea* and *Diploria* dominated portion of the caps. Large portions of this stratum contained *Ma. mirabilis* rubble from colonies thought to be impacted by a recent hurricane, which suggests that coverage historically was higher. *Ma. mirabilis* coverage was significantly less in high relief strata ($p<0.0001$) than in the EBL (Table 3.4; Figure 3.8) and showed a moderate positive relationship with depth ($\rho = 0.29$) and macroalgae ($\rho = 0.22$) and a weak relationship with sponges ($\rho = -0.13$). Although *Ma. mirabilis* is not as abundant overall as the other two genera analyzed, it may prove critical to the sanctuary's fish population as its branching morphology provides substantial shelter for juvenile fish species. This could be particularly important on the banks where typical nursery habitats such as seagrass beds and mangroves are absent. Additionally, there is evidence from blowholes at Bright Bank (east of the FGBNMS) to suggest that *Madracis* may be a principal framework builder for the banks on the outer shelf, probably by virtue of its relative fast growth and ability to recover after fragmentation during storms (Gittings, pers. comm.).

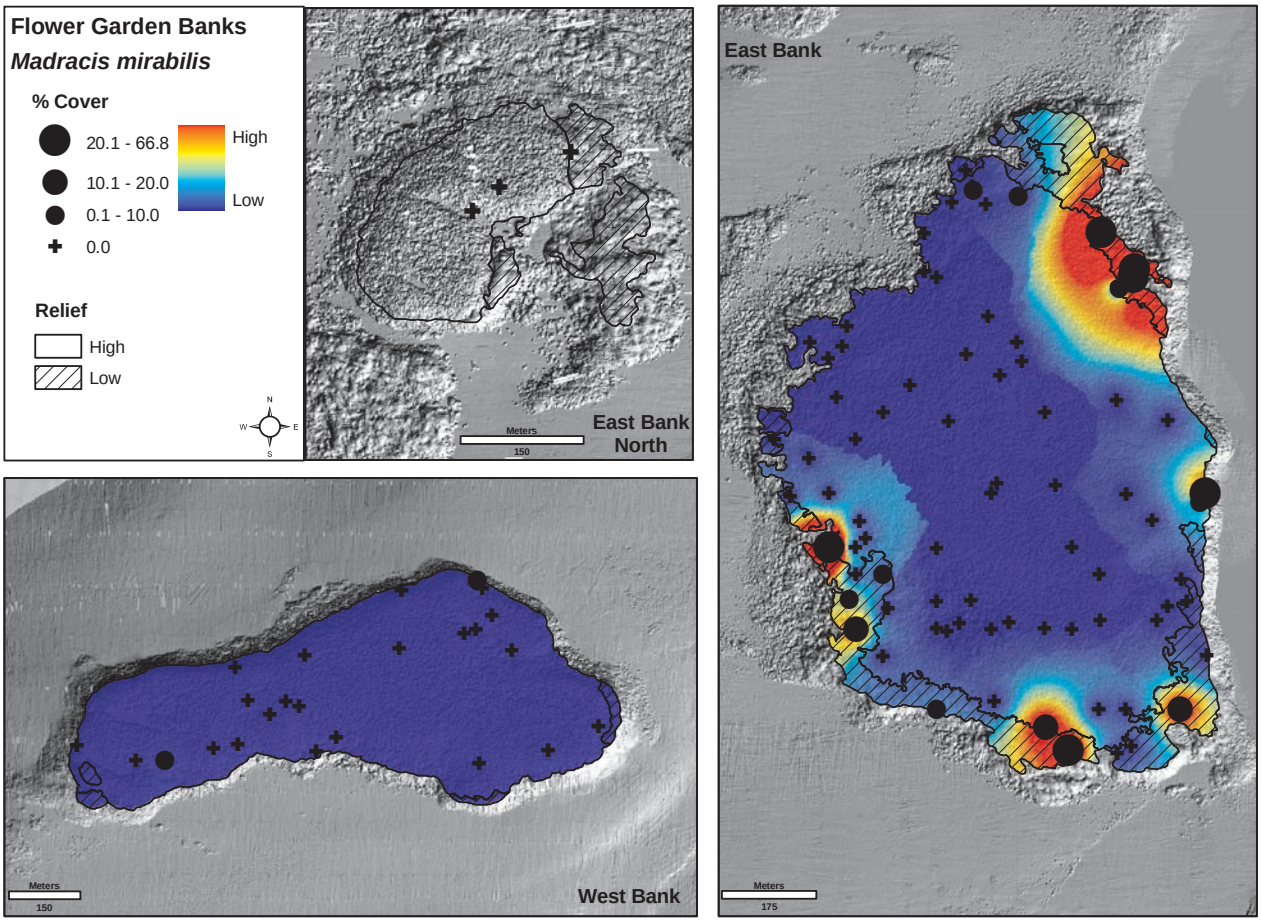


Figure 3.8. Spatial interpolation of Madracis mirabilis *among sample sites within FGBNMS.*

3.3.2.4 *Distribution of Coral Assemblages*

The nodal analysis of species and site groups utilizing the Bray-Curtis proximity coefficient revealed additional information about spatial patterning among corals (Figure 3.9). Group 1 was defined by the dominance of *Ma. mirabilis* and relatively low species richness. Groups 2 and 3 were dominated by *Stephanocoenia intercepta* and *Porites astreoides,* respectively; however other species such as *Mo. cavernosa*, *Mo. franksi* and *D. strigosa* were also present. Both groupings also contained colonies of *Ma. mirabilis*. These first three groupings were observed almost exclusively in the deeper water at the edges of the survey domain and comprised the majority of surveys conducted on the EBL. Group 4 was the largest of the groupings and contained the highest occurrences of the species most dominant on the high relief strata including *Mo. franksi*, *Mo. faveolata* and *D. strigosa*.

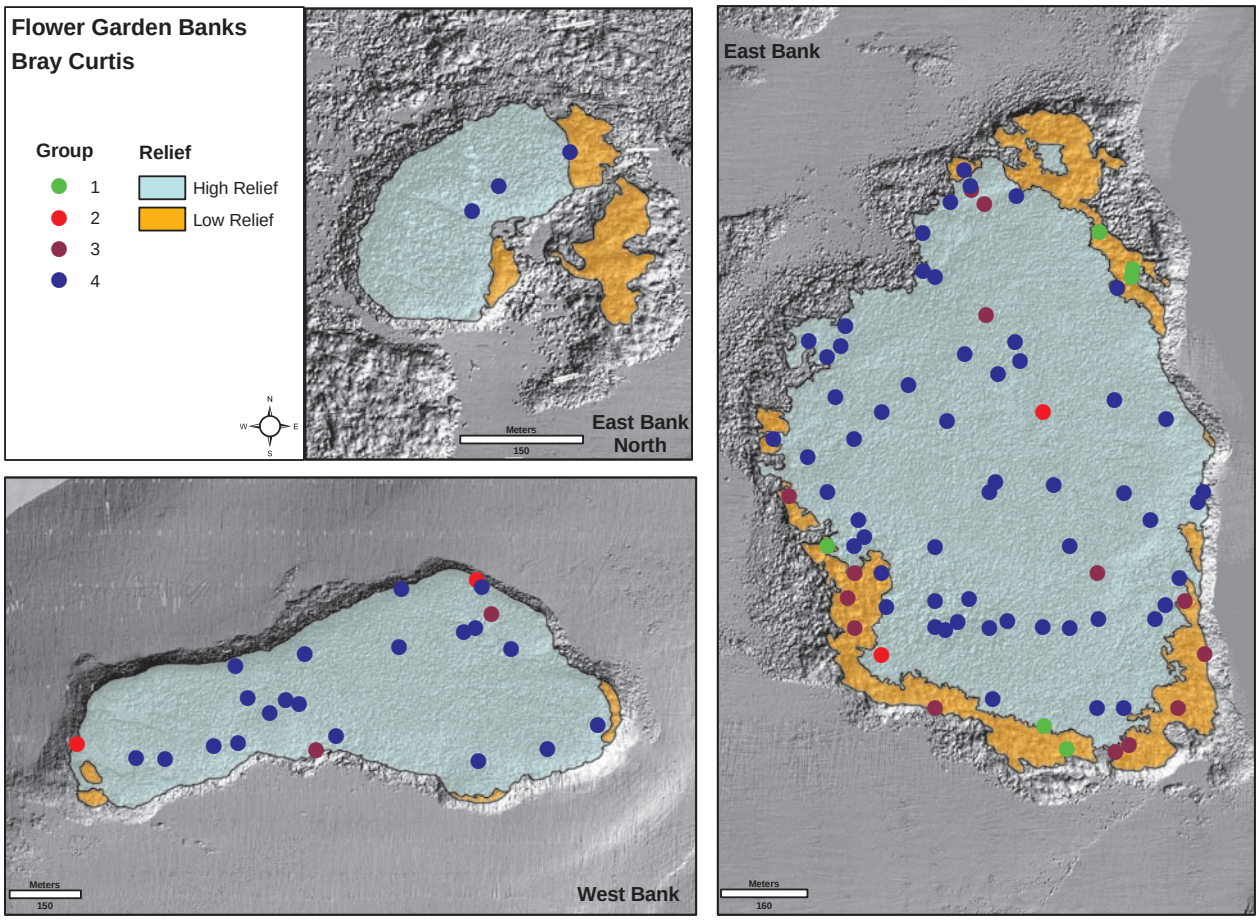
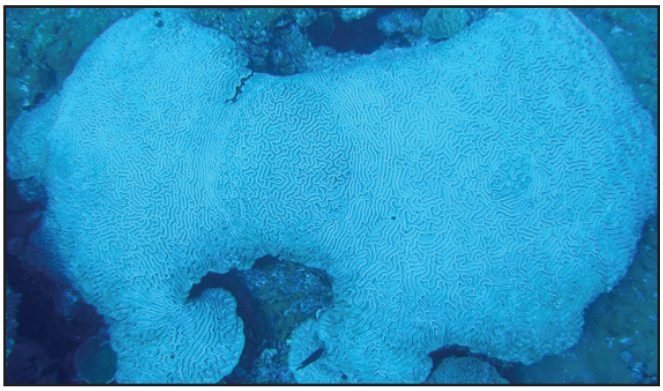


Figure 3.9. Spatial array of the site groups utilizing the Bray-Curtis proximity coefficient and color coded for reference.

3.3.3 Coral Bleaching

Throughout the Caribbean bleaching events have become more prevalent primarily due to increased sea surface temperatures (Wilkinson and Souter, 2008). An increase in temperature of even 1-1.5°C above summer maximums causes severe stress on coral colonies and results in the expulsion of zooxanthellae (Kleypas and Hoegh-Guldberg, 2008). Within the FGBNMS, there has been an increase in recent years of bleaching accounts; however, resident corals have demonstrated excellent recovery capabilities and re-establishment of symbiotic algae after bleaching (Gittings, 1998). According to reports by Hickerson et al (2008) bleaching estimates following two months of elevated temperatures in 2005 reached an estimated maximum of 46% of individual colonies. By March of 2006, bleaching had declined to 4%.



Bleached *Diploria strigosa* colony (CCMA)

In the current study, bleached corals comprised 18% of total coral cover (this includes *Millepora* spp.; 17% without). It must be noted that this estimate is different than proportion of colonies impacted as reported by Hickerson et al. (2008). Species specific bleaching estimates ranged widely from highly impacted species such as, *Millepora alcicornis* (92%), *Siderastrea siderea* (53%) and *Mo. cavernosa* (40%) to species minimally impacted, including *S. intercepta* (8%), *Colpophyllia natans* (7%) and *Ma. decactis* (3%). Several species reported no signs of bleaching. While bleaching showed no relationship with depth (Figure 3.10), the deeper water *Ma. mirabilis* was one of few coral species not impacted by the bleaching event (Table 3.5). Data presented are concordant with observations from Hickerson et al. (2008), who also observed high levels of susceptibility to bleaching in both *Mi. alcicornis* and *Mo. cavernosa*.

Table 3.5. Percent bleaching among coral species at FGBNMS in 2006.

Coral species	% bleach	Coral species	% bleach
Agaricia agaricites	19.8	*Montastraea faveolata*	27.1
Agaricia fragilis	38.9	*Montastraea franksi*	18.7
Colpophyllia natans	6.5	*Mussa angulosa*	0
Diploria strigosa	20.2	*Porites astreoides*	11.1
Madracis decactis	2.6	*Scolymia cubensis*	0
Madracis mirabilis	0	*Scolymia* spp	0
Millepora alcicornis	91.6	*Siderastrea siderea*	53.1
Montastraea annularis	18.2	*Stephanocoenia intercepta*	7.5
Montastraea cavernosa	39.9		

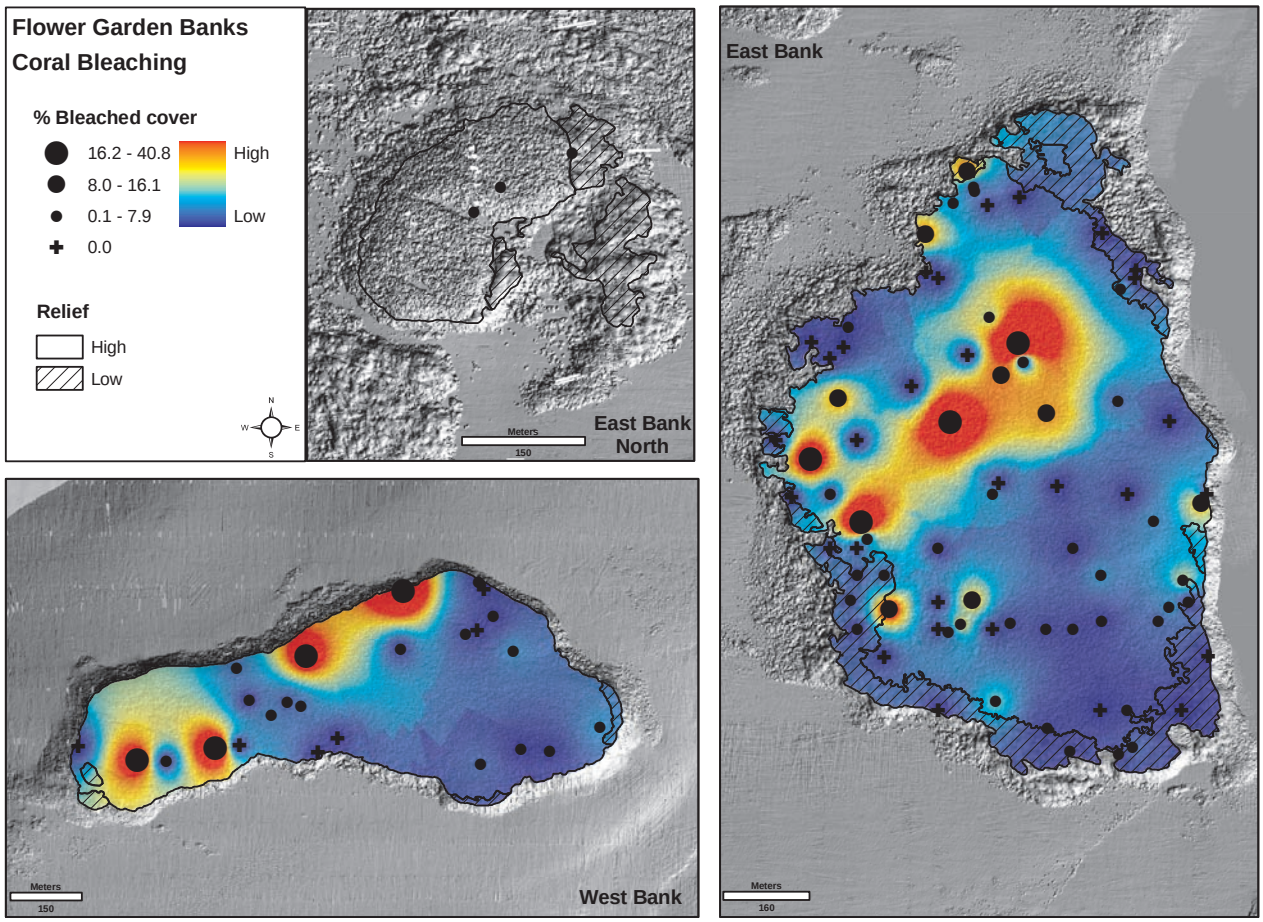
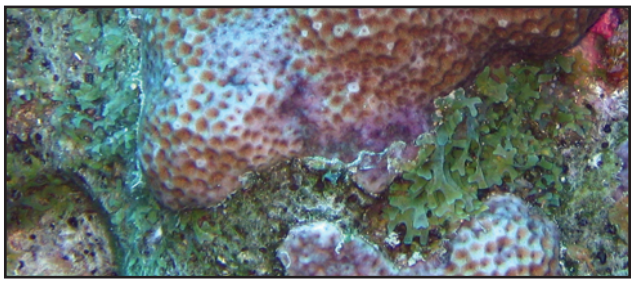


Figure 3.10. Spatial interpolation of bleached coral among sample sites within the FGBNMS.

3.3.4 Algal Cover

Algae covered approximately one quarter (28%) of the coral caps. This estimate is less than similar habitats in most Caribbean systems, which have experienced dramatic changes in benthic composition associated with declining coral populations. Macroalgae was the predominant functional algae group on the banks (13%), followed closely by turf algae (11%) and then crustose coralline algae (CCA; 4%; Table 3.6).



Dictyota spp. around *Siderastrea* spp. (CCMA)

Macroalgal cover, dominated by *Lobophora* and *Dictyota* spp., varied between 0% and 59% across sites. Significant differences were detected among strata (p=0.0332); however, the Nemenyi test was unable to parse out these differences possibly due to unequal sample sizes. In general, macroalgae was most common on EBL followed by EBH and finally WBH (Table 3.6; Figure 3.11). While macroalgae distribution was inversely related to live coral cover (ρ = -0.71) it had a positive relationship with both depth (ρ = 0.23) and sponges (ρ = 0.51). The strong relationship with live coral cover may reflect competition among these two benthic colonizers for space.

Table 3.6. Mean percent cover (± SE) of algal classes by strata and for the sanctuary. CCA=Crustose coralline algae.

Strata	N Rows	Macroalgae (± SE)	CCA (± SE)	Turf algae (± SE)
EBH	39	14 (2.2)	3 (0.6)	9 (1.9)
EBL	10	23 (6.6)	2 (0.7)	10 (3.7)
WBH	24	8 (1.6)	4 (1.0)	17 (3.2)
FGB	73	13 (1.6)	4 (0.5)	11 (1.6)

Turf algae was dominant within the WBH (17%) stratum at nearly double the mean percent cover of either habitat type on EB (Table 3.6); although, only differences between WBH and EBH were significant (p=0.0247). As with macroalgae, turf algal cover was moderately related to sponge cover (ρ = 0.30) and negatively related to coral cover (ρ = -0.21); however, no relationship was detected with depth.

Rezak et al. (1985) found CCA to be the dominant algal cover on the banks as a whole; however, on the coral caps CCA cover was relatively low (<4%) among the benthic habitat community compared to other functional groups. While no significant relations were observed among strata, similar to the other two functional groups, CCA was negatively related to coral cover (ρ = -0.39) and positively related to sponges (ρ = 0.23). No relationship was detected with depth.

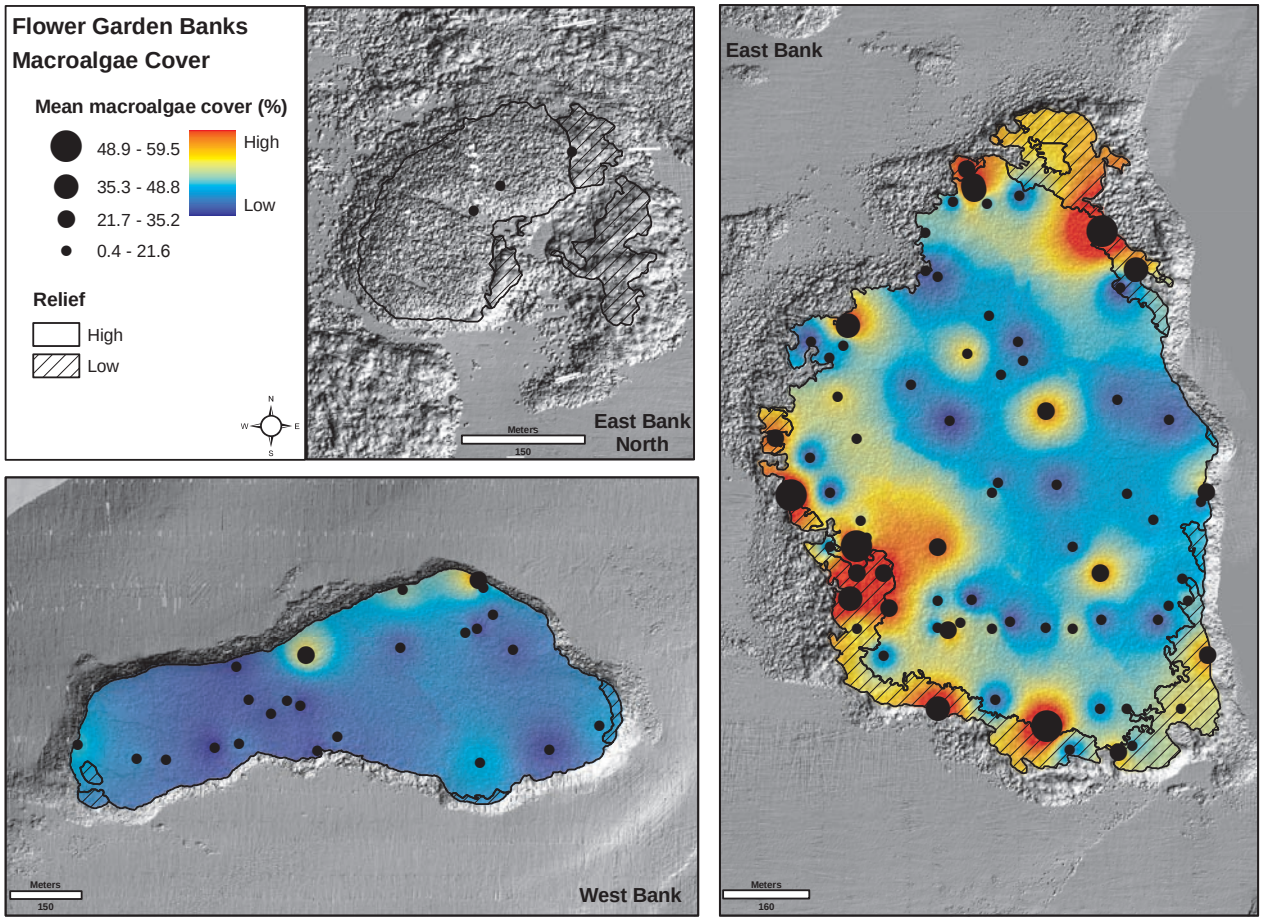
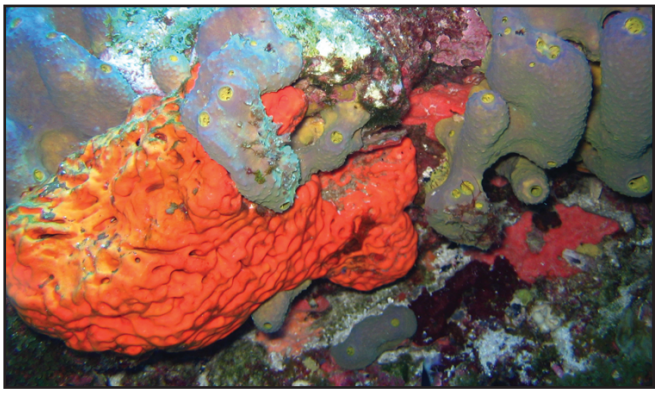


Figure 3.11. Spatial interpolation of macroalgae among sample sites within the FGBNMS.

3.3.5 Sponge Cover

Sponges made up a small proportion of the coral cap's benthic habitat. Mean sponge cover was <1% among all strata (Table 3.7) with only a third of the sites (25 out of 73) having more than 0.5% cover. Those sites with more than 1% cover were generally deeper and many were in low relief habitat, although differences among strata were not observed.



Sponge species *Agela clathrodes* and *Aiolochroia crassa.* (E. Hickerson)

The sponge community of the SCC was classified into two groupings based on morphology: the more commonly encountered group including barrel, tube and vase sponges and a group of encrusting sponges. The multitude of morphologies represented by the two groups provides a number of different habitats for fish species. Neither grouping showed clear spatial patterns by bank or depth although as previously mentioned sponges as a whole showed strong relationships with both corals (ρ = -0.56) and macroalgae (ρ = 0.51).

Table 3.7. Mean percent cover (± SE) of compiled sponges, barrel/tube/vase sponges (Porifera btv) and encrusting sponges (Porifera enc) by strata and for the sanctuary.

Strata	N Rows	Sponges (± SE)	Porifera btv (± SE)	Porifera enc (± SE)
EBH	39	0.7 (0.2)	0.4 (0.2)	0.3 (0.1)
EBL	10	0.7 (0.2)	0.5 (0.2)	0.2 (0.1)
WBH	24	0.7 (0.2)	0.4 (0.2)	0.3 (0.1)
FGB	73	0.7 (0.1)	0.4 (0.1)	0.3 (0.1)

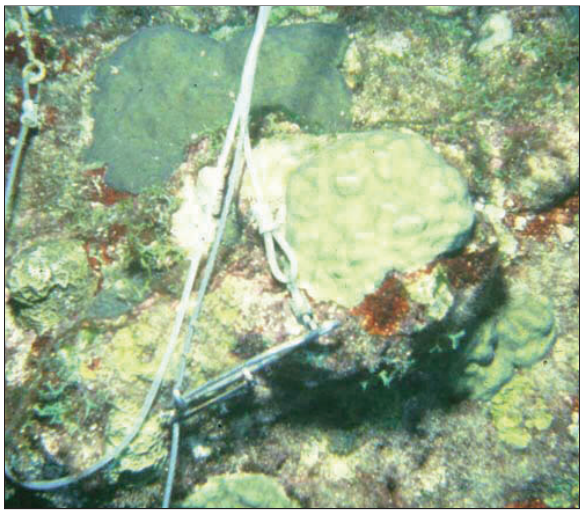
The sponge community of the banks is not prevalent above the 33.5 m (110 ft) isobath of the SCC, but it thrives in waters beyond the limits of conventional scuba diving. According to Rezak et al. (1985) the sponges, particularly *Neofibularia nolitangere*, are most dominant between depths of 46-82 m on the EB and 46-88 m on the WB.

3.3.6 Macroinvertebrates

Macroinvertebrates were included in the surveys to capture other key invertebrate organisms within the SCC. During the course of the 2006 and 2007 surveys only one Caribbean spiny lobster (*P. argus*) and one long-spined urchin (*D. antillarum*) were observed. *P. argus* have been reported as rare previously (Pequegnat and Ray, 1974) and a total of only four were recorded at the banks between 1998 and 2005 during the FGBNMS long-term monitoring (FGBNMS LTM) study (Dokken et al., 2003; Precht et al., 2006; Precht et al., 2008a). The density of *D. antillarum*, however, was historically reported as high as 2 individuals/m^2 (Burke, 1974). This was prior to the massive die-off that occurred region wide in the early 1980s. The most recent estimates provided from the FGNMS LTM study show *D. antillarum* densities between 0.005-0.11 individuals/m^2 (Precht et al. 2008a). Limited information is available on queen conch (*S. gigas*) on the banks; however initial population estimates are being researched (http://flowergarden.noaa.gov/science/conch_burnside.html).

3.3.7 Marine Debris

Marine debris at FGBNMS consists primarily of materials from scientific experiments destroyed in storms; oil exploration (seismic cables); vessels (lines, cables and anchors); and fishing gear (longlines and hook-and-line gear; Gittings, pers. comm.). During 2006, marine debris was reported at 10 sites (7.3% of all sites); four sites on the EB and six sites on the WB (Figure 3.12). Consistent with Gittings' observations, reported debris included anchors, fishing line and rope (Table 3.8). The anchors and associated anchor line observed were colonized by sizeable coral heads suggesting a lengthy period of time since their appearance on the reef. During 2007, marine debris was reported at only one site before the mission was terminated early. There may be a correlation between reports of marine debris and distance from the mooring buoys but that is speculative and more data are needed to target this research question.



Marine debris (Burek)

Marine debris is a potential threat to sessile benthic fauna as well as more mobile resident and transient fauna (i.e., sea turtles, sharks and reef fishes) within the sanctuary, either directly through entanglement (e.g., fishing line) or indirectly though habitat degradation (e.g., anchor damage). Our data indicate marine debris is present but is encountered relatively infrequently. Continued marine debris monitoring is needed to identify areas more prone to accumulation and confirm the apparent low frequency of debris introduction.

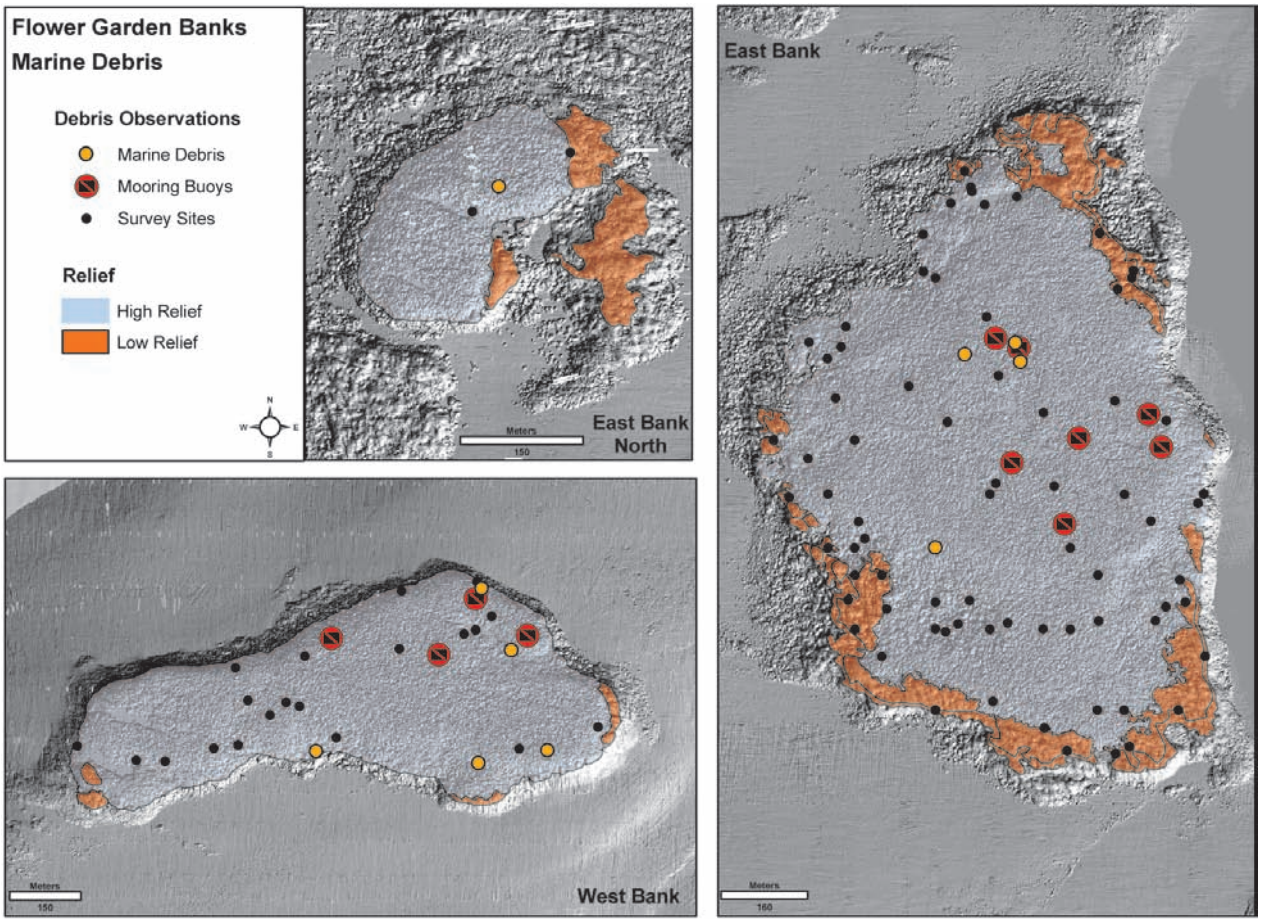


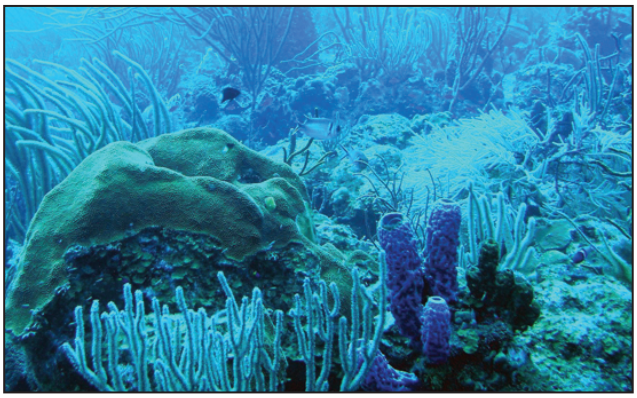
Figure 3.12. Locations of marine debris reports during 2006-2007 surveys in the FGBNMS. The locations of mooring buoys are noted for reference.

Table 3.8. Marine debris documented in the FGBNMS during 2006 and 2007 sampling.

Site #	Debris Type	Debris area (cm^2)	Colonized By	Area affected (cm^2)
2006				
EBF79	1" line - grown over	366	hard corals, calcareous algae, macroalgae	366
WBF8	anchor	75	macroalgae	75
WBF8	anchor line	50	algae and corals	50
WBF19	anchor	700	*Millepora alcicornis*	700
EBF43	anchor (old)	18	coral encrusted	18
EBF75	anchor rope	1000	reef/macroalgae	1000
WBS4	fishing line	10	*Millepora* spp.	10
EBF62	fishing line	150	crustose coralline algae	150
WBF30	fishing lure w/ monofilament	40	none	40
WBF7	plastic coated cable	40	turf algae	50
WBF16	rope	400	turf algae	1000
2007				
E981	fishing line	100	encrusting sponge	100

3.4 CARIBBEAN COMPARISON

Impacts such as chronic over-fishing, pollution, climate change and disease have deteriorated reefs globally. Resulting losses observed in coral cover and large predators have serious ramifications to supporting ecological function and diversity in reef ecosystems (Gardner et al., 2003; Sandin et al., 2008). As a mechanism for estimating the measure of these impacts, scientists have provided examples of comparatively pristine reefs in the Pacific Ocean (Friedlander and DeMartini, 2002). Few examples exist (e.g., Bonaire) or have yet to be described in the tropical western Atlantic Ocean. While we recognize the physical and geomorphological differences between the FGBNMS coral reefs and those in the Caribbean, the similarities in marine fauna, provide us an excellent opportunity to make similar comparisons between impacted and relatively non-impacted systems.



Caribbean shallow-water habitat type in St. John, USVI. (CCMA).

Benthic habitat data collected in 2006 was compared to other sites in the Caribbean (La Parguera, Puerto Rico; St. Croix and St. John, USVI; Figure 3.13) that have been monitored by CCMA using the same methods. To obtain sufficient sample size for analysis 2003-2006 data from the Caribbean locations was pooled. This assumes that there were no major changes in cover between the years and may be an invalid assumption given the 2005 coral bleaching event.

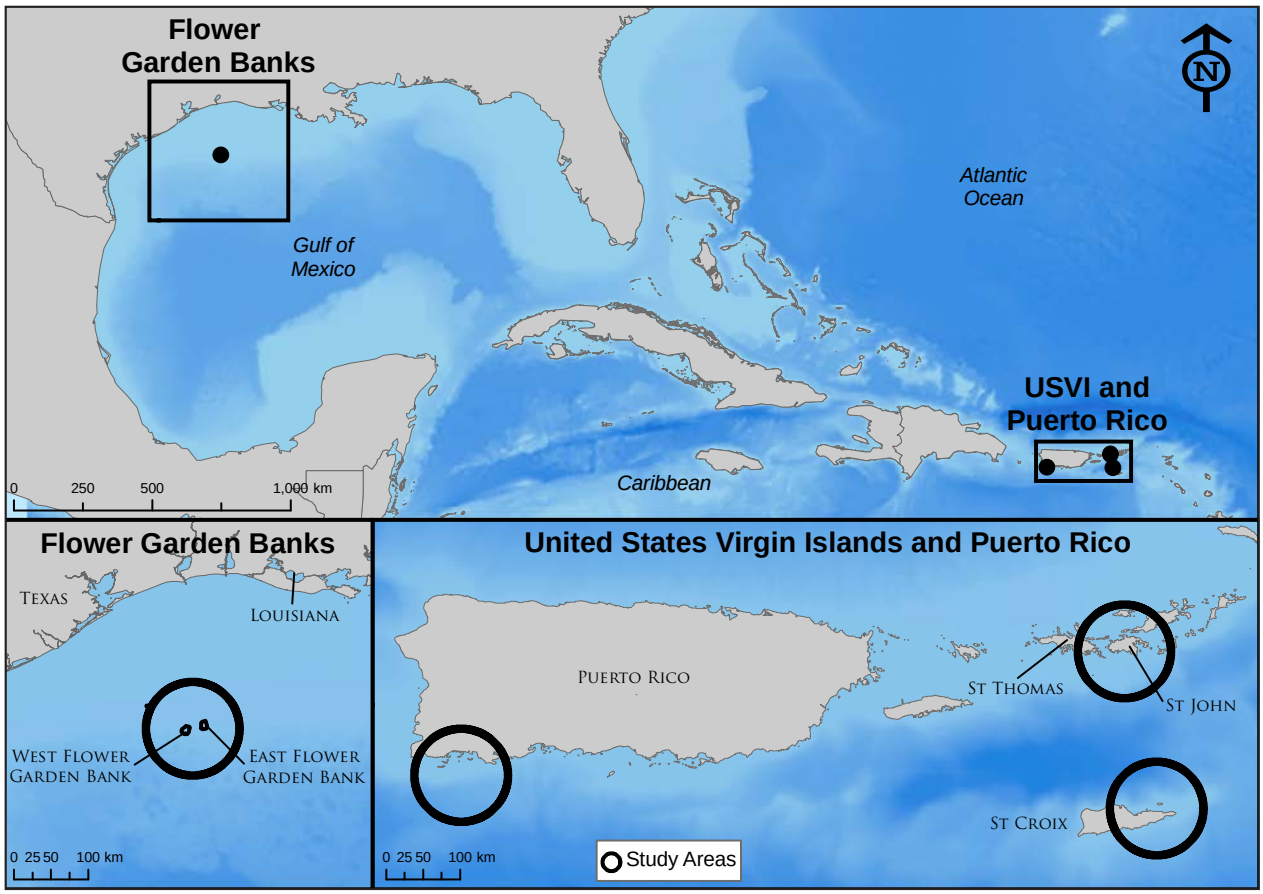


Figure 3.13. Locations of areas sampled in the US Caribbean.

3.4.1 Methods

3.4.1.1 *Study Areas*

The FGBNMS study area has been previously described in Chapter 2.

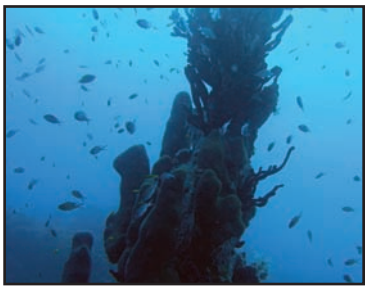
Puerto Rico

The La Parguera study area is located along the southwest corner of the island within the La Parguera National Wildlife Reserve. The broad shelf area contains a variety of habitat types including coral reefs, seagrass and sand patches, as well as an extensive system of mangroves along the shoreline and on offshore islands (Kendall et al., 2001).

Mangroves in Puerto Rico. (CCMA)

St. John, USVI

The St. John study area encompasses the Virgin Islands Coral Reef National Monument (VICRNM) and Virgin Islands National Park (VINP) managed by the U.S. National Park Service (NPS), as well as territorial waters. It includes the same habitat types as are found in Puerto Rico. The VICRNM was designated a "no-take" area (with limited exceptions for certain species of jacks and baitfish) in 2001; however, these regulations were not enforced until recently (see Monaco et al., 2007 for baseline assessment). The VINP permits resource harvest by artisanal fishers as allowed in its enabling legislation as well as hook and line fishing.



Fish assemblage in St. John, USVI. (CCMA)

St. Croix, USVI

In St. Croix, the study area is located on the northeastern shelf of the island and encompasses portions of the Buck Island Reef National Monument (BIRNM) also managed by the NPS and the East End Marine Park (EEMP) managed by the USVI territory. This area includes a lagoon environment as well as a shallow shelf community with coral reefs, seagrass and sand (Kendall et al., 2001). Mangroves are very limited within close proximity to the study area. Portions of BIRNM have been designated "no-take" since the 1960s, however the majority of the current boundaries including all the deeper waters were only recently designated no-take areas in 2001. These regulations, like VICRNM, were not enforced until recently.

Reef in St. Croix, USVI. (CCMA)

3.4.1.2 *Survey Data*

Section 3.2.1 describes sampling methods and Appendix B further details specifics of data collection. See Chapter 2 for information on site selection. While identical methods were utilized in the U.S. Caribbean, an additional quadrat was surveyed per station. Additionally, *Mo. annularis*, *Mo. faveolata*, and *Mo. franksi* were identified as *Mo. annularis* complex. For the purposes of comparison, data from FGBNMS were combined into this same grouping. Only data collected from hardbottom habitat types were used. Additionally, Caribbean surveys were further subset to include only those below 18 m (60) ft to match conditions at FGBNMS. As such, total sites for comparison from each location were: FGBNMS (n=73), La Parguera (n=61), St. Croix (n=66) and St. John (n=38). It must be noted that dives conducted in La Parguera and St. Croix typically do not exceed 27 m (90 ft) and so differences in depth profiles may contribute to observed differences at these locations. Other factors differing between study locations that may impact observed differences between communities include: oceanography, local geology, and availability and configuration of habitat types.

3.4.1.3 *Data Analysis*

Abiotic and biotic percent cover data were compared among the four study regions. Non-parametric Kruskall-Wallis tests were used to examine potential differences between locations and, where differences were statistically significant, Nemenyi tests (Zar, 1999) were used to compare pairwise differences.

3.4.2 Results and Discussion

3.4.2.1 *Abiotic Cover*

Abiotic substrate at all sites consisted of mixed proportions of hardbottom, rubble and sand, with considerable variability between locations (Figure 3.14). Hard-bottom at FGBNMS comprised nearly 88% of the total abiotic substrate and was significantly greater ($p<0.0001$) than St. Croix (78%), Puerto Rico (50%) and St. John (40%). Rubble was the smallest abiotic component at most locations but was a significant component at St. John (21%) where it was significantly greater ($p<0.0001$) than all other locations. Rubble was proportionally similar at St. Croix, Puerto Rico and FGBNMS ranging from 8-10%. Approximately 40% of substrate at sites in Puerto Rico and St. John was sand, which were significantly greater ($p<0.0001$) than St. Croix (13%) and FGBNMS (3%).

3.4.2.2 *Biotic Cover*

Five classes of biotic cover (coral, macroalgal, turf algal, CCA and sponge) were compared among locations. Like the abiotic cover, considerable variability was observed among the classes between locations (Figure 3.15). The most notable difference was observed in coral cover. As previously mentioned, FGBNMS coral cover accounted for 48% of the benthos and was 8-23 times greater than that observed at Caribbean locations ($p<0.0001$). Puerto Rico exhibited the second highest coral cover (7%) followed by St. John (5%) and St. Croix (2%).

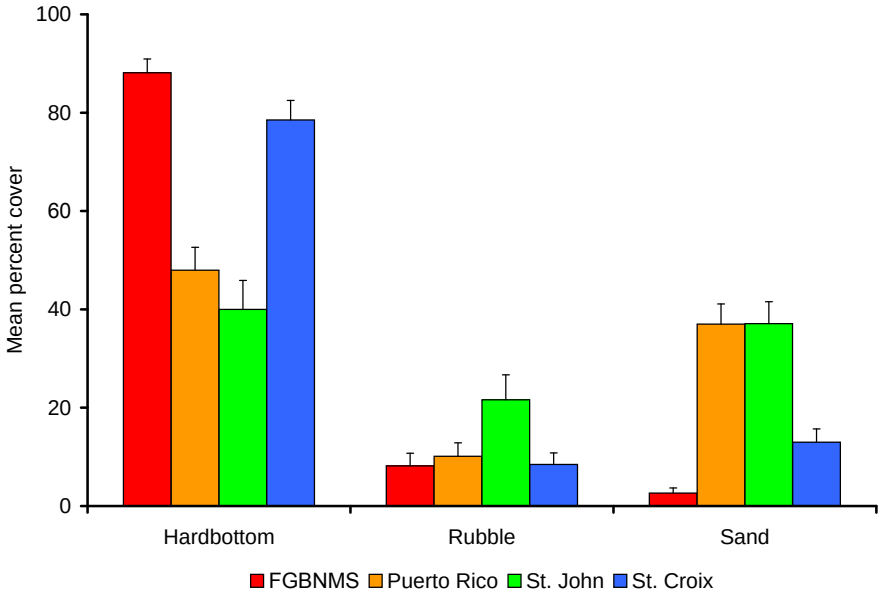


Figure 3.14. Estimated mean percent cover (± SE) of abiotic habitat groups among Caribbean (2003-2006; >18 m in depth) and FGBNMS (2006) sampling locations.

Across all regions, *Mo. annularis* complex, *Mo. cavernosa* and *P. astreoides* were the dominant coral types (Table 3.9). The brain corals, *D. strigosa* and *C. natans*, which were also comparatively dominant at the FGBNMS were less prevalent within the U.S. Caribbean locations and *Ma. mirabilis* which was found to be the dominant coral in the EBL strata was not observed.

Macroalgal cover in the SCC (13%) was comparable to that observed at St. Croix (14%) and Puerto Rico (15%). Macroalgal cover at St. John (25%) was significantly greater ($p=0.0025$) than all three locations.

Turf algal cover ranged from 12% in FGBNMS to 45% in St. Croix. In both Puerto Rico and St. Croix turf algal cover was greater than macroalgal cover. Turf algae was significantly greater at St. Croix ($p<0.0001$) with values 2-3 times greater than the other locations and values in Puerto Rico were significantly greater than St. John and FGBNMS.

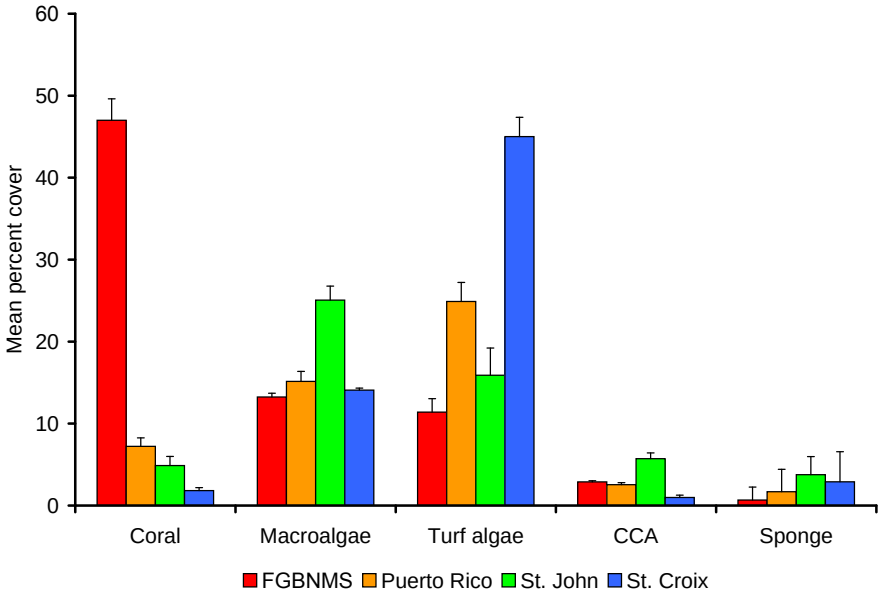


Figure 3.15. Estimated mean percent cover (± SE) of species groups at CCMA Caribbean (2003-2006; >18 m in depth) and FGBNMS (2006) sampling locations.

CCA was less than 10% at all locations. Cover at FGBNMS and St. John was significantly greater ($p<0.0001$) than in St. Croix and Puerto Rico.

Sponge cover was also a small component of the benthos at all sites ranging from 3.7% at St. John to 0.7% at FGBNMS. Sponge cover was comparable at St. John and St. Croix, but was significantly greater than Puerto Rico and FGBNMS ($p<0.0001$). Prior benthic investigations at FGBNMS have noted limited sponge abundance within the sanctuary.

Table 3.9. Mean percent coral cover (± SE) for individual species among Caribbean(2003-2006; >18 m in depth) and FGBNMS (2006) locations. FGBNMS values are corrected for sample area for comparison.

Coral species	FGBNMS (± SE)	Puerto Rico (± SE)	St. John (± SE)	St. Croix (± SE)
Montastraea annularis complex	36.34 (2.80)	3.84 (0.76)	2.72 (0.81)	0.39 (0.13)
Diploria strigosa	4.74 (0.84)	0.16 (0.06)	0.03 (0.02)	0.14 (0.03)
Montastraea cavernosa	3.59 (0.73)	0.73 (0.13)	0.48 (0.13)	0.22 (0.08)
Porites astreoides	2.89 (0.38)	0.65 (0.13)	0.35 (0.12)	0.19 (0.03)
Colpophyllia natans	2.68 (0.68)	0.10 (0.04)	0.23 (0.11)	0.02 (0.02)
Madracis mirabilis	2.06 (0.87)			
Millepora alcicornis	0.88 (0.29)			
Stephanocoenia intercepta	0.71 (0.20)	0.06 (0.02)	0.03 (0.01)	0.03 (0.01)
Madracis decactis	0.30 (0.09)	<0.01 (<0.01)	0.04 (0.03)	0.01 (0.01)
Siderastrea siderea	0.20 (0.12)	0.19 (0.06)	0.49 (0.18)	0.13 (0.04)
Millepora spp	0.16 (0.08)			
Mussa angulosa	0.12 (0.03)			<0.01 (<0.01)
Agaricia agaricites	0.12 (0.02)	0.03 (0.03)	0.15 (0.05)	0.04 (0.02)
Diploria spp	0.10 (0.09)			0.03 (0.01)
Acropora cervicornis	0.05 (0.05)	0.05 (0.05)		
Agaricia spp	0.04 (0.01)	0.64 (0.13)	0.23 (0.11)	0.10 (0.04)
Madracis spp	0.04 (0.04)	0.02 (0.01)		0.01 (0.01)
Agaricia fragilis	0.03 (0.01)			
Scolymia cubensis	0.01 (<0.01)			
Agaricia grahamae	<0.01 (<0.01)		0.01 (0.01)	0.01 (0.01)
Agaricia lamarcki	<0.01 (<0.01)		<0.01 (<0.01)	
Porites porites	<0.01 (<0.01)	0.20 (0.09)	0.20 (0.09)	0.06 (0.02)
Porites spp	<0.01 (<0.01)			0.02 (0.01)
Scolymia spp	<0.01 (<0.01)	0.01 (0.01)	<0.01 (<0.01)	0.01 (<0.01)
Dichocoenia stokesii		0.03 (0.01)	0.01 (<0.01)	0.02 (0.01)
Diploria clivosa		0.08 (0.04)	0.01 (0.01)	0.03 (0.02)
Diploria labyrinthiformis		0.06 (0.02)	0.02 (0.02)	0.02 (0.01)
Eusmilia fastigiata		<0.01 (<0.01)	0.01 (0.01)	<0.01 (<0.01)
Favia fragum		0.01 (0.01)		<0.01 (<0.01)
Helioceris cucullata		0.02 (0.02)	0.01 (0.01)	
Isophyllastrea rigida				<0.01 (<0.01)
Isophyllia sinuosa		<0.01 (<0.01)		0.01 (<0.01)
Manicina areolata		0.01 (0.01)	0.01 (0.01)	0.02 (0.01)
Meandrina meandrites		0.13 (0.03)	0.07 (0.03)	0.11 (0.02)
Mycetophyllia danaana			<0.01 (<0.01)	
Mycetophyllia ferox				0.01 (0.01)
Mycetophyllia lamarckiana		0.01 (0.01)	<0.01 (<0.01)	
Mycetophyllia reesi		<0.01 (<0.01)		0.15 (0.15)
Mycetophyllia spp		<0.01 (<0.01)	0.01 (<0.01)	<0.01 (<0.01)
Oculina diffusa			0.01 (0.01)	
Siderastrea radians		0.09 (0.03)	0.03 (0.02)	0.04 (0.01)
Siderastrea spp		0.07 (0.03)	0.01 (0.01)	0.01 (0.01)
Solenastrea spp		<0.01 (<0.01)		<0.01 (<0.01)
Tubastraea coccinea		0.01 (0.01)		

3.5 SUMMARY AND RECOMMENDATIONS

- Estimates of coral cover were high for the FGBNMS coral caps (48%) when compared with algae (13%) or sponges (1%). This value is comparable to historical values reported for live coral cover at the banks and is between 6 and 11 times higher than values estimated for the U.S. Caribbean locations.
- Coral cover tended to be higher on the high relief habitats and lower on the low relief areas while algae exhibited the opposite trend.
- Of the dominant taxa, *Mo. franksi* and *Mo. faveolata* were more prevalent in high relief habitats; *D. strigosa*, *Mo. cavernosa*, *P. astreoides* and *C. natans* were distributed throughout the banks; and *Ma. mirabilis* dominated low relief habitat.
- While coral coverage was estimated to be high, 18% was estimated to be affected by coral bleaching. The high values reported for coral bleaching suggest that the sanctuary may be more susceptible to environmental impacts than previously known.
- Reports of marine debris from this baseline assessment included anchors, fishing line and rope. While many of the items encountered were overgrown by corals and limited in their ecological impact, continued marine debris monitoring is needed to identify areas more prone to accumulation and confirm the apparent low frequency of debris introduction.
- Further monitoring and characterization of the benthic community will enable linkages to be made with the fish community (e.g., the role of *Ma. mirabilis*), a better understanding of impact and recovery from bleaching events or coral disease, and an evaluation of marine debris impacts.
- A better understanding of the deep water habitats surrounding the banks will provide the sanctuary with a better understanding of ecological linkages between these areas and the SCC.

3.6 REFERENCES

Aronson, R.B., W.F. Precht, T.J.T. Murdoch, and M.L. Robbart. 2005. Long-term persistence of coral assemblages on the Flower Garden Banks, Northwestern Gulf of Mexico: Implications for science and management. Gulf Mex. Sci. 1: 84-94.

Bright, T.J. and L.H. Pequegnat (eds.). 1974. Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division. Houston, TX. 435 pp.

Burke, T.E. 1974. Echinoderms. pp. 312-331. In: T.J. Bright and L.H. Pequegnat (eds.). Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division. Houston, TX. 435 pp.

Cochran, W.G. 1977. Sampling Techniques, 3rd edition. John Wiley and Sons, Inc., New York. 428 pp.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, Jr., T. Wade, K. Withers, S.J. Dilworth, T.W. Bates, C.R. Beaver, and C.M. Rigaud. 2003. Long-Term Monitoring at the East and West Flower Garden Banks, 1998-2001: Final Report. OCS Study MMS 2003-031. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Dept. of the Interior. New Orleans, LA. 90 pp.

Environmental Systems Research Institute, Inc (ESRI). 2006. ArcGIS 9.0. Redlands, CA.

Friedlander, A.M. and E.E. DeMartini. 2002. Contrasts in density, size, and biomass of reef fishes between the northwestern and the main Hawaiian islands: the effects of fishing down apex predators. Mar. Ecol. Progr. Ser. 230: 253-264.

Gardner, T.A., I.M. Cote, J.A. Gill, A. Grant, and A.R. Watkinson. 2003. Long-term region-wide declines in Caribbean corals. Science 301: 958-960.

Gittings, S.R. NOAA Office of National Marine Sanctuaries (ONMS). Silver Spring, MD. Personal Communication.

Gittings, S.R. NOAA Office of National Marine Sanctuaries (ONMS). Silver Spring, MD. Personal Observation.

Gittings, S.R. 1998. Reef Community Stability on the Flower Garden Banks, Northwest Gulf of Mexico. Gulf Mex. Sci. 16(2): 161.

Gittings, S.R. and E. Hickerson. 1998. Flower Garden Banks National Marine Sanctuary-Introduction. Gulf Mex. Sci. (Dedicated Issue) 16(2): 128-130.

Hickerson, E.L, G.P. Schmahl, M. Robbart, W.P. Precht, and C. Caldow. 2008. The State of Coral Reef Ecosystems of Flower Garden Banks. pp. 180-210. In: J.E. Waddell and A.M. Clarke (eds.), The State of Coral Reef Ecosystems of the United States and Pacific Freely Associated States: 2008. NOAA Technical Memorandum NOS NCCOS 73. Silver Spring, MD. 569 pp.

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. Silver Spring, MD. http://ccma.nos.noaa.gov/ecosystems/coralreef/usvi_pr_mapping.html.

Kleypas, J. and O. Hoegh-Guldberg. 2008. Coral Reefs and Climate Change: Susceptibility and Consequences. pp. 19-29. In: C. Wilkinson and D. Souter (eds.). Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre. Townsville, Australia. 152 pp.

Kovach Computing Services. 1999. Multivariate Statistical Package (MVSP©). Version 3.1. Whales, UK. http://www.kovcomp.co.uk/mvsp/

Menza, C., J. Ault, J. Beets, J. Bohnsack, C. Caldow, J. Christensen, A. Friedlander, C. Jeffrey, M. Kendall, J. Luo, M. Monaco, S. Smith, and K. Woody. 2006. A Guide to Monitoring Reef Fish in the National Park Service's South Florida / Caribbean Network. NOAA Technical Memorandum NOS NCCOS 39. Silver Spring, MD. 166 pp.

Monaco, M.E., A.M. Friedlander, C. Caldow, and J.D. Christensen. 2007. Characterizing reef fish populations and habitats within and outside the US Virgin Islands Coral Reef National Monument: a lesson in marine protected area design. Fish Manag. Ecol. 14: 33-40.

Pequegnat, L.H. and J.P. Ray. 1974. Crustacea and other arthropods. pp. 232-288. In: T.J. Bright and L.H. Pequegnat (eds.). Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division. Houston, TX. 435 pp.

Pittman, S.J., J.D. Christensen, C. Caldow, C. Menza, and M.E. Monaco. 2007. Predictive mapping of fish species richness across shallow-water seascapes in the Caribbean. Ecol. Model. 204: 9-21.

Precht, W.F., R.B. Aronson, K.J.P Deslarzes, M.L. Robbart, T.J.T Murdoch, A. Gelber, D.J. Evans, B. Gearheart, and B. Zimmer. 2006. Long-term monitoring at the East and West Flower Garden Banks, National Marine Sanctuary, 2002-2003: Final Report. OCS Study MMS 2006-035. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Dept. of the Interior. New Orleans, LA. 193 pp. http://www.gomr.mms.gov/homepg/regulate/environ/techsumm/rec_pubs.html.

Precht, W.F., R.B. Aronson, K.J.P Deslarzes, M.L. Robbart, D.J. Evans, B. Zimmer and L. Duncan. 2008a. Long-term monitoring at the East and West Flower Garden Banks, 2004-2005 – Interim Report Volume 1: Technical Report. OCS Study MMS 2008-27. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Dept. of the Interior. New Orleans, LA. 123 pp.

Precht, W.F., R.B. Aronson, K.J.P Deslarzes, M.L. Robbart, B. Zimmer and L. Duncan. 2008b. Post-hurricane assessment at the East Flower Garden Bank Long-Term Monitoring Site: November 2005. OCS Study MMS 2008-19. Minerals Management Service, Gulf of Mexico OCS Region, U.S. Dept. of the Interior. New Orleans, LA. 39 pp.

Rezak, R., T.J. Bright, and D.W. McGrail. 1985. Reefs and Banks of the Northwestern Gulf of Mexico: Their Geological, Biological and Physical Dynamics. John Wiley and Sons, NY. 259 pp.

Sandin, S.A., J.E. Smith, E.E. DeMartini, E.A. Dinsdale, S.D. Donner, A.M. Friedlander, T. Konotchick, M. Malay, J.E. Maragos, D. Obura, O. Pantos, G. Paulay, M. Richie, F. Rohwer, R.E. Schroeder, S. Walsh, J.B.C. Jackson, N. Knowlton, and E. Sala. 2008. Baselines and degradation of coral reefs in the northern line islands. PLoS ONE 3(2):e1548.doi:10.1371/journal.pone.0001548.

SAS Institute. 2000. JMP© Statistics and Graphics Guide, Version 4.00. SAS Institute, Inc. Cary, NC, USA.

SAS Institute. 2006. SAS/STAT© Software. SAS Institute, Inc. Cary, NC, USA.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research. W.H. Freeman and Company. USA. 887 pp.

Viada, S.T. 1980. Species composition and population levels of scleractinean corals within the *Diploria-Montastraea*-Porites zone of the East Flower Garden Bank., northwest Gulf of Mexico. M.S. Thesis Dept. of Oceanography, Texas A&M University, College Station, TX. 96 pp.

Wilkinson, C. and D. Souter. 2008. Status of Caribbean coral reefs after bleaching and hurricanes in 2005. Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre. Townsville, Australia. 152 pp.

Zar, J.H. 1999. Biostatistical Analysis., 4th edition. Prentice Hall. Englewood Cliffs, NJ. 929 pp.