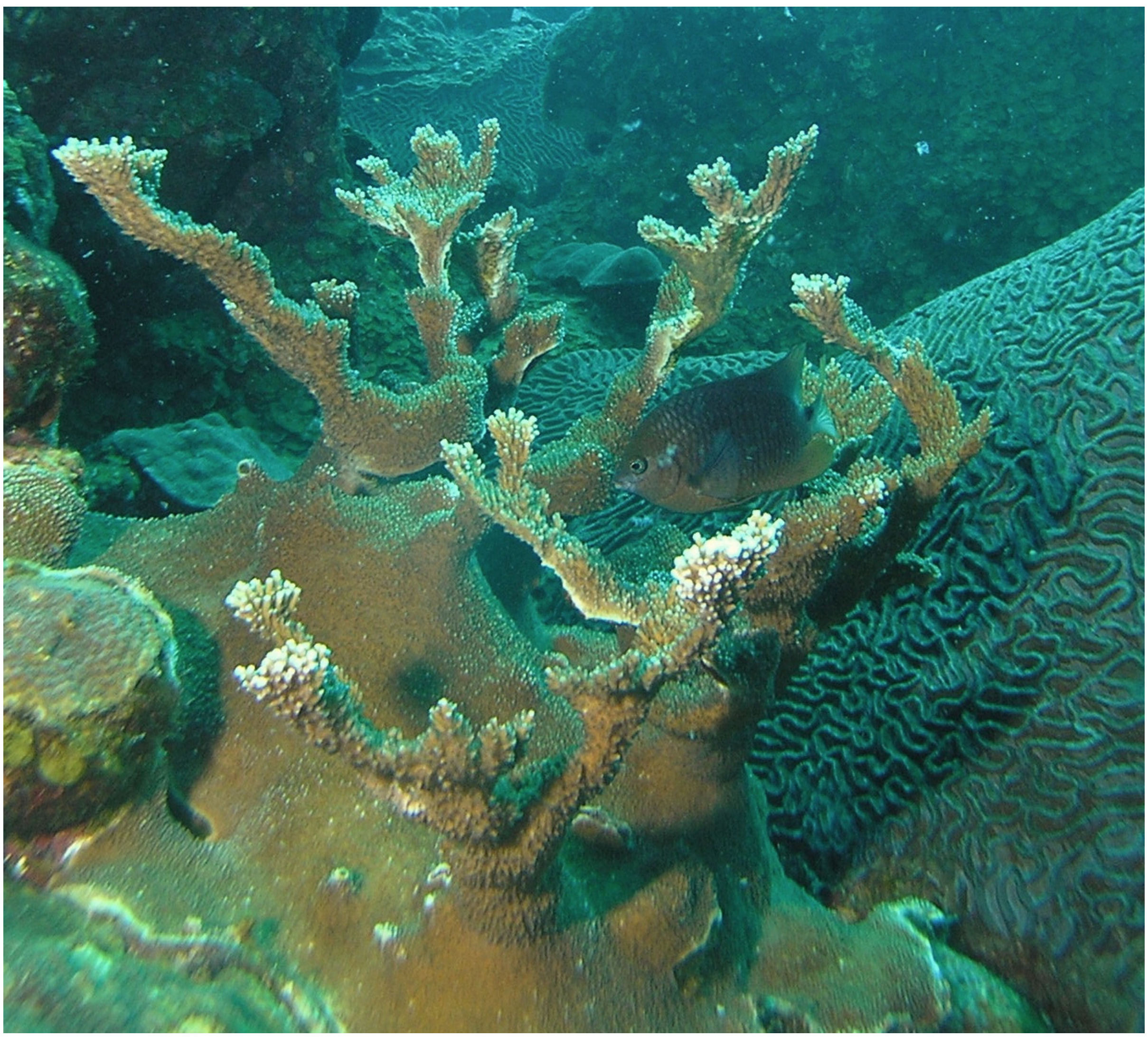
OCS Study
MMS 2008-027

Long-Term Monitoring at the East and West Flower Garden Banks, 2004-2005 – Interim Report

Volume I: Technical Report



MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

OCS Study
MMS 2008-027

Long-Term Monitoring at the East and West Flower Garden Banks, 2004-2005 – Interim Report

Volume I: Technical Report

Authors

William F. Precht
Richard B. Aronson
Kenneth J. P. Deslarzes
Martha L. Robbart
David J. Evans
Beth Zimmer
Leslie Duncan

Prepared under MMS Contract
1435-01-04-CT-33137 (M04PC00033)
by
PBS&J
2001 NW 107th Avenue
Miami, Florida 33172, USA

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

New Orleans
June 2008

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS), the National Oceanic and Atmospheric Administration (NOAA), and PBS&J Ecological Services, Miami, Florida, USA. This report has been technically reviewed by MMS and NOAA and has been approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of MMS and NOAA, nor does the mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with MMS editorial standards.

REPORT AVAILABILITY

Extra copies of this report may be obtained from the Public Information Office (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Public Information Office (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

Telephone: (504) 736-2519 or
1-800-200-GULF

CITATION

Suggested citation:

Precht, W.F., R.B. Aronson, K.J.P. Deslarzes, M.L. Robbart, D.J. Evans, B. Zimmer, and L. Duncan. 2008. Long-term monitoring at the East and West Flower Garden Banks, 2004-2005 - Interim report. Volume I: Technical report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. OCS Study MMS 2008-027. 123 pp.

ABOUT THE COVER

The cover art depicts a colony of *Acropora palmata* at the East Flower Garden Bank and was photographed by Emma Hickerson in 2005, Research Coordinator for the Flower Garden Banks National Marine Sanctuary.

TABLE OF CONTENTS

Page

LIST OF FIGURES ... ix
LIST OF TABLES ... xi
ACKNOWLEDGMENTS ... xiii
EXECUTIVE SUMMARY ... xv

1.0 INTRODUCTION ... 1

1.1 CORAL REEF MONITORING AT THE FLOWER GARDEN BANKS ... 1
1.2 THE FLOWER GARDEN BANKS IN THE GULF OF MEXICO ... 3
1.2.1 Habitat Description ... 3
1.2.2 The East and West Banks ... 3
1.3 MMS AND FGBNMS PROTECTIVE MEASURES ... 7

2.0 METHODS ... 9

2.1 STUDY SITES ... 9
2.2 RANDOM TRANSECTS ... 10
2.2.1 Methodological Rationale ... 10
2.2.2 Positioning of the Transects ... 15
2.2.3 Videography ... 15
2.2.4 Statistical Analysis of the Transect Data ... 16
2.3 SCLEROCHRONOLOGY ... 17
2.3.1 Methodological Rationale ... 17
2.3.2 Field Methods ... 17
2.3.3 Laboratory Methods ... 18
2.3.4 Data Presentation and Statistical Analysis ... 18
2.4 LATERAL GROWTH ... 18
2.4.1 Methodological Rationale ... 18
2.4.2 Field Methods ... 19
2.4.3 Image Analysis of Lateral Growth ... 19
2.4.4 Data Presentation and Statistical Analysis of Lateral Growth Stations ... 20
2.5 REPETITIVE QUADRATS ... 20
2.5.1 Methodological Rationale ... 20
2.5.2 Field Methods ... 20
2.5.3 Image Analysis of Repetitive Quadrats ... 20
2.5.4 Data Presentation and Statistical Analysis of Repetitive Quadrats ... 21
2.6 PERIMETER VIDEOGRAPHY ... 21
2.6.1 Methodological Rationale ... 21
2.6.2 Field Methods ... 21
2.6.3 Laboratory Methods ... 22

2.7 WATER QUALITY 22
2.7.1 Methodological Rationale 22
2.7.2 YSI Datasondes 22
2.7.3 HoboTemp Thermographs 24
2.7.4 Chlorophyll *a* and Nutrients 25
2.8. FISH SURVEYS 27
2.8.1 Methodological Rationale 27
2.8.2 Field Methods 27
2.8.3 Analysis and Statistical Methods 28
2.9 SEA URCHIN AND LOBSTER SURVEYS 29
2.9.1 Methodological Rationale 29
2.9.2 Field Methods 29
2.9.3 Statistical Methods 29

3.0 RESULTS 31

3.1 RANDOM TRANSECTS 31
3.2 SCLEROCHRONOLOGY 37
3.2.1 East Bank Cores 37
3.2.2 West Bank Cores 38
3.2.3 Analysis 38
3.3 LATERAL GROWTH 39
3.4. REPETITIVE QUADRATS 41
3.4.1 Repetitive Quadrat Analysis 41
3.4.2 Repetitive Quadrats Planimetry Analysis 47
3.4.3 Deep Repetitive Quadrat Analysis 48
3.4.4 Deep Repetitive Quadrat Planimetry Analysis 51
3.5. PERIMETER VIDEOGRAPHY 52
3.5.1 East Bank Perimeter Lines 52
3.5.2 East Bank 360° Panoramic Views 55
3.5.3 West Bank Perimeter Lines 55
3.5.4 West Bank 360° Panoramic Views 56
3.6 WATER QUALITY 57
3.6.1 YSI Water Quality 57
3.6.2 East Bank YSI Reef Cap Data Review 57
3.6.3 West Bank YSI Reef Cap Data Review 60
3.6.4 YSI Water Quality – Reef Cap 61
3.6.5 Water Quality – Vertical Profiles 63
3.6.6 HoboTemp Temperature 65
3.6.7 HoboTemp Data Review 65
3.6.8 Water Samples 67
3.6.9 Chlorophyll *a* 68
3.6.10 Nutrients 68
3.7. FISH SURVEYS 71
3.8 SEA URCHIN AND LOBSTER SURVEYS 81

4.0 DISCUSSION 83

4.1. CORAL 83
4.1.1 General 83
4.1.2 Random Transects 84
4.1.3 Sclerochronology 91
4.1.4 Lateral Growth 92
4.1.5 Repetitive Quadrats 93
4.1.6 Perimeter Videography 94
4.1.7 Disease and Bleaching at the Flower Garden Banks 95
4.1.8 Other Coral Mortality Factors at the Flower Garden Banks 98
4.2 WATER QUALITY PARAMETERS 98
4.2.1 Physical Parameters 98
4.2.2 Biological Parameters 104
4.2.3 Chemical Parameters 104
4.3 FISH SURVEYS 106
4.4 SEA URCHIN AND LOBSTER SURVEYS 111

5.0 LITERATURE CITED 113

LIST OF FIGURES

Page

Figure 1.2.1. Location map of the East and West Flower Garden Banks in relation to the Texas-Louisiana continental shelf and other topograhic features of the northwestern Gulf of Mexico (map created by Deslarzes in 2005)........................ 4

Figure 1.2.2. Topographic contour map of the East Bank (Gardner et al. 1998). 5

Figure 1.2.3. Topographic contour map of the West Bank (Gardner et al. 1998). 6

Figure 2.1.1. Topographic map of the East Bank (USGS 2001). 11

Figure 2.1.2. Topographic map of the West Bank (USGS 2001). 12

Figure 2.1.3. Locations of monitoring stations at the East Bank, 2005. 13

Figure 2.1.4. Locations of monitoring stations at the West Bank, 2005 14

Figure 2.3.2. Scientists use a pneumatic drill at the Flower Garden Banks to extract a core from a colony of *Montastraea faveolata*. 18

Figure 2.4.2. Image for analysis of *Diploria strigosa* lateral growth at the East Bank, showing 2004 (yellow line) and 2005 (orange line) comparison, using Adobe Photoshop. 19

Figure 3.1.1. Relative dominance of coral species at the East Bank in 2004 and 2005, expressed as percent cover. 32

Figure 3.1.2. Relative dominance of coral species at the West Bank in 2004 and 2005, expressed as percent cover. 33

Figure 3.1.3. Percent cover (+ SE) of four functional categories of sessile benthos at the Flower Garden Banks in 2004 and 2005. 34

Figure 3.2.3. X-ray images of *Montastraea faveolata* cores from East (left) and West (right) Banks showing a disconformity (arrow) in accretionary growth sometime in 2002-2003. 39

Figure 3.3.1. Mean proportional change in area of *Diploria strigosa* colonies, comparing the East and West Banks during the intervals 2003-2004 and 2004-2005. 41

Figure 3.4.1. Four functional groups in the East Bank repetitive quadrats in 2004 and 2005. 42

Figure 3.4.2. Four functional groups in the West Bank repetitive quadrats in 2004 and 2005. 43

Figure 3.4.3. Relative dominance of coral taxa at the East Bank in 8 m^2 repetitive quadrats, expressed as percent cover + SE. 44

Figure 3.4.4. Relative dominance of coral species at the West Bank in 8 m^2 repetitive quadrats, expressed as percent cover + SE. 44

Figure 3.4.5. Mean proportional change + SE in *Montastraea annularis* species complex at the East and West Banks between 2003-2004 and 2004-2005. 48

Figure 3.4.6. Percent cover (+ SE) data for four benthic categories in the East Bank deep repetitive quadrats in 2004 and 2005. 49

Figure 3.4.7. Relative dominance (+ SE) of coral species in the East Bank deep repetitive quadrats in 2004 and 2005. 50

Figure 3.4.8. Deep repetitive 8 m^2 quadrat at the East Bank in June 2005. 51

Figure 3.4.9. Mean proportional change + SE in *Montastraea annularis* species complex at East Bank deep stations, 2003-2004 and 2004-2005. 52

Figure 3.6.6. Vertical profile of turbidity at the East Bank study site (8 June 2005). 64

Figure 3.6.7. Vertical profiles of temperature and salinity at the East Bank study site (8 June 2005). 64

Figure 3.6.8. Mean daily temperature measured at the East and West Bank reef caps using HoboTemp thermographs. 67

Figure 3.7.1. Herbivore size-frequency distributions at West (A) and East Banks (B) recorded during 2004 and 2005. 77

Figure 3.7.2. Carnivore size-frequency distributions at West (A) and East Banks (B) recorded during 2004 and 2005. 78

Figure 4.1.2. Mean percent coral cover at the Flower Garden Banks over time, showing the consistently high coral cover. 85

Figure 4.1.3. Percent cover of *Montastraea annularis* complex, algae, and reef rock from 1992-2005: East and West Banks. 90

Figure 4.1.7. (A) Photograph of a *Montastraea faveolata* colony exhibiting white plague-like disease signs at the East Bank in May 2005. (B) Close-up photograph of the disease lesion on this colony. 96

Figure 4.1.8. *Siderastrea siderea* with disease-like signs. Photographs A and B were taken around the perimeter of the 2 m coral head, documenting potential disease lesion. Photographs C and D exhibit overgrowth by *Millepora* sp. 97

Figure 4.2.1. Seawater temperature on the East Bank reef cap in 2004 and 2005, using combined YSI temperature and HoboTemp records. 99

Figure 4.2.2. Seawater temperature on the West Bank reef cap in 2004 and 2005, using combined YSI temperature and HoboTemp records. 100

Figure 4.2.3. Comparison of the 2004 and 2005 seawater temperature records at the East Bank, using combined YSI and HoboTemp records. 101

Figure 4.2.4. Comparison of water temperature at the East Bank in 1990 and 2005. 102

Figure 4.3.1. Fish diversity and evenness found at the East and West Banks from 2002 to 2005, with the percent of the study-site area covered by the surveys. 110

Figure 4.3.2. Species richness and family richness found at the East and West Banks from 2002 to 2005, with number of diver surveys/samples (n) shown. 110

Figure 4.3.3. Fish abundance observed at the East and West Banks from 2002 to 2005. 111

LIST OF TABLES

Page

Table 2.1.1. GPS coordinates for the East Bank and West Bank study-site corner markers......... 9

Table 2.7.2. Schedule of YSI water quality datasonde deployments, change outs, and retrievals at the East and West Banks in 2004 and 2005. 24

Table 2.7.3. Schedule of HoboTemp thermograph deployments, change outs, and retrievals at the East and West Banks in 2004 and 2005. 25

Table 2.7.4. Water sampling schedule, depth, and number of samples taken at the East and West Banks in 2004 and 2005. 26

Table 2.7.5. Standard U.S. Environmental Protection Agency methods used to analyze water samples taken at the Flower Garden Banks in 2004 and 2005. 27

Table 3.1.1. Cover of benthic categories in random video transects at the East and West Banks in 2004 and 2005. 31

Table 3.1.2. Results of two-way ANOVAs on proportional cover estimates and H' from the random video transects. 36

Table 3.2.1. Mean annual growth (mm) of four *Montastraea faveolata* colonies each from the East and West Banks, June 2005. 38

Table 3.3.1. Results of repeated-measures ANOVA on proportional change in areas of *Diploria* colonies, comparing the East and West Banks during the intervals 2003-2004 and 2004-2005. 40

Table 3.4.1. Percent paling, bleaching, concentrated fish biting, isolated fish biting, and disease (± SE), in 8 m^2 repetitive quadrats at the East and West Banks, 2004 and 2005.. 45

Table 3.4.2. Percent cover of isolated fish biting, concentrated fish biting, paling, and bleaching at the East and West Banks, 2004 and 2005. 46

Table 3.4.3. Results of ANOVA on proportional change in planar area of colonies of *Montastraea annularis* species complex in the repetitive quadrats......................... 48

Table 3.5.1. Comparison of observations of the condition of coral colonies at the East Bank along perimeter lines and 360º panoramic views between 2004 (n≈660) and 2005 (n≈730) 53

Table 3.5.2. Fish species composition and individual counts for the East and West Banks in 2004 and 2005 along perimeter lines and 360º panoramic views at corner markers.. 54

Table 3.5.3. Comparison of observations of the condition of coral colonies at the West Bank along perimeter lines and 360º panoramic views between 2004 (n≈955) and 2005(n≈ 825).. 56

Table 3.6.1. Summary of YSI water quality records collected at the East and West Bank reef caps from March 2004 to November 2005. 57

Table 3.6.7. Summary of temperature data collected at the East and West Bank reef caps using HoboTemp thermographs from March 2004 to November 2005. 66

Table 3.6.10. Nutrient concentrations in water samples taken at the East and West Banks in 2004. 69

Table 3.6.11. Nutrient concentrations in water samples taken at the East and West Banks in 2005. 70

Table 3.7.1. Visual fish survey sampling statistics for the East and West Banks in 2004 and 2005.. 71

Table 3.7.2. Species and family richness and density values for the East and West Banks recorded during 2004 and 2005 survey efforts. 72

Table 3.7.3. Fish diversity and evenness values calculated for fish communities surveyed at the East and West Banks in 2004 and 2005. 74

Table 3.7.4. Weighted mean sizes (visual estimation of fork length) of the top five largest carnivore species at the East and West Banks in 2004 and 2005. 74

Table 3.7.5. Mean densities of fishes recorded per survey at the Flower Garden Banks during the 2004-2005 surveys (densities in numbers of fish per 100 m^2). 76

Table 3.7.6. Species list of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005... 79

Table 4.1.1. Percent coral cover (± SE) at both banks for both sampling years from random transect videography data. 84

Table 4.1.2. East and West Bank Random Transect Data for predominant cover categories as reported in CSA (1996) for data from 1992-1995 and Dokken et al. (2003) for data from 1996-2001. 89

Table 4.2.1. List of tropical cyclones that entered the Gulf of Mexico in 2004 and 2005. 103

ACKNOWLEDGMENTS

We thank the many individuals, listed below, who contributed their time and expertise to make this monitoring effort successful. We are grateful to MMS and NOAA for their invaluable institutional knowledge. In particular we acknowledge James Sinclair, the MMS Contracting Officer's Technical Representative, for his ongoing support and enthusiasm. We also thank Florida International University and Nova Southeastern University for facilitating the processing and analysis of the coral cores.

Project Personnel and Their Major Responsibilities

William F. Precht	Project Manager, Co-Principal Investigator/Data Analysis
Richard B. Aronson	Scientist, Co-Principal Investigator/Data Analysis
Kenneth J.P. Deslarzes	Scientist, Co-Principal Investigator/Data Analysis
Martha L. Robbart	Scientist/Data Analysis
Adam Gelber	Scientist/Logistics/Field Management
David J. Evans	Scientist/Data Analysis
Beth Zimmer	Scientist/Data Analysis
Ryan Moody	Statistical Design and Analysis

Project Divers

Martha Robbart	Don Deis	Mark Henry	Robert Nawojchik
David Roberts	Bob Woithe	Ken Deslarzes	Adam Gelber
Ken Jones	William Precht	Stacey Roberts	Beth Zimmer
David Evans	Marty Heaney	Ray Kurz	Melisa Reiter

Individual Authors/Contributors and the Tasks They Performed

REPORT	Task/Analysis	Author/Contributor
LONG-TERM MONITORING AT THE EAST AND WEST FLOWER GARDEN BANKS, 2004-2005 – INTERIM REPORT. VOLUME 1: TECHNICAL REPORT.	Project Management, Discussion, Conclusions, Recommendations, Editorial Management	William F. Precht Richard B. Aronson Kenneth J.P. Deslarzes Martha Robbart
	Executive Summary, Introduction, Study Site, Methods, Discussion	Martha L. Robbart
	Random Photographic Transects	Martha L. Robbart, Richard B. Aronson, Leslie Duncan
	Encrusting Growth Stations	Martha L. Robbart, Beth Zimmer, Richard B. Aronson, Leslie Duncan, Ryan Moody
	Sclerochronology	Martha L. Robbart, Mark Henry
	Repetitive Quadrats	Martha L. Robbart, Richard B. Aronson, Karlisa Callwood, Ryan Moody
	Water Chemistry	Kenneth J.P. Deslarzes, Bob Woithe, Marty Heaney
	Insolation	Kenneth J.P. Deslarzes, Bob Woithe, Marty Heaney
	Temperature	Kenneth J.P. Deslarzes, Bob Woithe, Marty Heaney
	Urchin Surveys	Martha L. Robbart
	Report Layout & Preparation	Martha L. Robbart, Leslie Duncan

EXECUTIVE SUMMARY

The Flower Garden Banks, remotely located topographic features on the continental shelf in the Gulf of Mexico, are afforded a certain measure of natural protection due to their geographic distance from land. Problems that affect coral reefs throughout the region, including land-based sources of pollution, overfishing, and coral disease have, to date, not had a measurable effect at the Flower Garden Banks. In addition to their relative isolation, the depth of these reefs, 18-48 m, has protected the corals from severe bleaching events that have had devastating effects on most western Atlantic reefs. Although coral disease has been identified at the Flower Garden Banks, the incidence and prevalence have been low compared to other sites within the western Atlantic reef-building province.

Monitoring results for 2004-2005 highlight a continuing state of high coral cover, with a mean of 57.12% for both banks and both years, as well as a continuing trend of positive coral growth. Robust fish populations and oligotrophic water conditions persisted, while occurrences of disease and bleaching were low, ranging from 0-0.57% at both banks in both years. Sea urchins continued to occur at low densities, averaging 0.033/m^2 (both banks, both years); however, there was an unusually high density of *Diadema* observed on the West Bank (0.11/m^2) during the 2004 monitoring event. Herbivorous fishes continue to be present in large numbers and appear to keep algal cover under control.

Random transect results revealed high coral cover at both banks, consistent with previous monitoring results, with 64.13% coral cover at the East Bank in 2004 and 49.55% in 2005, and 60.41% at the West Bank in 2004 and 54.41% in 2005. Macroalgal cover was stable at ~20% at both banks in both years, but high at the East Bank in 2005 and showed a significant site X year interaction ($P<0.001$). Crustose coralline algae, fine turf, and bare rock (CTB) averaged ~18% for 2004 and 2005, and also showed a significant site X year interaction ($P=0.012$).

The *Montastraea annularis* complex was the predominant component of coral cover at both banks in both years. Cover at the East Bank was 30.14 ± 4.76 % in 2004 and 26.8 ± 4.09% in 2005. At the West Bank cover was 31.70 ± 2.70% in 2004 and 36.20 ± 3.50% in 2005. Due to difficulty in differentiating the three species of the complex in the videographic images, *M. annularis, M. faveolata* and *M. franksi* were combined. *Diploria strigosa* was the next most abundant species, ranging at the East Bank from 12.13 ± 2.82% in 2004 to 5.95 ± 1.26% in 2005. The West Bank estimates were 13.41 ± 1.74% and 6.68 ± 1.29% in 2004 and 2005, respectively.

The Shannon-Weiner diversity index, H', was calculated from species-specific coral-cover data from each video transect. At the East Bank, H' ranged from a low of 1.45 in 2004 to a high of 1.53 at the East Bank in 2005. At the West Bank, H' was 1.52 in 2004 and 1.36 at the West Bank in 2005. A two-way ANOVA showed no significant effect of year or site, and the site X year interaction was also not significant.

Sclerochronology was used to measure the accretionary growth rates of *Montastraea faveolata*. Cores taken at both banks revealed annual growth bands spanning 1992 to 2005. Yearly growth rates ranged from 2.75 mm to 14.54 mm between banks. Interestingly, a disruption in accretion

was seen in three quarters of the samples from both banks, associated with 1997-1998. This was the year of widespread bleaching throughout western Atlantic coral reefs.

Lateral growth stations were monitored to measure changes in *Diploria strigosa* colonies. *Diploria strigosa* is important at the Flower Garden Banks because it is the second largest contributor to coral cover within the 10,000 m^2 monitoring sites. Overall there was a 14% increase in the area covered by *Diploria strigosa* colonies from 2004 to 2005.

Repetitive quadrats were photographed to monitor 8 m^2 areas and their coral communities over time. Repetitive quadrats showed changes in coral species cover and coral condition (disease, paling, bleaching, and fish biting) from 2004 to 2005. The incidence of paling and bleaching were low at both banks in both years; none of these metrics was above 0.57%, and there was no evidence of disease in any of the repetitive quadrats analyzed. Planimetry results of select colonies within the repetitive quadrats showed an increase in the area covered by these colonies from 2004-2005 at both banks.

Nine deep repetitive quadrats (32-40 m depth) were established on the East Bank in April 2003 and photographed in September 2004 and June 2005. Coral cover was high, averaging 83%. The *Montastraea annularis* complex and *M. cavernosa* were the dominant species in these 8 m^2 quadrats. Crustose coralline algae, fine turf, and bare rock (CTB) averaged ~11% at the deep stations in 2004 and 2005, while macroalgae averaged ~5%.

Water quality parameters, including photosynthetically active radiation (PAR), turbidity, temperature, salinity, pH, and dissolved oxygen, were recorded using YSI datasondes. Chlorophyll *a* and nutrients were recorded using water samples. No anomalies were detected in water quality parameters during the study period. Hobo temperature probes were deployed and these data are included as a complement to the YSI records.

Fish surveys were conducted using the Bohnsack and Bannerot (1986) method. A mean of 57 fish species were observed per bank per year in 2004 and 2005. This is an increase from the 51 mean fish species recorded during the previous 2002-2003 surveys. Herbivores were the dominant fish guild, with Pomacentridae (damselfish) and Labridae: Scarinae (parrotfish) representing the largest portion of these. Bell-shaped size distribution curves suggest that herbivore populations are healthy, with the largest proportion of fish being in the 11 to 20 cm range at both banks in both years. Carnivorous fish were represented by fewer families than herbivores and most of these individuals were in the Serranidae and Lutjanidae. Sixty percent or more of carnivores were estimated to be above 21 cm, suggesting a robust population of carnivores at both banks.

Sea urchin surveys documented low densities of *Diadema antillarum* at both banks in both years. Density ranged from 0.005 - 0.11 individuals/m^2. Two *Panulirus argus* (spiny lobster) were recorded along transects at the West Bank in 2004 and one at the East Bank in 2005.

The Flower Garden Banks support healthy coral and fish assemblages compared to reefs elsewhere in the region. Continued monitoring will document their long-term condition and will be useful for studies focused on the dynamics of the robust benthic communities and fish populations they support. The following are recommendations for improving the monitoring protocol and increasing the scientific value of the ongoing contract:

- Monitor areas outside of the 100 x 100 m study sites. In particular, *Madracis mirabilis* forms a large field located near the southeast corner of the East Bank study site. This field should be monitored and cored to chronicle disturbances, such as hurricanes and illegal anchoring, within the Sanctuary.

- Replace YSI datasondes or datasonde sensors more frequently to obtain more consistent and accurate results for water quality parameters. Place a PAR sensor on an oil platform in close proximity to East or West Bank.

- Mount the YSI datasondes on the reef cap to measure water quality parameters more accurately in the reef community. Remove YSI datasondes from sand flats, where they are currently located. Certain parameters, in particular, PAR and turbidity may be affected by the sandflat environment, where sedimentation and reflectance exert an influence. Furthermore, dissolved oxygen is potentially greater on the sand flats during daylight hours.

- Increase YSI change-outs to 5-8 times per year, to monitor water quality parameters more precisely.

- Purchase additional YSI instrumentation for rotation and repair so there are always units available to change.

- Monitor the concentration of trace metals in bivalves to evaluate the bioavailability of trace metals at the Flower Garden Banks. Filter-feeders are known to concentrate the heavy metals they ingest from surrounding waters.

- Do a one-time sclerochronology study, incorporating at least a dozen corals from each bank. The purpose would be to correlate stress events temporally between the banks.

- Work to isolate the pathogens responsible for coral disease at the banks.

- Search for species representing range extensions to the banks (e.g. *Acropora palmata*).

- Monitor for exotic species, including the orange cup coral *Tubastraea coccinea*.

- Expand the ongoing invitations to visiting scientists and graduate students on the annual monitoring cruises to represent a wide range of scientific disciplines.

- Continue and if possible increase the large number of presentations and peer-reviewed publications resulting from this work.

1.0 INTRODUCTION

1.1 CORAL REEF MONITORING AT THE FLOWER GARDEN BANKS

The biotic assemblages of the Flower Garden Banks constitute low-diversity, high-coral-cover and low-algal-cover reef communities with robust fish assemblages (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2001, 2003; Pattengill-Semmens and Gittings 2003, Precht et al. 2006). No significant long-term changes were detected in coral cover or diversity at the Flower Garden Banks from 1988 to June 2005. In nearly 15 years of continuous monitoring, the coral reefs of the Flower Garden Banks have maintained high levels of coral cover, suffered minimally from bleaching and disease, and supported diverse and abundant fish populations as well as other vertebrate and invertebrate species. While the rest of the Caribbean has experienced a decline in coral cover and subsequent increases in macroalgal cover, the Flower Garden Banks remain a stable coral reef system in the western Gulf of Mexico. These reefs, therefore, represent a natural laboratory for understanding the causes of stability and change in reef systems.

Gittings et al. (1992) established the 100 x 100 m study sites at the East and West Banks to monitor benthic community structure from 1988 to 1991—measured by coral cover, relative dominance, diversity, evenness, and accretionary and encrusting growth rates—as well as water quality parameters. Comparisons between the 1988-1991 results and those of previous studies from 1978-1982 (Rezak et al. 1985) showed no significant differences in any of the parameters, indicating ecological stability at the Flower Garden Banks over the period examined. Coral cover was ~50% and dominated by the *Montastraea annularis* species complex (~25%) and *Diploria strigosa* (~8%) (Gittings et al. 1992). Gittings et al. (1992) considered spills from oil tankers, discharged mud and drill cuttings from oil and gas operations, seismic activity due to oil and gas exploration, and platform accidents to be the greatest threats to the reefs.

No long-term changes in coral community structure were reported for 1992-1995 by CSA (1996). However, variation in individual coral species was detected between banks and between the sampling years, which were 1992, 1994 and 1995. Coral bleaching was documented in 1990, 1992, 1994, and 1995 when water temperatures rose above 30°C (Hagman and Gittings 1992; Dokken et al. 1999, 2001, 2003).*Montastraea cavernosa* and *Millepora alcicornis* were the species most affected by bleaching, but post-bleaching mortality rates were low at 0.2%-2.8% from 1992-1995 and displayed a patchy distribution. Although small-scale spatial variation exists at the Flower Garden Banks, as it does on other coral reefs, it is apparent that at the larger scale of the reef landscape (km), the biota exhibit relative stability.

Dokken et al. (1999, 2003) continued the monitoring effort from 1996 through 2001 and documented no significant changes in coral growth or condition. Biodiversity inventories were conducted for algae and mollusks: 73 species of algae were documented as well as over 230 species of mollusks (Dokken et al. 2001, 2003). Fish assemblages were also studied in detail (Pattengill 1998).

Using the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol in 1999, Pattengill-Semmens and Gittings (2003) observed high coral cover of ~50% at 20-28 m, dominated by large coral heads (mean diameter 81-93 cm), with a level of partial colony mortality (recent and long-dead portions of colonies) of only 13%. In concordance with earlier findings, turf was the predominant functional group of algae, whereas macroalgae accounted for less than 10% cover (Pattengill-Semmens and Gittings 2003).

Monitoring in 2002-2003 by Precht et al. (2006) also highlighted the long-term stability of the coral reef communities. Coral cover was ~50% at both banks in those years, and neither significant bleaching nor disease was detected. The relative dominance of coral species was consistent with past findings. *Diploria strigosa* margins grew overall from 2001-2002, whereas a low sample size for 2002-2003 (due to replacement of monitoring stations in 2003) prevented firm conclusions from being drawn. Repetitive quadrat data from 2002 and 2003 revealed low prevalence of disease and bleaching (<0.61%) and planimetry results showed an increase in surface area of selected corals at both banks. Oceanic water quality conditions prevailed at both banks in 2002 and 2003; however YSI maintenance issues produced data gaps where conclusions could not be made, particularly regarding turbidity and PAR. Fish populations continued to be robust and *Diadema* and *Panulirus* abundance remained low.

The results of the 2004-2005 monitoring efforts, conducted in September and November 2004 (East and West Banks, respectively) and in June 2005, demonstrated the continued stability of the coral reef community and its associated fish populations. Coral cover remained ~57% at both banks and no significant amount of bleaching or disease was documented and the relative dominance of coral species was consistent with past findings. *Diploria strigosa* margins grew on average from 2003 to 2005. Repetitive quadrat data from 2004 and 2005 revealed a low prevalence of disease and bleaching (<0.57%), and planimetry results showed an increase in surface area of selected corals at both banks. Oceanic water quality conditions prevailed at both banks in 2004 and 2005; however, YSI maintenance issues produced data gaps. Fish populations remained large and *Diadema* and *Panulirus* abundance remained low, except at the West Bank in 2004, when the mean *D. antillarum* density was $0.11/m^2$. The results reflected findings of past studies and showed the Flower Garden Banks to support among of the highest coral cover in the western Atlantic (Pattengill-Semmens and Gittings 2003).

On September 23, 2005 Hurricane Rita (Category 3 Saffir-Simpson Index) passed within 50 miles of the East Bank on its route north to the mainland United States. Hurricane Rita's winds were up to 125 mph and the closest weather buoy, buoy #42019, located 143 miles west, recorded waves close to twenty feet. An October cruise, conducted by the National Oceanographic and Atmospheric Administration (NOAA), revealed physical damage, including overturned and dislodged coral heads the size of small buses, broken corals of smaller sizes, gouged coral heads damaged by projectiles, and the displacement of sand. Additionally, the summer of 2005 was unusually warm and sea surface temperatures in the Eastern Caribbean (Trinidad and Tobago, the British Virgin Islands), as well as at the Flower Garden Banks, were high for an extended period of time. Corals that were bleached during the October cruise, mainly *Montastraea cavernosa, Millepora alcicornis*, and the *M. annularis* complex were noted. As a result of the hurricane, a post-hurricane cruise was conducted at the East Bank in November 2005. Although some recovery was evident on the November cruise, *Montastraea cavernosa* and *Millepora alcicornis* continued to be bleached. Study site repetitive quadrats, deep station repetitive quadrats, videography of two perimeter lines and water quality data were collected and analyzed. The results of the post-hurricane cruise are reported as a separate report.

1.2 THE FLOWER GARDEN BANKS IN THE GULF OF MEXICO

1.2.1 Habitat Description

The Flower Garden Banks are located in the northwestern Gulf of Mexico and form part of a discontinuous arc of reef environments along the outer continental shelf (Rezak et al. 1985; Figure 1.2.1). These coral reef banks are the largest charted calcareous banks in the northwestern Gulf of Mexico (Bright et al. 1985) and are the northernmost coral reefs on the continental shelf of North America (Bright et al. 1984). Although coral and non-coral dominated communities exist on neighboring banks (e.g. Sonnier Bank, Stetson Bank), the reefs at Cabo Rojo in Mexico are the nearest developed coral reefs in the Gulf of Mexico.

The large-scale topographic features of the Flower Garden Banks were created by salt diapirs of Jurassic Louann origin and the consequent uplifting of sedimentary rocks (Rezak 1981). The caps of these salt domes extend into the photic zone in clear oceanic waters, where conditions are ideal for colonization by species of corals, algae, invertebrates, and fish typical of coral reefs of the Caribbean basin. Although coral species richness is lower at the Flower Garden Banks than on Caribbean reefs, 21 species of scleractinian corals and 177 species of tropical Atlantic fish are present at the banks (Pattengill-Semmens and Gittings 2003). Oceanic salinity conditions prevail at the Flower Garden Banks and range from 34 to 36 ppt, with water temperatures ranging from 18°C (in mid-February) to ~30°C (in August). Water clarity at the Banks is excellent - commonly 30 m or more - providing light to photosynthesizing organisms.

1.2.2 The East and West Banks

The East Bank (27º 54.5' N, 93º 36.0' W) is located approximately 193 km southeast of Galveston, Texas. The East Bank encompasses 67 km^2, sloping from its shallowest point at 18 m to the terrigenous mud seafloor at a depth of 100-120 m. The eastern and southern edges of the bank slope steeply whereas the northern and western edges slope more gently (Figure 1.2.2). The West Bank (27º 52.4' N, 93º 48.8' W) is located 20 km west of the East Bank and 172 km southeast of Galveston and is more than twice as large (137 km^2) as the East Bank (Figure 1.2.3). The two peaks that comprise the West Bank are aligned along an east-west axis. The West Bank study site is located on the eastern peak. Coral species diversity at both banks is low, with 21 species from 12 genera represented (Bright et al. 1984), compared to 67 species found on some Caribbean reefs (Goreau and Wells 1967). Shallow-water gorgonians and acroporids were not found in the past. However, one colony of *Acropora palmata* was discovered in 2001 at the West Bank and was still present and growing at the time of this writing. Another living colony of *A. palmata* was discovered at the East Bank, southeast of the study site, in June 2005.

Previous investigators described three biological zones at the Flower Garden Banks: the *Montastraea-Diploria-Porites* Zone (< 36 m), the *Stephanocoenia-Millepora* Zone (36-52 m), and the algal-sponge zone (46-88 m) (Rezak et al. 1985). All monitoring at both banks is conducted within the *Montastraea-Diploria-Porites* Zone, except for the deep stations at the East Bank (32-40 m), which were established in 2003. Contradicting previous descriptions of species dominance in the *Stephanocoenia-Millepora* Zone, these new deep stations were dominated by the *M. annularis* species complex (*M. annularis, M. faveolata*, and *M. franksi*) and *M.*

cavernosa. The difference in coral dominance between these newly established deep sites and previous descriptions illustrates the high degree of spatial variability in the composition of benthic assemblages.

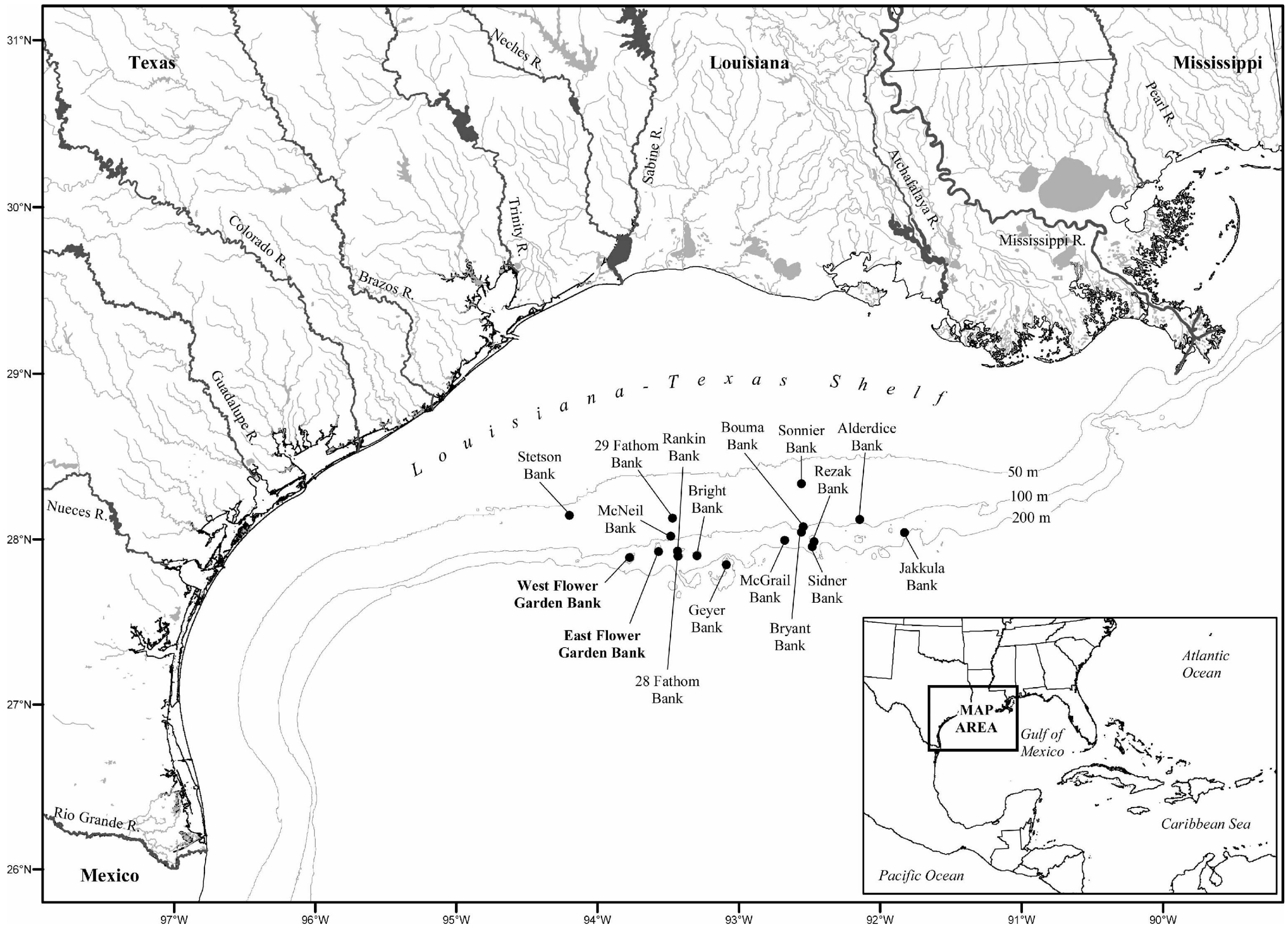


Figure 1.2.1. Location map of the East and West Flower Garden Banks in relation to the Texas-Louisiana continental shelf and other topographic features of the northwestern Gulf of Mexico (map created by Deslarzes in 2005).

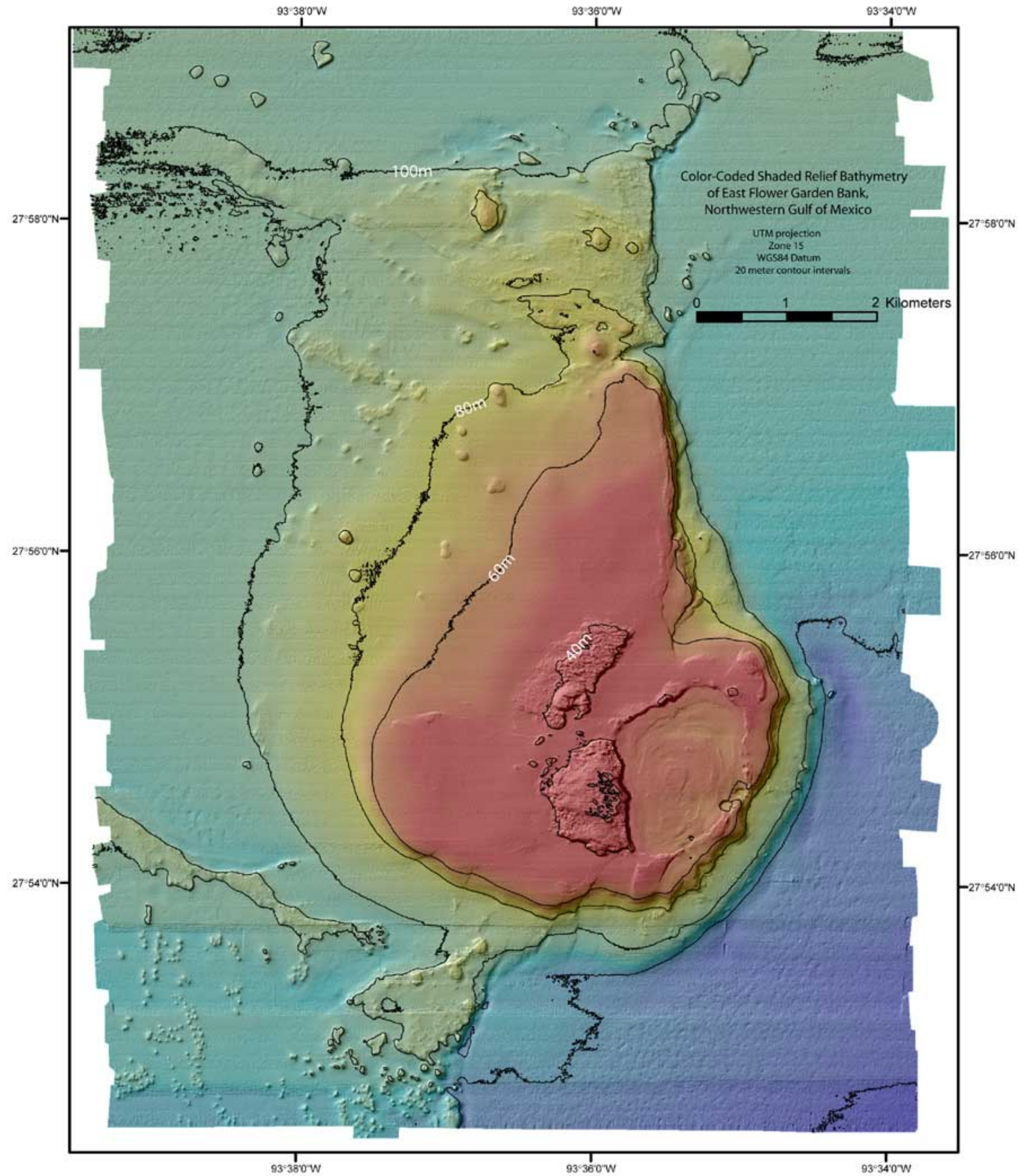


Figure 1.2.2. Topographic contour map of the East Bank (Gardner et al. 1998).

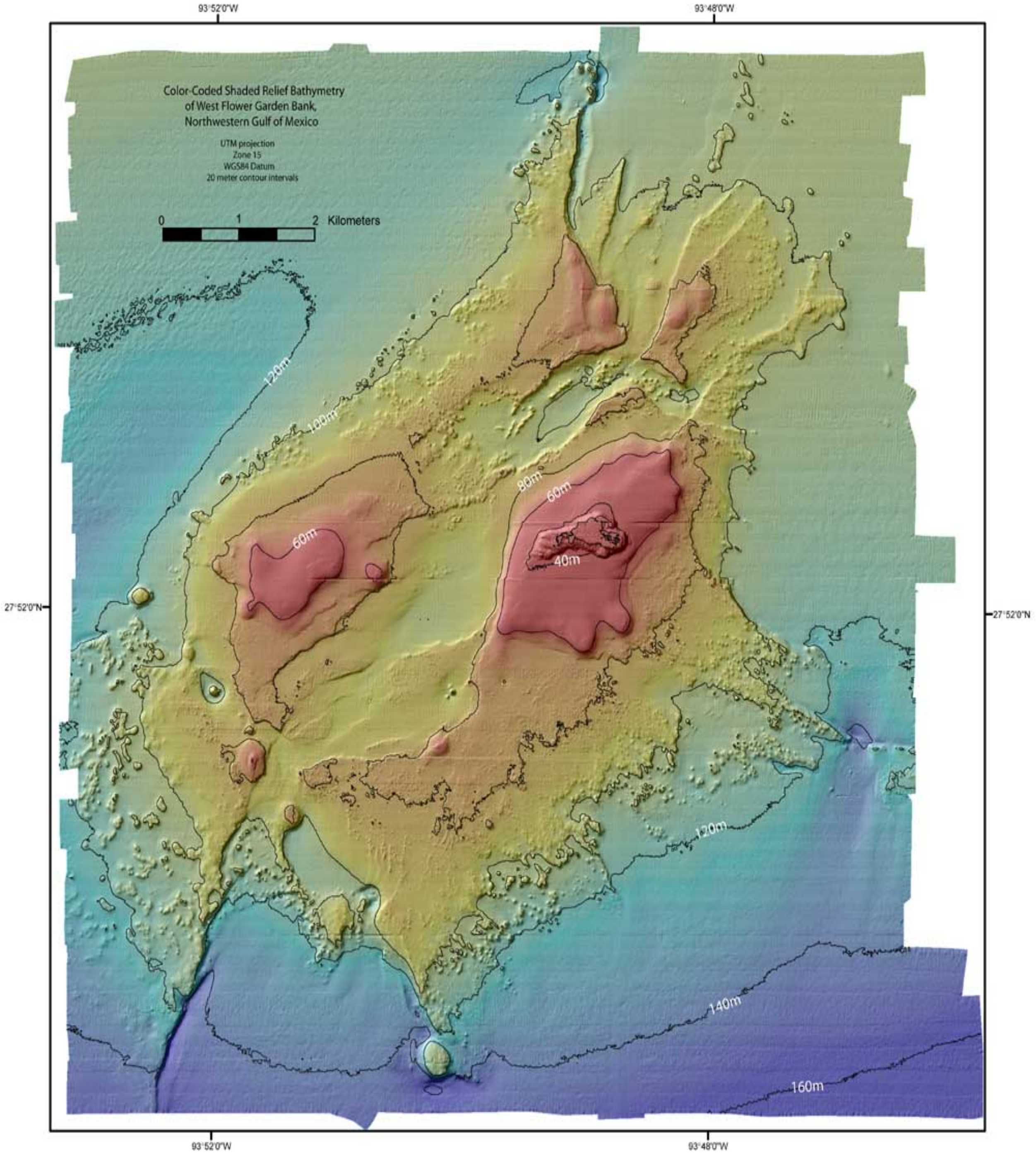


Figure 1.2.3. Topographic contour map of the West Bank (Gardner et al. 1998).

1.3 MMS and FGBNMS Protective Measures

Oil and gas activity in the vicinity of the Flower Garden Banks has been ongoing since the 1970s. The Minerals Management Service (MMS), under the U.S. Department of the Interior (USDOI), has regulated the development of the oil and gas industry within the Gulf of Mexico outer continental shelf. In addition, MMS has, since 1973, conducted a program of protective activities at the Flower Garden Banks coral reefs and sponsored numerous studies of the banks. The Topographic Features Stipulation as applied to the Flower Garden Banks was designed to protect sensitive biological resources from the adverse effects of routine oil and gas activities (USDOI, MMS 2002). Since 1983, the Stipulation has protected the biota of the Flower Garden Banks from physical damage associated with oil and gas activities including anchoring, and rig emplacement, as well as potential toxic and smothering effects from drilling muds and cuttings discharges (USDOI, MMS 2002). The Stipulation defines a No Activity Zone (NAZ) around each of the banks. The boundary of the NAZ overlaps the 100- to 120-m isobaths at the West Bank and the 100- to 130-m isobaths at the East Bank. No oil or gas structures, drilling rigs, pipelines, or anchoring are allowed within the NAZ. The Stipulation also defines a "4-Mile Zone" outside the No Activity Zone, within which operators are to shunt all drill cuttings and drilling fluids to within 10 m of the seafloor.

In addition to the protections provided by MMS, the Flower Garden Banks were designated a United States National Marine Sanctuary in 1992 (Code of Federal Regulations, 15 CFR Part 992, Subpart L, Section 922.120). The Flower Garden Banks National Marine Sanctuary (FGBNMS) regulates, restricts and/or prohibits:

(1) anchoring or mooring of all vessels within the Sanctuary boundaries;
(2) discharge of any material or matter within the Sanctuary boundaries;
(3) any alteration of the seabed within the Sanctuary boundaries;
(4) any injury or removal or attempt of injury or removal of any living or non-living Sanctuary resource;
(5) taking of marine mammals and sea turtles;
(6) possessing or using within the Sanctuary boundaries any fishing gear except conventional hook and line gear; and
(7) possessing or using explosives within the Sanctuary boundaries or releasing electrical charges within the Sanctuary boundaries.

From 1988 to 1995, the MMS monitored the Flower Garden Banks coral reefs to detect any incipient changes that may be caused by oil and gas activities, as well as by any other disturbances (Gittings et al. 1992; Gittings 1998). Since 1996, the FGBNMS and the MMS have partnered to continue the long-term monitoring at the Flower Garden Banks.

2.0 METHODS

The Flower Garden Banks are roughly 190 km offshore and are submerged in more than 18 m of water; therefore, the monitoring effort was conducted from a dive vessel that remained at each bank for about two days per year. The benthos (with an emphasis on corals) was examined along videographic transects and in stationary repetitive photographs. Sclerochronology was used to document the accretionary growth rate of corals, and photography was done at permanent stations to monitor the lateral growth of corals. Water quality was assessed to characterize the Flower Garden Banks reef cap and water column environment. Fish surveys were conducted at haphazardly located stations. Sea urchins and lobsters were surveyed on perimeter lines.

2.1 STUDY SITES

Data were collected within the established 100 x 100 m sites at the East Bank in September 2004, at the West Bank in November 2004, and at both banks in June 2005. The general locations of the study sites are marked by permanent mooring buoys: FGBNMS permanent mooring number 2 at the East Bank (27° 53' 35.80" N, 93° 38' 23.90" W; Figure 2.1.1) and mooring number 5 at the West Bank (27° 52' 50.86" N, 93° 52' 25.34" W; Figure 2.1.2). Subsurface buoys were installed at the corners of the sites to facilitate underwater relocation. Geographical Positioning System (GPS) coordinates taken at the site corners in 2002 allowed for quick site relocation and initial mapping of the corners (Table 2.1.1). For each survey, temporary buoys were dropped from a launch to visually mark the corners from the surface and for quick location by divers. Divers used polypropylene lines to temporarily mark the perimeters of the study sites and the north/south and east/west center lines (commonly referred to as the "crosshairs"). Establishment of the perimeter and crosshairs divided each site into four quadrants. The lines aided divers in orientation and in completing their monitoring tasks efficiently. Each dive team was supplied with detailed underwater maps of the study sites. Additionally, master maps were updated on the dive vessel with new data on station numbers, locations, replacements and revisions. These revisions are reflected in the current site maps (Figures 2.1.3 and 2.1.4).

Table 2.1.1.

GPS coordinates for the East Bank and West Bank study-site corner markers.

East Bank			West Bank		
Corner	**North**	**West**	**Corner**	**North**	**West**
NE	27º54'32.8	93º35'48.1	NE	27º52'31.8	93º48'53.6
NW	27º54'32.2	93º35'51.6	NW	27º52'31.5	93º48'56.9
SE	27º54'29.6	93º35'48.6	SE	27º52'28.7	93º48'53.2
SW	27º54'30.1	93º35'52.1	SW	27º52'28.5	93º48'56.8

Metal rods were previously installed in the reef to mark permanent monitoring stations. There were two types of permanent monitoring stations: (1) lateral growth stations on *Diploria strigosa* colonies, marked by two short rods per station; and (2) 8 m^2 repetitive quadrats, the centers of which were marked by 0.5 m tall rods. Eighty repetitive quadrats (station numbers 1-40 at the East Bank and numbers 41-80 at the West Bank) and 120 lateral growth stations (numbers 1-60 at the East Bank and numbers 61-120 at the West Bank) exist at the East and West Banks.

2.2 Random Transects

2.2.1 Methodological Rationale

To estimate the areal coverage of benthic components such as corals and macroalgae, sixteen 10 m long fiberglass surveyor's tapes were positioned at each study site. Four transects were positioned randomly within each quadrant, starting at a random location and laid out in a random direction according to a set of randomly generated numbers. Coverage was estimated from these transects using videography, which was shown to be equal in power and accuracy to still photography results (Precht et. al 2006). Digital videography provides a logistically simpler and more reliable alternative, while permitting direct comparison to past results from still photography.

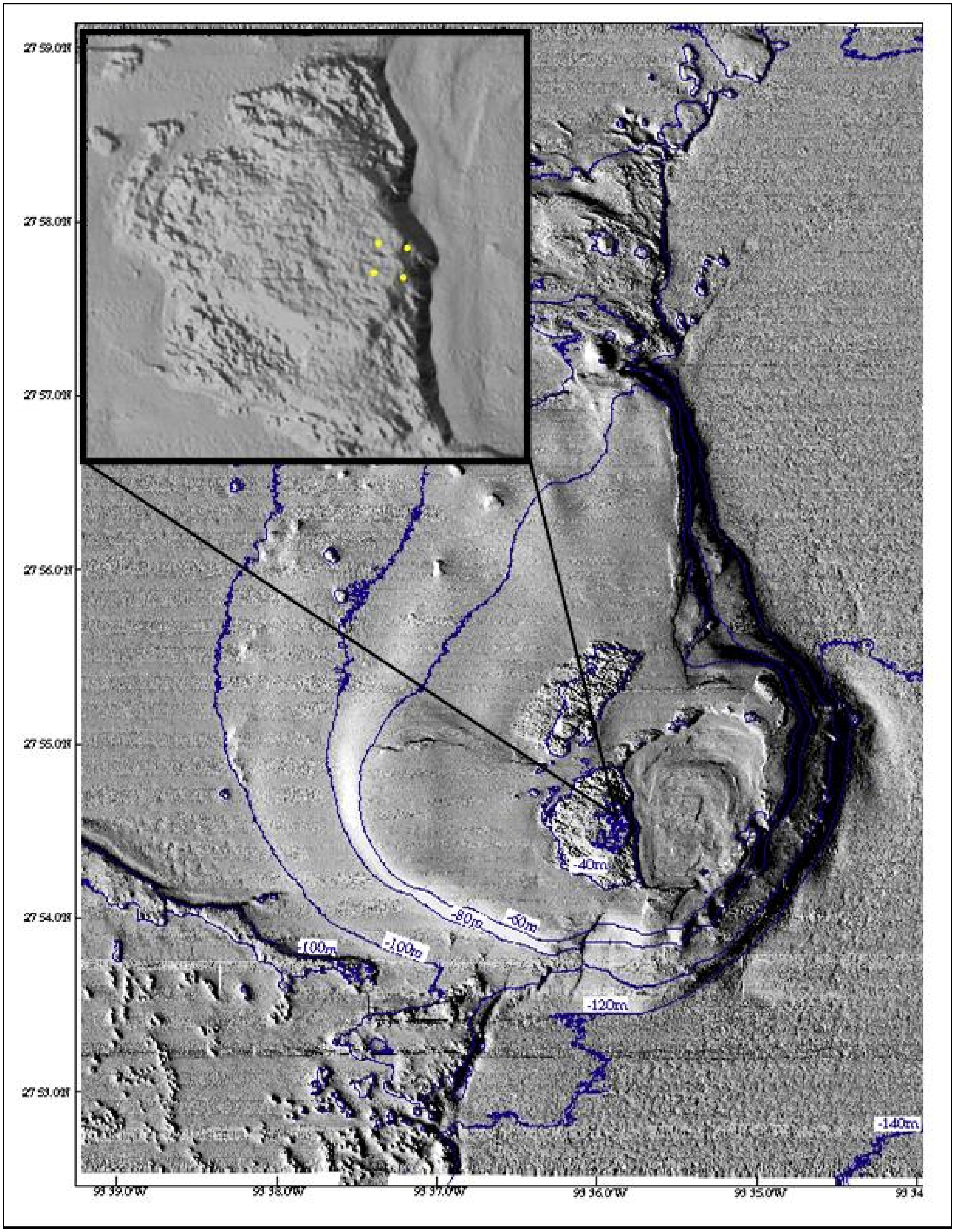


Figure 2.1.1. Topographic map of the East Bank (USGS 2001). Inset shows the locations of the corners of the study site.

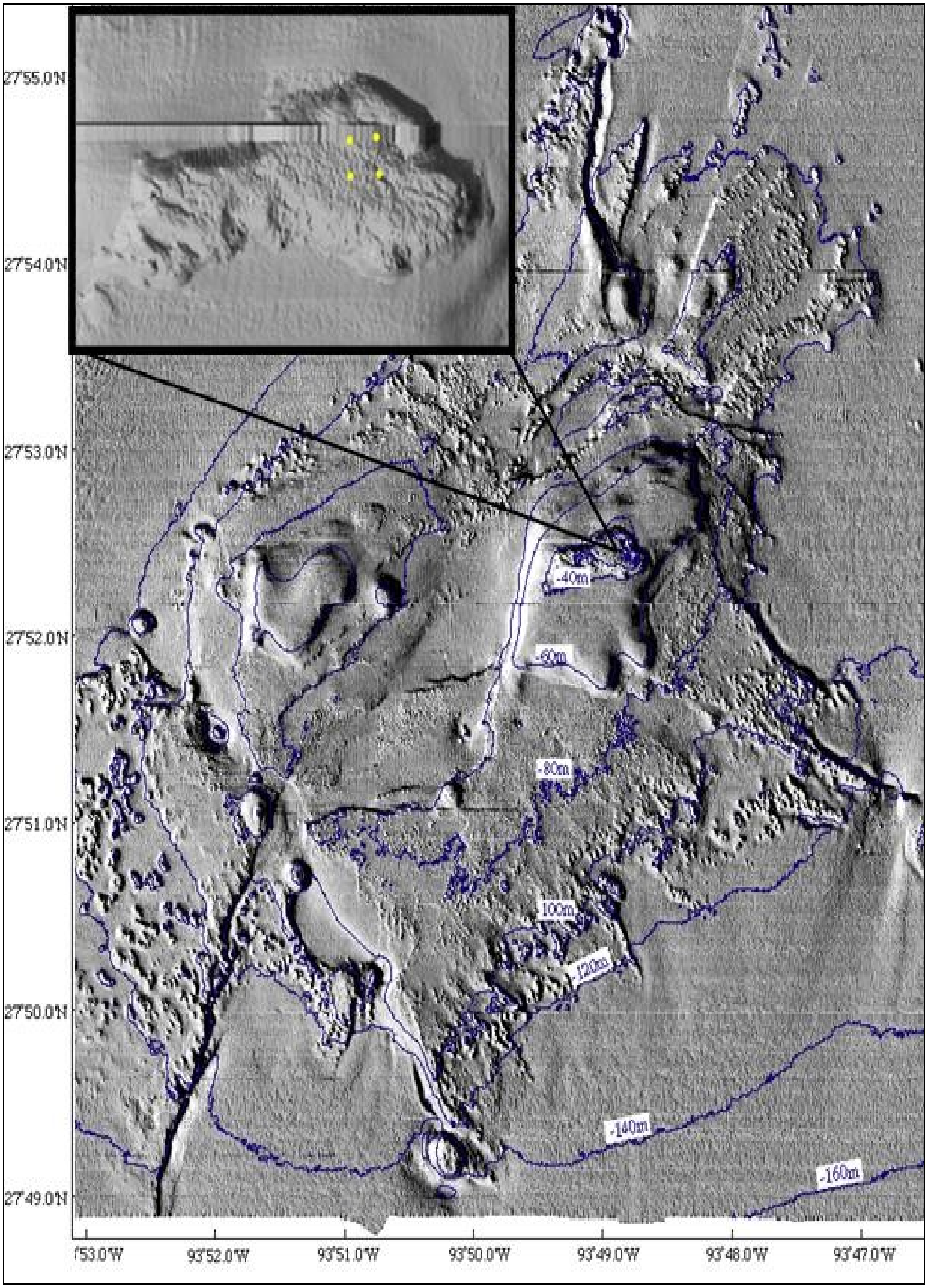


Figure 2.1.2. Topographic map of the West Bank (USGS 2001). Inset shows the locations of the corners of the study site.

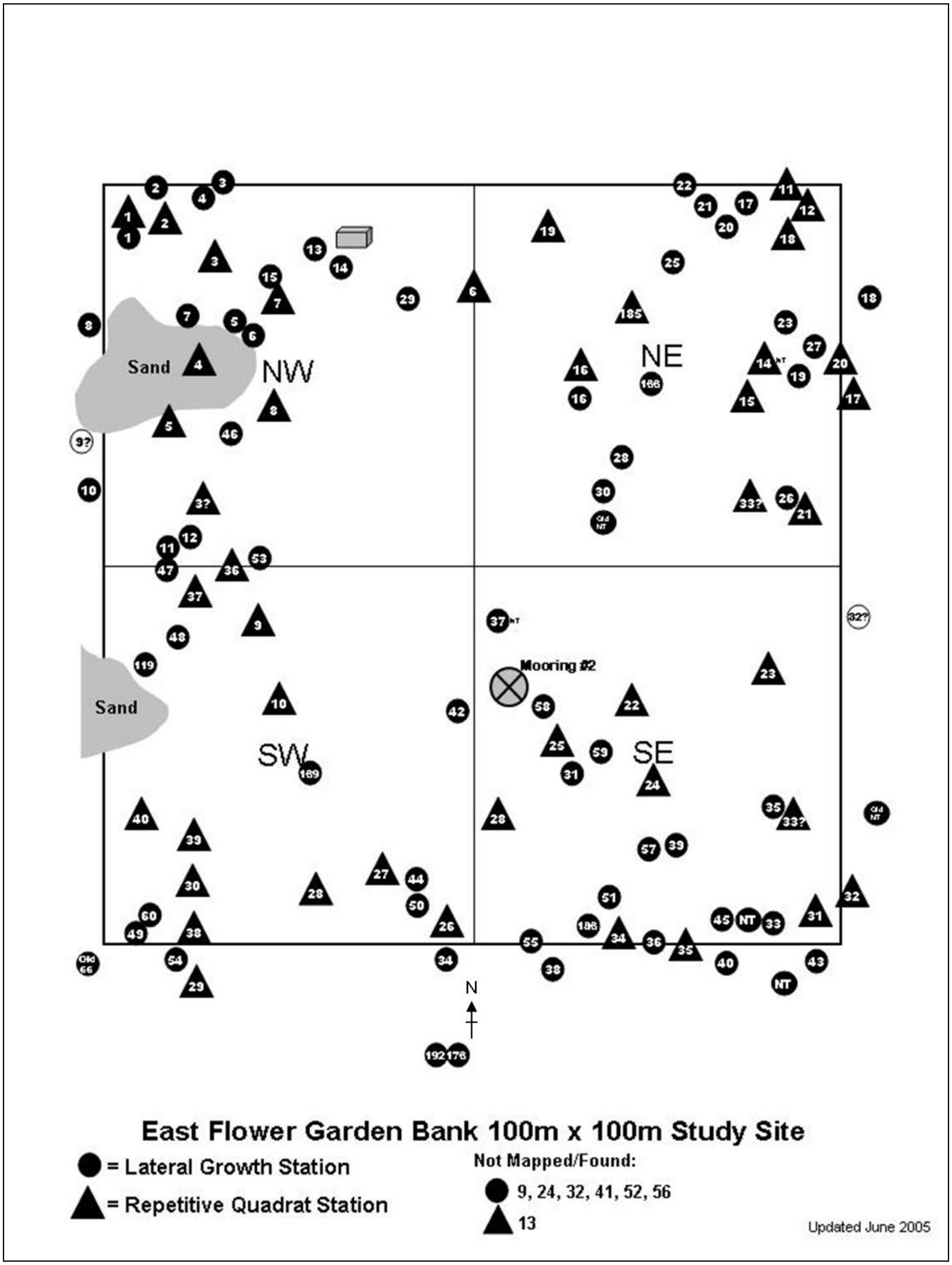


Figure 2.1.3. Locations of monitoring stations at the East Bank, 2005.

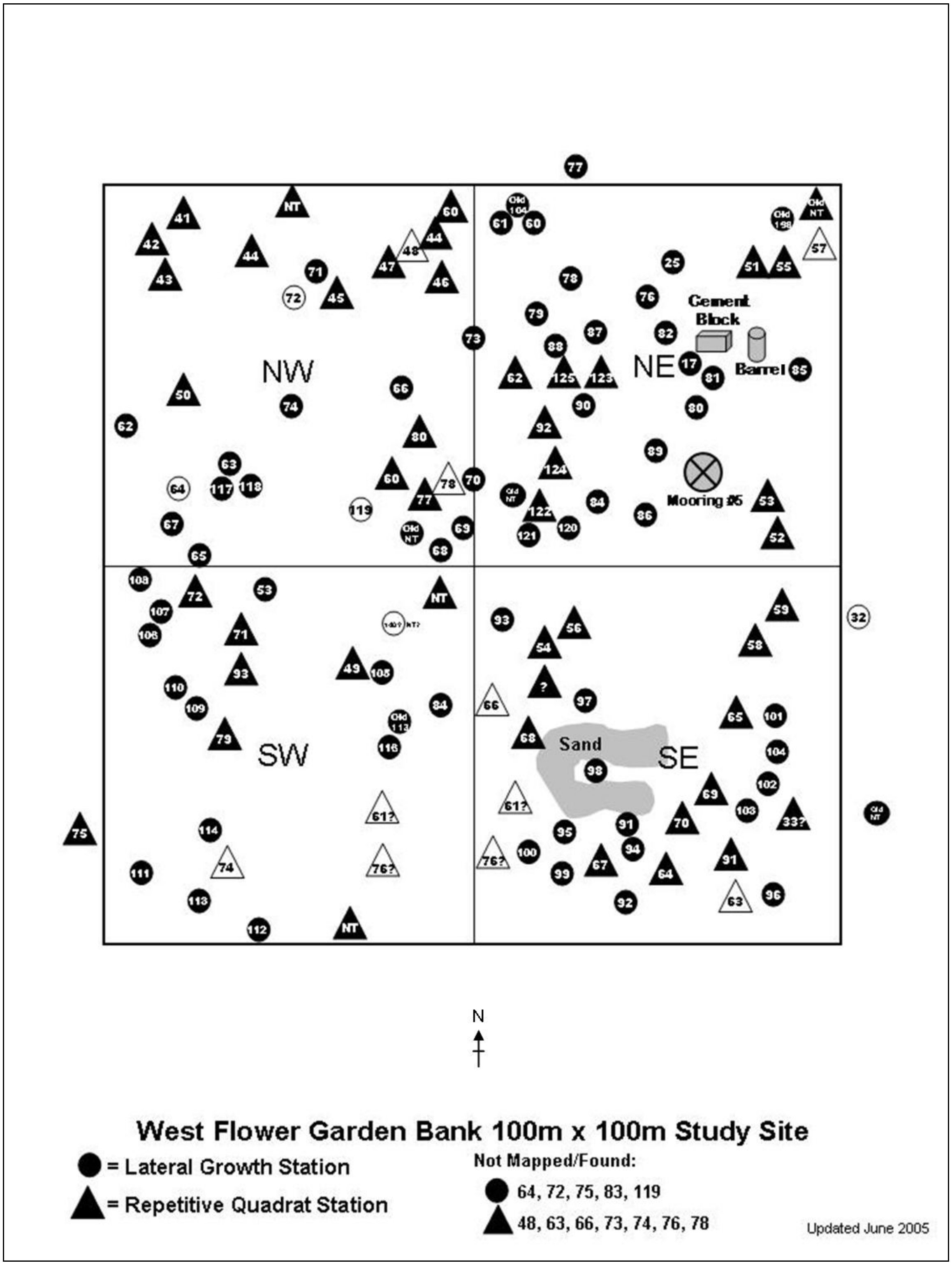


Figure 2.1.4. Locations of monitoring stations at the West Bank, 2005.

Data collected using video transects were categorized as follows. Corals were identified to species; sponges were combined into a single group; macroalgae were identified to species where possible and included anything longer than ~3 mm (including thick algal turfs); crustose coralline algae, fine turfs, and bare rock were grouped as "CTB." CTB components are difficult to distinguish visually in still photographs and video transects. All three connote high levels of physical disturbance and/or herbivory, and so it is reasonable to combine them (Aronson and Precht 2000). These methods are a refinement of past methods at the Flower Garden Banks and have been used successfully in a separate, NOAA-funded study comparing Fully Protected Zones (FPZs) and reference sites within the Florida Keys National Marine Sanctuary (Aronson et al. 2005).

2.2.2 Positioning of the Transects

Four transects were laid randomly within each quadrant for a total of sixteen transects per study site in each monitoring year. Upon arrival in the quadrant a diver would swim a random number of kicks and secure the transect at its starting point. Another randomly generated number would be used to denote a heading in one of eight directions. The beginning of the next transect was positioned a random number of kicks in the same direction as the first transect and a random heading was used to lay the second transect. The third transect was laid in the same manner relative to the second, and so on. If a transect reached the border of the study site, it was reflected off the border and continued as a "bent" line.

The transects sampled the quadrants with equal intensity. This design was considered more desirable than the sparse sampling of areas that can occur when transects are positioned at random within the study site as a whole.

2.2.3 Videography

Digital videography provides a permanent record and is a reliable and logistically simple method of obtaining benthic cover data. A diver swam slowly along each transect, videotaping at a height of 40 cm from the substratum, using a digital video camera in an underwater housing fitted with a wide-angle lens and underwater video lights. A depth gauge and scaling bar were attached to an aluminum bar that projected forward from the video housing. The gauge and bar ensured that the camera remained a constant distance from the bottom. By holding the video camera perpendicular to the substratum and swimming slowly along the transect it was possible to produce clear stop-action images for analysis (Aronson et al. 1994; Murdoch and Aronson 1999).

The video frames covered a 40 cm wide swath along each of the 10 m transects, for a total area of 4 m^2 per transect, or 64 m^2 per site per year. Each video frame covered a 40 x 27 cm area, or 1080 cm^2 of the substrate. This size is designed to enable investigators to identify corals and many other sessile invertebrates to species down to a colony size of approximately 3 cm. Such precision is not attainable using video frames that record larger areas of the substratum.

Non-overlapping video frames were captured from each of the 16 video transects using ULead® VideoStudio® 9. Digital filters were applied using the ULead® software in order to enhance image quality. The original videotape of the transect was used in order to gain more detail or a different perspective on a specific still image. Substrate cover was assessed from all captured images.

After image capture and enhancement, randomly placed dots were added to each frame using Coral Point Count® (CPCe), for a total of 500 dots per transect. Organisms positioned beneath each random dot were identified to the lowest possible taxonomic level. After each image was analyzed, the data were entered into project-specific Microsoft Excel spreadsheets.

Quality assurance/quality control (QA/QC) for the video method consisted of multiple, trained individuals diving together on the study sites and identifying corals and other taxa. These individuals then viewed captured video frames to ensure that (1) they agreed on species identifications (which was particularly an issue with respect to the *Montastraea annularis* species complex) and (2) the taxa were recognizable on the frames.

2.2.4 Statistical Analysis of the Transect Data

Each transect was treated as a replicate at the scale of the study site, yielding an estimate of coral cover and the cover of other benthic categories. Percent covers were calculated for each transect from the 500 analyzed points. Data were collected on the point-counts of each coral species; sponges as a group; macroalgae, which included thick turfs greater than 3 mm; crustose coralline algae, fine turfs, and bare rock as a single category, "CTB"; and sand and other inanimate categories of substrate. Graphs were produced to allow the comparison of each reef in the average percent cover of major substrate types, coral species, coral functional types and algal functional types. Previous examination of means and variances, using different numbers of random dots, suggested that 500 dots per transect provide accurate and precise estimates of the coverage of benthic components, regardless of the length of the transects (Aronson et al. 1994; Carleton and Done 1995).

Two-way Analyses of Variance (ANOVAs) were performed to test the null hypotheses that the response variables did not differ between banks or among years. Tests for normality and homogeneity of variances were followed by transformation as necessary. ANOVAs were calculated for each substratum variable with the statistical software Minitab® 14.2.

The random sampling approach to videography provided sufficient statistical power to test hypotheses of change in community composition in previous studies in Florida and the Caribbean. Differences on the order of 3-5% in univariate coral cover were detectable at the 5% level (i.e., at $P<0.05$) with 80% power (Aronson et al. 1994; Murdoch and Aronson 1999). The technique has also performed well in multivariate analyses (Aronson and Swanson 1997). For the Flower Garden Banks, analysis of the monitoring data collected in 2002-2003 showed that differences on the order of 7.5% coral cover were detectable at the 5% level with 80% power (Aronson et al. 2005).

2.3 SCLEROCHRONOLOGY

2.3.1 Methodological Rationale

Sclerochronology is the determination of annual growth rates through the measurement of accretionary growth bands in coral core samples taken perpendicular to coral growth. The method of counting seasonal density bands within the skeleton, as revealed by X-radiography, has been used for some time (Buddemeier et al. 1974; Knutson et al. 1972), though there is still considerable controversy as to the exact cause of the variations in density of the skeleton. It is generally believed (Highsmith 1979) that low-density bands are produced under optimal growth conditions (fall/winter) and that high density bands accrete during suboptimal growth conditions (spring/summer). Physical environmental factors which are known to influence coral skeletal density are: (1) light (Macintyre and Smith 1974; Knutson et al. 1972; Wellington and Glynn 1983); (2) temperature (Highsmith 1979; Hudson et al. 1976); and (3) suspended sediment (Dodge et al, 1974; Brown and Howard 1985). Salinity and water agitation may also exert some control. Other factors, which influence the metabolism of the coral, may be reflected in skeletal growth, including nutrient availability and reproductive activity (Wellington and Glynn 1983). The roles played by the symbiotic zooxanthellae in influencing calcification, and endolithic algae in modifying density patterns, as well as the effects of boring organisms, are further complications.

The most commonly measured growth parameter in corals is linear extension. Thus, skeletal growth rate can be determined on the basis of the length of a corallite within a given band. Skeletal growth rate is also known to vary with orientation of the corallites, which can be determined by measuring the corallite growth angle (Graus and Macintyre 1982). Skeletal density and mass growth are additional parameters which may be obtained using image analysis densitometry (Dodge and Kohler 1984). The area between two sequential high-density growth bands is considered an annual growth increment, and measurements of linear extension can be compared within a coral colony, between colonies on the same bank, and between banks.

Skipped or stressed bands are commonly observed during years of significant coral bleaching or other stresses, including cold-air outbreaks, freshwater pulses, concentrated parrotfish biting, and damselfish territories (Wells 1963; Kaufman 1977; Buddemeier et al. 1974; Dodge 1975; Hudson et al. 1976; Highsmith 1979; Dodge 1980; Hudson 1981a, b; Hudson et al. 1989; Smith et al. 1989; Heiss and Dullo 1995; Insalco 1996). Finally, care must be taken to differentiate between normal, annual bands and other bands produced by non-cyclic environmental fluctuations (Graus and Macintyre 1982; Leder et al.1991).

2.3.2 Field Methods

Four cores were extracted from *Montastraea faveolata* colonies at each bank during the 2005 monitoring cruise. A SCUBA tank-powered pneumatic drill, fitted with a diamond-tipped, 7.62 cm lapidary bit, was used to extract cores from the apex of large *M. faveolata* heads. Cores were 30 mm in diameter and 80 mm long, spanning several years of growth. The holes left from core extraction were filled with a pre-formed limestone plugs inscribed with the dates of core extraction (Figure 2.3.2).

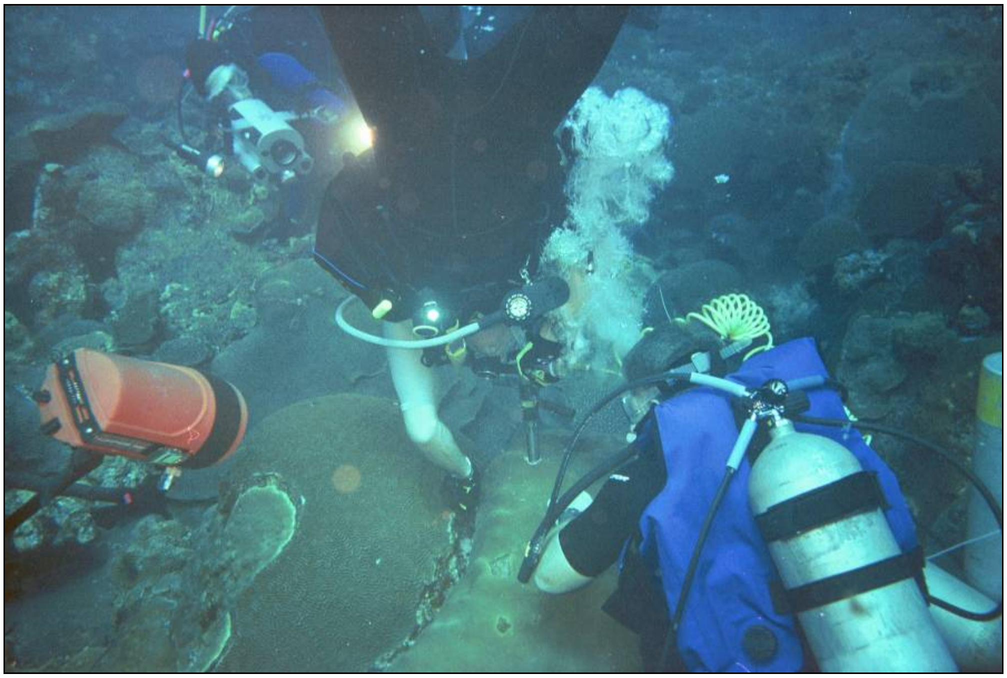


Figure 2.3.2. Scientists use a pneumatic drill at the Flower Garden Banks to extract a core from a colony of *Montastraea faveolata*. The core measures 30 mm in diameter and 80 mm long.

2.3.3 Laboratory Methods

Cores were longitudinally sectioned into 3 to 4 mm thick slabs using a single-blade diamond-impregnated rock saw. Coral slabs were arranged on Kodak Industrix 400 x-ray film and exposed to x-rays (70 kV, 15 ma for 7 sec) to reveal annual density bands.

Growth of the *Montastraea faveolata* colonies was determined directly by measuring distances between consecutive high-density bands. Three measurements were made along each growth band and averaged for an estimate of growth rate per year.

2.3.4 Data Presentation and Statistical Analysis

Overall mean growth rates and standard errors were calculated for each bank and year (1992-2005) from the four cores at each bank. Data are presented for each year by bank in tabular form. A t-test assuming equal variances compared growth rates between the East and West Banks.

2.4 LATERAL GROWTH

2.4.1 Methodological Rationale

Diploria strigosa is the second largest contributor to coral cover at the Flower Garden Banks (Bright et al. 1984; USDOI, MMS 1996; Dokken et al. 2003; Gittings et al. 1992; Precht et al. 2006). For this reason, the margins of *D. strigosa* colonies are monitored to detect changes.

2.4.2 Field Methods

Sixty lateral growth stations, located on the margins of *Diploria strigosa* colonies, are maintained at each bank. In 2004, 36 and 27 lateral growth stations were photographed at East and West Banks, respectively. Sixty colonies of *Diploria strigosa* on the East Bank and 58 colonies on the West Bank were photographed in June 2005. The low sample sizes in 2004 resulted from poor weather conditions.

Divers were equipped with a Nikonos V camera with a 28 mm lens, Nikonos close-up kit, and strobe. The camera was set at f22 and a distance of infinity, and the strobe set to TTL. This produced 13.3 x 19.7 cm (262.01 cm^2) photographic images (Figure 2.4.2). The framer was placed on corner pins at each station, ensuring a repeated image of the station. Many stations were missing identification tags. Those stations that did have tags were photographed with the tag in the frame. For stations without tags, the current photographs were matched with past photographs using the ridge patterns of the *Diploria* colonies.

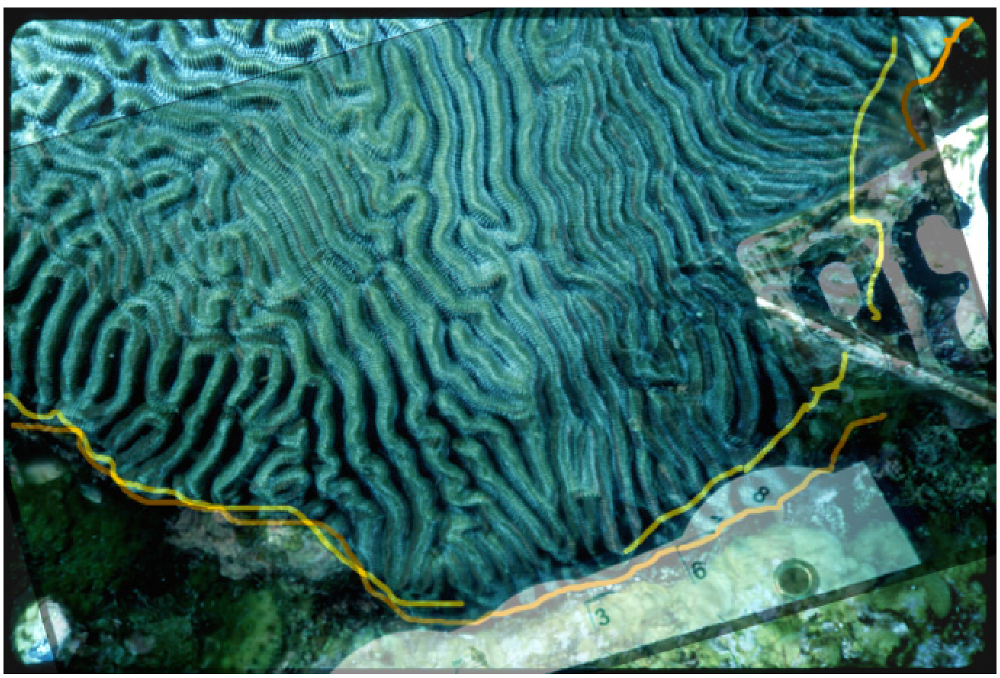


Figure 2.4.2. Image for analysis of *Diploria strigosa* lateral growth at the East Bank, showing 2004 (yellow line) and 2005 (orange line) comparison, using Adobe Photoshop.

2.4.3 Image Analysis of Lateral Growth

Images corresponding to a specific lateral growth station were compared between consecutive years. Comparisons were made between 2003 and 2004 images as well as 2004 and 2005 images. Lateral changes in the margins of the *Diploria strigosa* colonies were evaluated by overlaying the pairs of photographs and calculating the area of advance or retreat laterally, using Sigma Scan Pro 5®. Successive photographs of a given colony were lined up using the colony's ridge patterns.

2.4.4 Data Presentation and Statistical Analysis of Lateral Growth Stations

The data were examined for conformity to the normality and homogeneity-of-variances assumptions of parametric statistics, and were transformed as necessary. A repeated-measures ANOVA design was employed to analyze the data, as described in section 3.3.

Proportional annual changes in the area of individual *Diploria* colonies, whether positive or negative, were examined by site (East Bank and West Bank) and by interval (2003-2004 and 2004-2005). A total of 24 colonies from the East Bank and 21 colonies from the West Bank were analyzed between 2003 and 2004. Thirty colonies from the East Bank and 25 colonies from the West Bank were analyzed between 2004 and 2005.

2.5 Repetitive Quadrats

2.5.1 Methodological Rationale

To monitor changes in coral reef community structure, repetitive 8 m^2 quadrats were photographed and analyzed in two ways. The first method of analysis measured percent benthic cover components in 2004 and 2005 using random dot analysis. Then, to determine whether specific coral colonies grew or lost tissue laterally, select corals within the repetitive quadrats were analyzed using planimetry to measure growth or loss of tissue. Due to variability from year to year in the photographs, colonies of frame-building species were matched between years based on their visible margins. These corals tended to be near the centers of the photographs.

2.5.2 Field Methods

In 2004, 41 and 23 quadrats were photographed at East and West Banks, respectively; and 41 photographs were taken at the East Bank and 38 at the West Bank in 2005. Nine deep-station quadrats were photographed in 2004 and 2005 at the East Bank. Stations were photographed using a Nikonos V camera and 15 mm lens. The camera was loaded with Kodak Ektachrome EliteChrome 200 ASA, 36-exposure slide film and standard settings were applied (distance = 2 m, f8). It was mounted in the center of a T-bar camera frame, with a distance of 2 m from the substrate and 1.2 m between strobes. Two Ikelite 75 watt-second strobes were mounted on the ends of the T-bar and set on TTL and slave (Gittings et al. 1992). The camera was positioned in a north-facing direction to ensure repetitive photographs from year to year. The consistent orientation of the camera was achieved with a compass and a bubble level. The nine deep stations, established in 2003 and located between 32-40 m depth, were included in the comparison of coral cover and planimetry analysis.

2.5.3 Image Analysis of Repetitive Quadrats

Study Site and Deep Station Quadrats. Percent cover of corals by species; the cover of coral bleaching, paling, concentrated and isolated fish biting, and disease; and the cover of algae were determined by overlaying 300 random dots on each photograph using CPCe® point-count software with Excel extensions. Percent cover was calculated from 2004 and 2005 images. Thirty eight images were analyzed for the East Bank in 2004 and 41 images were analyzed in 2005. Twenty images were analyzed for the West Bank in both 2004 and 2005. It is important to note that only matching photographs taken at the West Bank between 2004 and 2005 were analyzed using random dots.

Planimetry was used to measure tissue change between select coral colonies within quadrat matches. Between 2003 and 2004, there were 38 matches at the East Bank and 23 matches at the West Bank. Between 2004 and 2005, there were 36 matches at the East Bank and 20 matches at the West Bank. Four to six coral colonies were chosen within each repetitive quadrat. These colonies were chosen based on the ability to decipher their boundaries and their importance to reef accretion (i.e. the dominant frame-builders *Montastraea annularis* species complex, *Diploria strigosa*, and *Colpophyllia natans*). Areal measurements were taken using Sigma Scan Pro 5® planimetry software.

2.5.4 Data Presentation and Statistical Analysis of Repetitive Quadrats

Mean percent cover of corals, algae, bleaching, fish biting, and disease were calculated using random-dot analysis with CPCe® software. Because *Montastraea annularis* species complex, *Diploria strigosa*, and *Colpophyllia natans* are dominant frame-building corals in the repetitive quadrats, the cover of these taxa (from the planimetry measurements) were compared between banks and through time using both parametric and nonparametric approaches.

Planimetry was calculated by taking areal measurements of dominant, frame-building corals each year. The areal values obtained in 2004 were subtracted from those calculated in 2005, yielding a change in area from 2004-2005. The change (either positive=growth, or negative=tissue loss) in cm^2 was divided by the 2004 areal value (cm^2) to determine growth or loss of tissue relative to the 2004 colony size.

2.6 Perimeter Videography

2.6.1 Methodological Rationale

The perimeter lines were videotaped each year to document change at known locations along the perimeter and within the study site. General aspects of coral condition and fish populations were documented and compared year to year.

2.6.2 Field Methods

Divers videotaped two 100 m segments of the perimeter lines at the East Bank (north and east margins) and West Bank (south and west margins) in 2004 and 2005. At the East Bank, divers started at the northwest corner and videotaped the north line to the northeast corner, then swam the east line to the southeast corner. At the West Bank, divers captured footage of the south and west lines, starting at the southeast corner and ending at the northwest corner. The videographer maintained ~2 m distance above the benthos using a weighted line attached to the video housing. The camera was aimed down at a 45° angle to capture the substratum. At each corner divers recorded a 360° panoramic view of the reef.

2.6.3 Laboratory Methods

The video footage was reviewed to record the general condition of coral health and fish populations along the perimeter of the study sites. Individual coral heads displaying possible disease, bleaching, paling, and tissue loss due to fish biting were identified and recorded. Analysis categories were as follows: bleaching, paling, healthy colony, concentrated fish biting, isolated fish biting (damselfish territory), growth infilling (tissue regrowth), new incidence of fish biting, surface replaced by turf algae, and unchanged. Concentrated fish biting (CFB) represents the concentrated biting which removes the coral polyps completely from an affected area and may be due to activity of the parrotfish *Sparisoma viride* (Bruckner and Bruckner 1998; Bruckner et al. 2000). Isolated fish biting describes less dense and smaller-scale fish biting, typically representative of damselfish territories. Affected coral colonies were compared between 2004 and 2005, and changes in their condition were recorded. During analysis of the East Bank video footage, those corals observed in one year and not found in the other were designated NP (not photographed). During the West Bank video analysis, only corals found in both years were considered, so there were no "NP" colonies. In addition to coral colony comparison, coral species composition and fish counts were assessed. These analyses were qualitative and therefore no statistical analyses were conducted.

2.7 Water Quality

2.7.1 Methodological Rationale

Physical and chemical characteristics of the seawater recorded over the reef cap and in the vicinity of the Flower Garden Banks characterize local water quality. From March 2004 to November 2005, the water quality overlying the reef caps at the Flower Garden Banks was assessed by monitoring temperature, salinity, dissolved oxygen, pH, turbidity, and content of chlorophyll *a*, dissolved inorganic nitrogen (ammonia [$NH_4^+$and NH_3], nitrate [NO_3^-], and nitrite [NO_2^-]), dissolved organic nitrogen (Total Kjeldahl nitrogen [TKN]), and inorganic phosphorous (soluble reactive phosphorous, a soluble inorganic form of phosphorous directly taken up by plant cells). These water quality parameters were selected to characterize the environmental background in which the Flower Garden Banks coral reef resources exist. As well as serving as a valuable record of environmental parameters, any changes in the coral reef biota which may be linked to water quality changes, could be verified by looking at the water quality data.

2.7.2 YSI Datasondes

The YSI 6600 Series datasonde used in this study is a multiparameter, deployable monitoring system capable of measuring and recording temperature, depth, pH, dissolved oxygen, specific conductance, turbidity, and photosynthetically active radiation. The sondes typically have up to a 75-day battery life (at 15-minute sampling intervals) and store 150,000 individual parameter readings. The sondes are 51.8 cm (20.4 in) long and have an 8.9 cm (3.5 in) diameter. The sondes are internally powered by 8 C-size, alkaline batteries. Following were the datasonde measurement methods:

Specific Conductance. The sondes utilize a cell with four nickel electrodes to measure solution conductance. Two of the electrodes are current-driven, and two are used to measure the voltage drop. The measured voltage drop is then converted into a conductance value in milli-Siemens (millimhos). The sonde reports the conductance value as specific conductance, a calculated value that corrects for the effect of temperature. The reported salinity values are also calculated values. The values are calculated from the conductivity and temperature readings according to accepted algorithms and reported as parts per thousand (ppt).

Temperature. The sondes utilize a thermistor of sintered metallic oxide that changes predictably in resistance with temperature variation. The algorithm for conversion of resistance to temperature is built into the sonde software, and accurate temperature readings in degrees Celsius, Kelvin, or Fahrenheit are provided automatically. No user calibration or maintenance of the temperature sensor is possible.

pH. The sondes employ a field-replaceable pH electrode for the determination of hydrogen ion concentration. The probe is a combination electrode consisting of a proton-selective glass reservoir filled with buffer at approximately pH 7, and an Ag/AgCl reference electrode that utilizes electrolyte that is gelled. A silver wire coated with AgCl is immersed in the buffer reservoir. Protons (H^+ ions) on both sides of the glass (media and buffer reservoir) selectively interact with the glass, setting up a potential gradient across the glass membrane.

Depth. The sondes are equipped with depth sensors, which measure depth by non-vented methods. The sensor uses a differential strain-gauge transducer to measure pressure, with one side of the transducer exposed to the water and the other side exposed to a vacuum.

Dissolved Oxygen. The sondes employ a proprietary YSI Rapid Pulse system for the measurement of dissolved oxygen (DO). The Rapid Pulse system utilizes a Clark-type sensor that is similar to other membrane-covered, steady-state, dissolved oxygen probes. The system measures the current associated with the reduction of oxygen which diffuses through a Teflon membrane. This current is proportional to the partial pressure (not the concentration) of oxygen in the solution being evaluated. The membrane isolates the electrodes necessary for this reduction from the external media, encloses the thin layer of electrolyte required for current flow, and prevents other non-gaseous, electrochemically active species from interfering with the measurement.

Turbidity. Turbidity is the measurement of the content of suspended solids (cloudiness) in water. It is typically determined by shining a light beam into the sample and then measuring the light that is scattered off the particles that are present. For turbidity systems capable of field deployment (including YSI), the usual light source is a light-emitting diode (LED) that produces radiation in the near infrared region of the spectrum. The YSI turbidity system sondes consist of a probe that conforms to ISO recommendations. The output of the sonde turbidity sensor is processed via the sonde software to provide readings in nephelometric turbidity units (NTUs).

Photosynthetically Active Radiation. Photosynthetically active radiation (PAR) is the portion of the light spectrum from 400-700 nm. PAR is used by primary producers to perform photosynthesis. As primary producers (turf, macroalgae and symbiotic algae living within sessile invertebrates) are critical to the reef community and form the basis of the food web, it is important to measure this component of light on the reef cap.

One YSI datasonde was deployed at the East Bank (23 m water depth) and one at the West Bank (27 m water depth). Sand flats were used as deployment locations to accommodate the secure attachment of the datasondes to galvanized train wheels. Water quality data were gathered every 30 min to every 1.5 hr, depending on battery life. The deployment schedule of the YSI datasondes is shown in Table 2.7.2. It is important to note that the data collected between February and May 2005 at the East and West Banks and between August and October 2005 at the West Bank were inadequate due to hardware failure.

Table 2.7.2.

Schedule of YSI water quality datasonde deployments, change outs, and retrievals at the East and West Banks in 2004 and 2005.

East Bank		West Bank	
Date	**Deployment**	**Date**	**Deployment**
03/11/04-07/15/04	1	03/11/04-07/15/04	1
07/15/04-02/25/05	2	07/15/04-11/19/04	2
02/25/05-05/11/05	3	11/19/04-02/23/05	3
05/11/05-06/08/05	4	02/23/05-05/09/05	4
06/08/05-08/27/05	5	05/09/05-06/07/05	5
08/27/05-10/12/05	6	06/07/05-08/25/05	6
10/12/05-11/02/05	7	08/25/05-10/11/05	7

2.7.3 HoboTemp Thermographs

HoboTemp recorders have an accuracy of ± 0.2°C, and resolution is 0.02°C at 25°C. A HoboTemp thermograph was attached to each of the YSI instruments as a backup recorder of water temperature. The HoboTemp recorders were therefore deployed in 23 m water depth at the East Bank and in 27 m water depth at the West Bank. Temperature was recorded every hour. The HoboTemp deployment schedule is shown in Table 2.7.3. Data were absent between November 2004 and May 2005 at the East and West Banks as a result of the loss of the Hobotemp from the YSI datasonde. Between August and October 2005 at the East Bank, the Hobotemp was lost as a result of hurricane damage. Therefore data were not recorded during this period.

Table 2.7.3.

Schedule of HoboTemp thermograph deployments, change outs, and retrievals at the East and West Banks in 2004 and 2005.

East Bank		West Bank	
Date	**Deployment**	**Date**	**Deployment**
03/11/04-07/15/04	1	03/11/04-07/15/04	1
07/15/04-11/19/04	2	07/15/04-11/19/04	2
11/19/04-2/23/05	3	11/19/04-02/23/05	3
02/23/05-05/11/05	4	02/23/05-05/07/05	4
05/11/05-06/08/05	5	05/07/05-06/07/05	5
06/08/05-08/26/05	6	06/07/05-08/25/05	6
08/26/05-10/12/05	7	08/25/05-10/11/05	7
10/12/05-11/14/05	8		

2.7.4 Chlorophyll *a* and Nutrients

Surface (< 1 m), midwater (~9 m), and near-bottom (~18 m) water samples were acquired at three different times at the East Bank and West Bank in 2004, and at five different times at the East Bank and West Bank in 2005 (Table 2.7.4). During each sampling event, water was sampled four times at each depth using a vertical sampling bottle (Wildco®). Samples were taken off the bow of the dive vessel while the vessel was moored over the monitoring site. Water samples were immediately transferred into pre-cleaned polyethylene containers (tested monthly using nanopure water) provided by an independent, EPA-certified analytical laboratory (Anacon, Inc.). Water samples were acquired to analyze for chlorophyll *a*, ammonia, nitrate, nitrite, total Kjeldahl nitrogen (TKN), and soluble reactive phosphorous. Water samples for chlorophyll *a* analyses were collected in 1000 ml containers with no preservatives. Samples for reactive soluble phosphorous were placed in 250 ml bottles with no preservatives. Samples for ammonia, nitrate, nitrite and TKN were collected in 1000 ml bottles with sulphuric acid (H_2SO_4) as a preservative. For each water sampling effort, one blind duplicate water sample was taken at one of the sampling depths on one of the banks. Within minutes of sampling, labeled containers were stored in an iced cooler at 4 °C and a chain of custody record was initiated. Once back onshore, the water samples were sent to the laboratory for analysis. Water samples were analyzed using standard USEPA methods (Table 2.7.5) to assess concentrations of chlorophyll *a* and nutrients (ammonia, nitrate and nitrite, TKN, soluble reactive phosphorous).

Table 2.7.4.

Water sampling schedule, depth, and number of samples taken at the East and West Banks in 2004 and 2005.

East Bank			West Bank		
Sampling Date	**Depth**	**Samples**	**Sampling Date**	**Depth**	**Samples**
3/11/04	Surface (< 1 m)	4	3/11/04	Surface (< 1 m)	4
3/11/04	Midwater (~ 9 m)	4	3/11/04	Midwater (~ 9 m)	4
3/11/04	Reef cap (~ 18 m)	4	3/11/04	Reef cap (~ 18 m)	4
7/16/04	Surface	4	7/15/04	Surface	4
7/16/04	Midwater	4	7/15/04	Midwater	4
7/16/04	Reef cap	4	7/15/04	Reef cap	4
9/21/04	Surface	4	11/19/04	Surface	4
9/21/04	Midwater	4	11/19/04	Midwater	4
9/21/04	Reef cap	4	11/19/04	Reef cap	4
2/23/05	Surface	4	2/23/05	Surface	4
2/23/05	Midwater	4	2/23/05	Midwater	4
2/23/05	Reef cap	4	2/23/05	Reef cap	4
5/11/05	Surface	4	5/10/05	Surface	4
5/11/05	Midwater	4	5/10/05	Midwater	4
5/11/05	Reef cap	4	5/10/05	Reef cap	4
6/8/05	Surface	4	6/7/05	Surface	4
6/8/05	Midwater	4	6/7/05	Midwater	4
6/8/05	Reef cap	4	6/7/05	Reef cap	4
8/26/05	Surface	4	8/25/05	Surface	4
8/26/05	Midwater	4	8/25/05	Midwater	4
8/26/05	Reef cap	4	8/25/05	Reef cap	4
10/12/05	Surface	4	10/11/05	Surface	4
10/12/05	Midwater	4	10/11/05	Midwater	4
10/12/05	Reef cap	4	10/11/05	Reef cap	4

Table 2.7.5.

Standard U.S. Environmental Protection Agency methods used to analyze water samples taken at the Flower Garden Banks in 2004 and 2005.

Parameter	Method	Detection Limit
Chlorophyll *a*	10200HPLC	1 mg/m^3
Ammonia	E350.3	0.03 mg/l
Nitrate	E353.3	0.15 mg/l
Nitrite	E353.2	0.15 mg/l
Total Kjeldahl nitrogen (TKN)	E351.3	0.10 mg/l
Soluble reactive phosphorous	300.0	0.40 mg/l

2.8. FISH SURVEYS

2.8.1 Methodological Rationale

Surveys of fish assemblages have been conducted at the Flower Garden Banks since at least the 1980s (Boland et al. 1983; Rezak et al. 1985; Dennis and Bright 1988; Pattengill 1998). Generally, the fish assemblage of the coral reef zone at the Flower Garden Banks is composed of Caribbean reef species; however, the total number of species is reduced and certain families such as the Lutjanidae and Haemulidae are underrepresented or absent at the banks (Jones and Clark 1981; Lukens 1981; Rezak et al. 1985). The influence of offshore gas and petroleum production platforms has been and is continuing to be investigated (Rooker et al. 1997). Continued monitoring of the Flower Garden Banks is vital to increase our understanding of this unique habitat in light of ongoing, as well as changing, natural and anthropogenic pressures on fish populations. Stationary visual fish surveys were conducted at the East Bank in September 2004 and June 2005 and at the West Bank in November 2004 and June 2005.

2.8.2 Field Methods

Fishes were visually assessed using SCUBA and a stationary visual census technique (Bohnsack and Bannerot 1986). Observations of fishes were restricted to an imaginary cylinder with a radius and height of 7.5 m from the diver. All fish species observed within the first 5 minutes of the survey were recorded. Immediately following, additional time was used to record abundance (number of individuals per species) and total length in cm (minimum, maximum, and average) of those species noted in the first five minutes. Surveys lasted from 10 to 15 minutes. When necessary, species identifications were verified using Humann (1994) and Humann and DeLoach (2002). Depth, visibility, temperature, and survey location were also recorded.

An average of 21.5 surveys each were performed at East and West Banks in 2004 and 2005. The fewest surveys (12) occurred at the East Bank in 2004. Survey dives began in the early morning, before other dive activities were started, generally between 0700 and 0900, and were repeated by two to three divers throughout the day until dusk. One or two days were spent surveying each bank and individual survey locations were spread evenly within the 100 x 100 m study site to achieve maximum coverage of the reef habitat while excluding sand patches. The visibility for all surveys was greater than 10 m and survey depths ranged from 16 to 23 m at the East Bank and 19 to 25 m at the West Bank.

2.8.3 Analysis and Statistical Methods

Fish densities were expressed as the number of fish per 100 m^2 horizontal area. For each bank and year, densities were calculated as the mean number of individuals recorded per species, with each diver survey serving as a replicate, divided by the horizontal area of the survey cylinder (176.7 m^2).

Relative abundance for each species was expressed as the percentage of the total number of times the species was recorded out of the total number of surveys for the site (bank and year). Species richness was the total number of species for each site (bank and year).

Size-frequency distributions for two trophic levels, herbivores and carnivores, were calculated as the proportions of fish belonging to that trophic level falling within different size categories (0-5 cm, 6-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, and >40 cm), based on average fish lengths recorded during the surveys. Parrotfishes (Labridae: Scarinae), surgeonfishes (Acanthuridae), and Yellowtail damselfish (*Microspathodon chrysurus*) comprised the herbivore guild, whereas snappers (Lutjanidae) and select groupers (Serranidae) comprised the demersal carnivore guild. The groupers in the carnivore guild included yellowmouth grouper (*Mycteroperca interstitialis*), tiger grouper (*M. tigris*), graysby (*Epinephelus cruentatus*), and coney (*E. fulvus*) (Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003).

Weighted means for fish lengths were calculated as follows (Zar 1984):

$$\bar{x} = \frac{\sum_{i=1}^{n} w_i \cdot x_i}{\sum_{i=1}^{n} w_i}$$

Diversity was calculated using the Shannon-Wiener diversity index and from it, species evenness for each site and year was determined. The Shannon-Wiener diversity index, H', was calculated as:

$$H' = -\sum_{i=1}^{k} p_i \log p_i$$

where k was the number of species present and p_i was the proportion (n_i/N) of the i-th species. Evenness (J') was calculated as:

$$J' = \frac{H'}{H'_{\max}}$$

where H'_{max} was the maximum possible diversity ($H'_{max} = \log k$).

To allow the valid application of parametric analyses of variance, fish abundances were $\log_{10}+1$ transformed to make them normal, homoscedastic, and additive (Zar 1984; Aronson et al. 1994; Edmunds and Carpenter 2001). Two-sample t-tests (two-tailed) were used to compare the densities and species-richness values by bank and year.

2.9 Sea Urchin and Lobster Surveys

2.9.1 Methodological Rationale

Sea urchins, specifically *Diadema antillarum*, were important herbivores on coral reefs throughout the Caribbean until 1983-1984. At that time, an unknown pathogen decimated populations throughout the region, including the Flower Garden Banks. Patchy recovery has been documented in the Caribbean (Edmunds and Carpenter 2001). *D. antillarum* populations at the Flower Garden Banks pre-1984 were near 1 individual/m^2 (Gittings et al. 1992). Lobsters are commercially important but their population dynamics at the Flower Garden Banks are not well understood.

2.9.2 Field Methods

The sea urchin *Diadema antillarum* and the spiny lobster, *Panulirus argus*, were surveyed at night, at least 1.5 hours after sundown. In 2004 and 2005, belt transects, 2 m x 100 m, were surveyed along the northern and eastern boundaries at the East Bank and along the southern and western boundaries at the West Bank, for a total of 400 m^2 surveyed at each site each year. Surveys begin with the northeast corner at the East Bank and with the southeast corner at the West Bank.

2.9.3 Statistical Methods

Due to low sample numbers, only qualitative analyses were possible for the sea urchin and lobster surveys.

3.0 RESULTS

3.1 Random Transects

Data collected in 2004 and 2005 showed persistence of the *Montastraea annularis* species complex as the dominant coral species and *Diploria strigosa* as the second most prevalent coral species (Table 3.1.1). *Porites astreoides* and *Montastraea cavernosa* were consistently the third and fourth most dominant corals (Figures 3.1.1 and 3.1.2). Macroalgal cover in 2005 was higher than previously recorded, and this was due in large part to the genus *Lobophora,* which exhibited high cover in June 2005 (Appendix 1).

Table 3.1.1.

Cover of benthic categories in random video transects at the East and West Banks in 2004 and 2005.Values are expressed as percent cover ± SE.

Cover Category	East Bank 2004	East Bank 2005	West Bank 2004	West Bank 2005
Coral				
Agaricia agaricites	0.3 ± 0.11	0.11 ± 0.07	0.29 ± 0.11	0.24 ± 0.07
Colpophyllia natans	2.81 ± 1.28	1.77 ± 1.08	3.48 ± 1.56	1.4 ± 0.54
Diploria strigosa	12.13 ± 2.82	5.95 ± 1.26	13.41 ± 1.74	6.68 ± 1.29
Madracis decactis	0.7 ± 0.32	0.88 ± 0.38	0.54 ± 0.42	0.08 ± 0.04
Millepora alcicornis	1.41 ± 0.49	1.63 ± 0.59	1.05 ± 0.51	1.68 ± 0.47
Montastraea annularis complex	30.14 ± 4.76	26.8 ± 4.09	31.70 ± 2.70	36.20 ± 3.50
Montastraea annularis	0.00	0.32 ± 0.32	1.28 ± 0.86	0.00
Montastraea cavernosa	7.73 ± 1.94	3.4 ± 1.14	3.7 ± 1.02	2.43 ± 0.69
Montastraea faveolata	10.99 ± 4.00	7.12 ± 1.40	11.61 ± 2.03	10.03 ± 2.38
Montastraea franksi	19.16 ± 4.06	19.36 ± 3.43	18.81 ± 3.21	26.18 ± 2.86
Mussa angulosa	0.03 ± 0.02	0.07 ± 0.05	0.16 ± 0.07	0.13 ± 0.08
Porites astreoides	8.19 ± 0.99	7.55 ± 1.19	5.19 ± 0.62	4.04 ± 0.46
Scolymia cubensis	0.00	0.01 ± 0.01	0.00	0.01 ± 0.01
Siderastrea siderea	0.27 ± 0.27	0.6 ± 0.38	0.00	1.1 ± 0.73
Stephanocoenia intersepta	0.33 ± 0.24	0.47 ± 0.47	0.59 ± 0.27	0.00
Unidentifiable coral	0.09 ± 0.04	0.32 ± 0.15	0.3 ± 0.11	0.45 ± 0.12
Total Coral	**64.13 ± 2.70**	**49.55 ± 3.01**	**60.41 ± 2.94**	**54.41 ± 3.13**
Sponge				
Unidentifiable sponge	0.26 ± 0.24	0.23 ± 0.08	0.24 ± 0.08	0.25 ± 0.11
Xestospongia sp.	0.06 ± 0.06	0.25 ± 0.25	0.16 ± 0.15	0.00
Total Sponge	**0.31 ± 0.24**	**0.48 ± 0.26**	**0.4 ± 0.15**	**0.25 ± 0.11**
CTB				
Crustose coralline, fine turf, bare	20.87 ± 3.08	8.68 ± 1.17	17.50 ± 1.34	15.31 ± 1.79
Crustose coralline algae	0.01 ± 0.01	3.28 ± 0.82	3.35 ±1.16	2.96 ± 0.65
Total CTB	**20.89 ± 3.08**	**11.96 ± 1.49**	**20.85 ± 2.11**	**18.27 ± 1.67**
Macroalgae				
Dictyota sp.	0.00	0.23 ± 0.14	0.00	0.00

Table 3.1.1. Cover of benthic categories in random video transects at the East and West Banks in 2004 and 2005. Values are expressed as percent cover ± SE (continued).

Cover Category	East Bank 2004	East Bank 2005	West Bank 2004	West Bank 2005
Lobophora sp.	1.86 ± 0.27	22.59 ± 2.11	1.13 ± 0.41	13.53 ± 1.64
Unidentifiable macroalgae	0.3 ± 0.15	0.07 ± 0.04	0.03 ±0.02	0.06 ± 0.03
Thick turf algae	9.87 ± 2.73	11.15 ± 1.55	13.6 ± 1.34	4.76 ± 1.16
Total Macroalgae	**12.03 ± 2.77**	**34.03 ± 2.58**	**14.75 ± 1.50**	**18.35 ± 1.44**
Total Algae	**32.91 ± 2.87**	**45.99 ± 2.89**	**35.60 ± 2.80**	**36.62 ± 2.57**
Other				
Ascidian	0.00	0.01 ± 0.01	0.00	0.01 ± 0.01
Other	0.03 ± 0.02	0.05 ± 0.02	0.00	0.03 ± 0.02
Serpulidae	0.17 ± 0.08	0.09 ± 0.04	0.04 ± 0.03	0.08 ± 0.04
Rubble	0.04 ± 0.04	0.00	0.06 ± 0.05	0.4 ± 0.4
Sand	0.13 ± 0.11	0.51 ± 0.25	1.66 ± 0.61	0.75 ± 0.49
Unknown	2.27 ± 0.57	3.32 ± 0.41	1.83 ± 0.40	7.45 ± 0.9

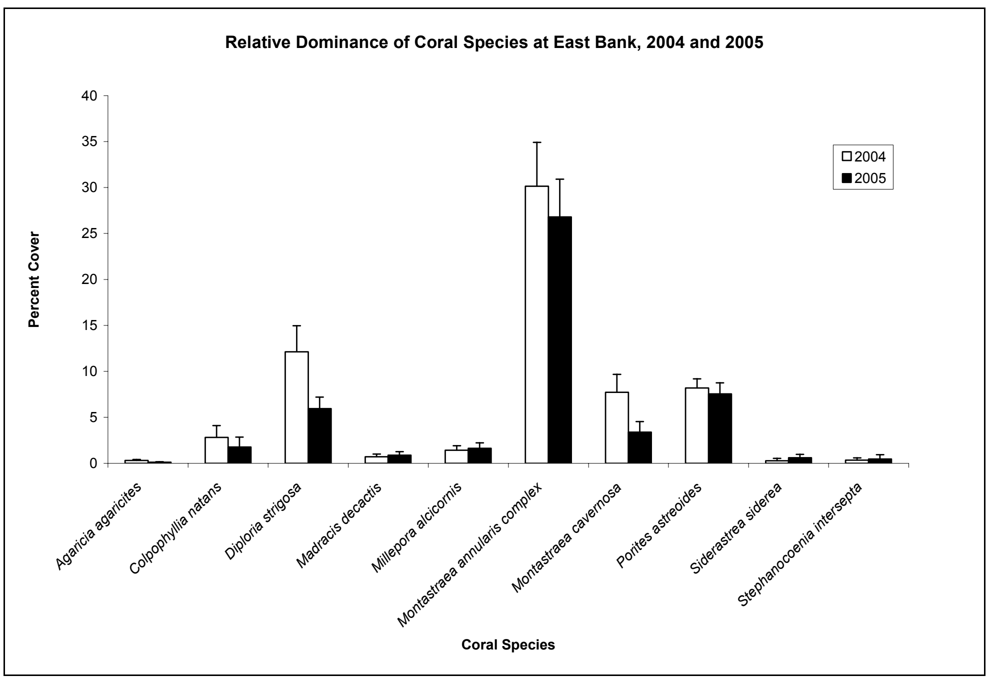


Figure 3.1.1. Relative dominance of coral species at the East Bank in 2004 and 2005, expressed as percent cover. Error bars represent 1 SE. Values are calculated from random transect videography.

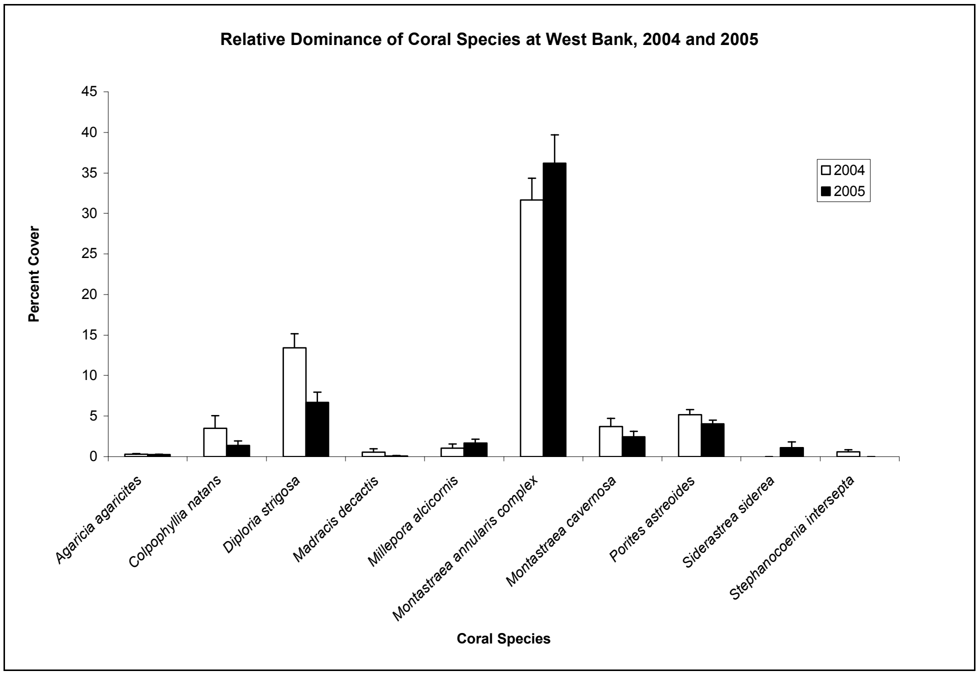


Figure 3.1.2. Relative dominance of coral species at the West Bank in 2004 and 2005, expressed as percent cover. Error bars represent 1 SE. Values are calculated from random transect videography.

The point counts from the video transects were grouped into major functional categories and expressed as percent covers (Figure 3.1.3). The univariate data were expressed as proportions and analyzed by two-way analysis of variance (ANOVA), with site (East and West Banks) and year (2002, 2003, 2004, and 2005) as fixed factors. Prior to ANOVA, the data were tested for conformity to the parametric assumptions of normality and homogeneity of variances. The Anderson-Darling test was used to test normality, and Bartlett's and Levene's tests were used to test for homogeneity of variances.

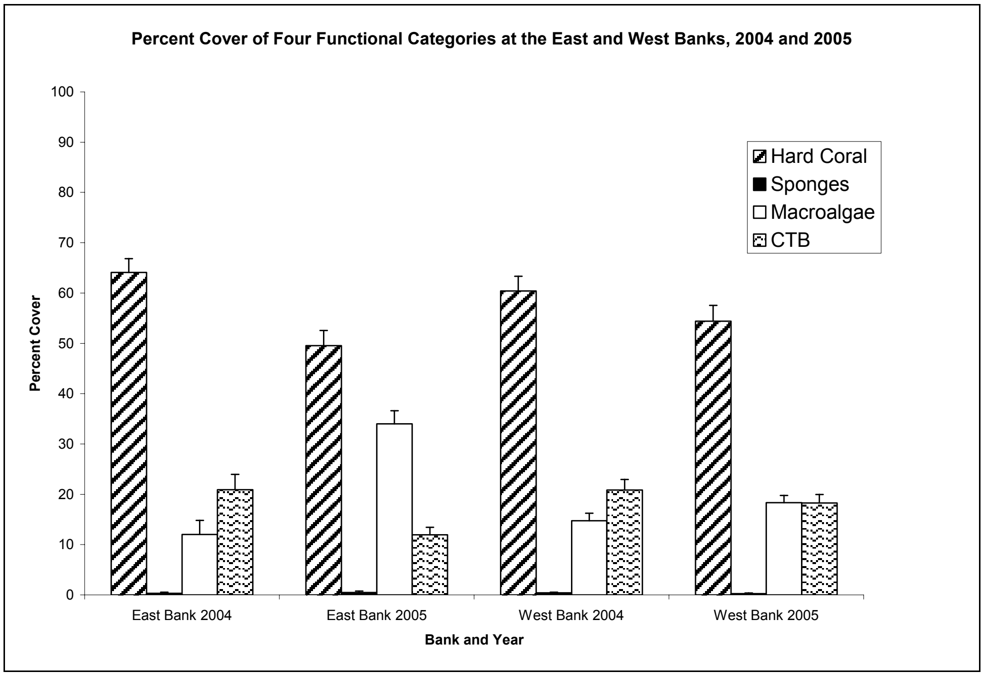


Figure 3.1.3. Percent cover (+ SE) of four functional categories of sessile benthos at the Flower Garden Banks in 2004 and 2005. Abbreviation: CTB, crustose coralline algae, fine turf algae, and bare rock. The "macroalgae" category includes thick turfs as well as fleshy macroalgal species. Values are calculated from random transect videography.

The data on proportional cover of all living hard corals (Scleractinia and Milleporina) conformed to the assumptions of parametric statistics so the data were not transformed. A two-way ANOVA showed no significant effect of site, and the site x year interaction was also not significant (Table 3.1.2A). There was, however, a significant effect of year. Tukey *a posteriori* multiple comparisons revealed no temporal trend: coral cover was significantly higher in 2004 than in 2002 and 2005, but not significantly different from 2003; and 2002, 2003 and 2005 were not significantly different from each other. ANOVA using arcsine-transformed, proportional cover data yielded essentially the same results.

The *Montastraea annularis* species complex was the most abundant coral taxon, accounting for nearly 55% of hard coral cover. The data on proportional cover of *Montastraea annularis* complex conformed to the assumptions of normality and homogeneity of variances, with the exception that one of the eight data sets (two banks in four years) violated the normality assumption. Arcsine transformation failed to correct this problem. Because ANOVA is robust to violations of the normality assumption, the ANOVA was performed on the untransformed data. A two-way ANOVA showed no significant effect of either site or year, and the site x year interaction was also not significant (Table 3.1.2B). ANOVA on the arcsine-transformed data yielded essentially the same results.

Data on the proportional cover of sponges satisfied the assumption of homogeneity of variances, but five of the eight data sets violated the normality assumption. Arcsine transformation failed to correct the normality problem, because of the large numbers of zeroes in the data sets. Again, because ANOVA is robust to violations of the normality assumption, the ANOVA was performed on the untransformed data. A two-way ANOVA showed no significant effect of site, but there was a significant effect of year (Table 3.1.2C). There was no significant site x year interaction. Tukey tests revealed that sponge cover in 2002 and 2003 was significantly higher than in 2004. Sponge cover in 2005 was not significantly different from cover in 2002 and 2003, and also not significantly different from cover in 2004. The extremely low values measured for sponge cover (Figure 3.1.3) render the decline during 2004–2005 ecologically insignificant. ANOVA on the arcsine-transformed data yielded essentially the same results.

The data on proportional cover of macroalgae were normally distributed, with the exception of two of the eight data sets. In addition, the variances were not homogeneous. Arcsine transformation corrected both of these problems. A two-way ANOVA revealed a highly significant site x year interaction (Table 3.1.2D). That interaction is clearly visible in Figure 3.1.3: macroalgal cover increased at the East and West Banks from 2004 to 2005. The significant interaction makes it difficult to interpret the significant effects of site and year. Separate one-way ANOVAs were performed on the arcsine transformed data to compare years within sites. These tests yielded significant effects of year for both the East Bank ($F=61.69$, $df=3,53$, $P<0.001$) and the West Bank ($F=24.54$, $df=3,55$, $P<0.001$). Tukey tests showed a large and significant increase in macroalgal cover at both Banks from 2004 to 2005. This increase was due to the increase in cover of *Lobophora* sp. (Table 3.1.1) from 2004 to 2005. It is likely that season may play a role for the difference in abundance from 2004 (fall monitoring) to 2005 (summer monitoring).

The fourth univariate cover category that was analyzed combined crustose coralline algae, fine algal turfs and bare rock (abbreviated CTB). These components are difficult to distinguish visually in the field, and they are equally if not more problematic in still photographs and video transects. All three connote high levels of physical disturbance and/or herbivory, and so it is reasonable to combine them (Aronson and Precht 2000). Only one of the eight data sets departed from normality. Both tests for homogeneity of variances gave marginally non-significant results (Bartlett's test: $P=0.062$; Levene's test: $P=0.073$). Arcsine transformation corrected the normality problem and homogenized the variances (Bartlett's test: $P=0.249$; Levene's test: $P=0.188$). A two-way ANOVA revealed a significant site x year interaction (Table 3.1.2E) and a significant effect of year. Separate one-way ANOVAs were performed on the arcsine transformed data to compare years within sites. These tests yielded significant effects of year for both the East Bank ($F=21.31$, $df=3,53$, $P<0.001$) and the West Bank ($F=6.06$, $df=3,55$, $P<0.001$). Tukey tests showed a large and significant decline in the cover of CTB on the East Bank from 2004 to 2005, and a non-significant decline at the West Bank during the same period. These trends were opposite the trends for macroalgal cover.

Finally, the Shannon-Wiener diversity index, H', was calculated from the species-specific coral cover data from each transect. Mean H' ranged from a low 1.35 at the West Bank in 2003 to a high 1.52 at the West Bank in 2004. The data conformed to the assumptions of normality and homogeneity of variances, with the exception of one data set that departed from normality. A two-way ANOVA on the untransformed data showed no significant effect of either site or year, and the site x year interaction was also not significant (Table 3.1.2F).

In summary, mean coral cover exceeded ~ 50% at the two banks in all four years. These values are consistent with measurements of coral cover at the Flower Garden Banks in previous years (Dokken et al. 2003, Precht et al. 2006) and they are high compared to other western Atlantic reefs (e.g., Aronson et al. 1994; Gardner et al. 2003). CTB was the next most abundant category in terms of cover, except at the East Bank in 2005, indicating high levels of herbivory and a generally healthy reef ecosystem. Macroalgal cover and the cover of CTB fluctuated in a reciprocal fashion, as expected from our preliminary results from 2002–2003 (Precht et al. 2006) and previous work in the Caribbean (Aronson and Precht 2000). The cover of sponges was extremely low (Table 3.1.1).

Table 3.1.2.

Results of two-way ANOVAs on proportional cover estimates and H' from the random video transects.

A. Hard Corals (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0008	1	0.0008	0.06	0.815
Year	0.2017	3	0.0672	4.98	0.003
Site*Year	0.0812	3	0.0271	2.01	0.117
Error	1.4572	108	0.0135		
Total	1.7409	115			
B. *Montastraea annularis* species complex (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0327	1	0.0327	1.59	0.210
Year	0.0027	3	0.0008	0.04	0.988
Site*Year	0.0589	3	0.0196	0.95	0.418
Error	2.2223	108	0.2058		
Total	2.3166	115			
C. Sponges (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.000003	1	0.000003	0.02	0.891
Year	0.0030	3	0.0010	6.57	<0.001
Site*Year	0.0002	3	0.0001	0.46	0.710
Error	0.0165	108	0.0002		
Total	0.0197	115			
D. Macroalgae (arcsine transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.1658	1	0.1658	18.94	<0.001
Year	1.6237	3	0.5412	61.83	<0.001
Site*Year	0.5364	3	0.1788	20.43	<0.001

Table 3.1.2. Results of two-way ANOVAs on proportional cover estimates and H’ from the random video transects (continued).

D. Macroalgae (arcsine transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Error	0.9454	108	0.0088		
Total	3.2713	115			
E. CTB (arcsine transformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.0019	1	0.0019	0.15	0.696
Year	0.8431	3	0.2810	22.61	<0.001
Site*Year	0.1425	3	0.0475	3.82	0.012
Error	1.3422	108	0.0124		
Total	2.3297	115			
F. Shannon-Wiener Diversity, H' (untransformed)					
Source	**Sum of Squares**	**df**	**Mean Square**	**F-ratio**	***P* value**
Site	0.2200	1	0.2200	2.54	0.114
Year	0.0868	3	0.0290	0.33	0.801
Site*Year	0.4288	3	0.1429	1.65	0.182
Error	9.3609	108	0.0867		
Total	10.0965	115			

3.2 SCLEROCHRONOLOGY

Eight cores were taken from separate *Montastraea faveolata* colonies at both the East Bank (4 cores) and the West Bank (4 cores) in June 2005. Cores were longitudinally sectioned to reveal accretionary growth bands. Growth increments were measured for the years 1997-2005 at the East Bank and from 1992-2005 at the West Bank. See Appendix 2 for growth rates of the 2003 and 2005 cores.

3.2.1 East Bank Cores

Estimated annual growth at the East Bank ranged from 3.19-14.54 mm/yr from 1997-2005, with an overall mean of 6.06 ± 1.2 SE mm. The highest mean growth rate occurred in 2004 (Table 3.2.1). Numerous cores showed mortality scars around 1999 and regrowth sometime thereafter (Figure 3.2.3). It is important to note that the black cells in Table 3.2.1. represent a disconformity in accretionary growth.

Table 3.2.1.

Mean annual growth (mm) of four *Montastraea faveolata* colonies each from the East and West Banks, June 2005.

	East Bank						West Bank					
Year	**C1**	**C2**	**C3**	**C4**	**Mean**	**SE**	**C1**	**C2**	**C3**	**C4**	**Mean**	**SE**
2005	5.94	3.36	6.54	8.69	6.13	1.10	7.31	2.75	4.13	5.43	4.91	0.97
2004	7.31	3.78	7.39	14.54	8.26	2.26	8.78	3.18	6.63	6.11	6.18	1.15
2003	7.05	3.62	8.25		6.31	1.39	6.79	5.24	6.02	4.99	5.76	0.41
2002	7.83	5.42			6.63	1.21	6.97	6.11	5.85	6.98	6.48	0.29
2001	8.94	6.11			7.53	1.42		5.84	6.46	2.84	5.05	1.12
2000		5.16			5.16			4.99	5.33	3.53	4.62	0.55
1999		3.19			3.19			3.78	5.00	3.96	4.25	0.38
1998		6.97			6.97			6.20	6.19	2.24	4.88	1.32
1997		4.39			4.39			6.11		7.75	6.93	0.82
1996								6.45		6.89	6.67	0.22
1995								5.94		6.29	6.12	0.18
1994								6.02		3.10	4.56	1.46
1993										3.70		
1992										7.66		

3.2.2 West Bank Cores

Estimated annual growth at the West Bank ranged from 2.75-8.78 mm/yr from 1992-2005, with an overall mean of 5.53 ± 1.3 SE mm. The highest mean growth rate occurred in 1997 and the lowest in 1999 (Table 3.2.1). As at the East Bank, some cores showed partial mortality in 1999 and subsequent recovery in later years (Figure 3.2.3).

3.2.3 Analysis

Mean growth rates were calculated for each core and a Student's t-test was performed to compare growth rates between the East and West Banks from 1992-2005. The mean growth rates were not significantly different between the East Bank and the West Bank ($t=0.96$, $df=19$, $P=0.35$).

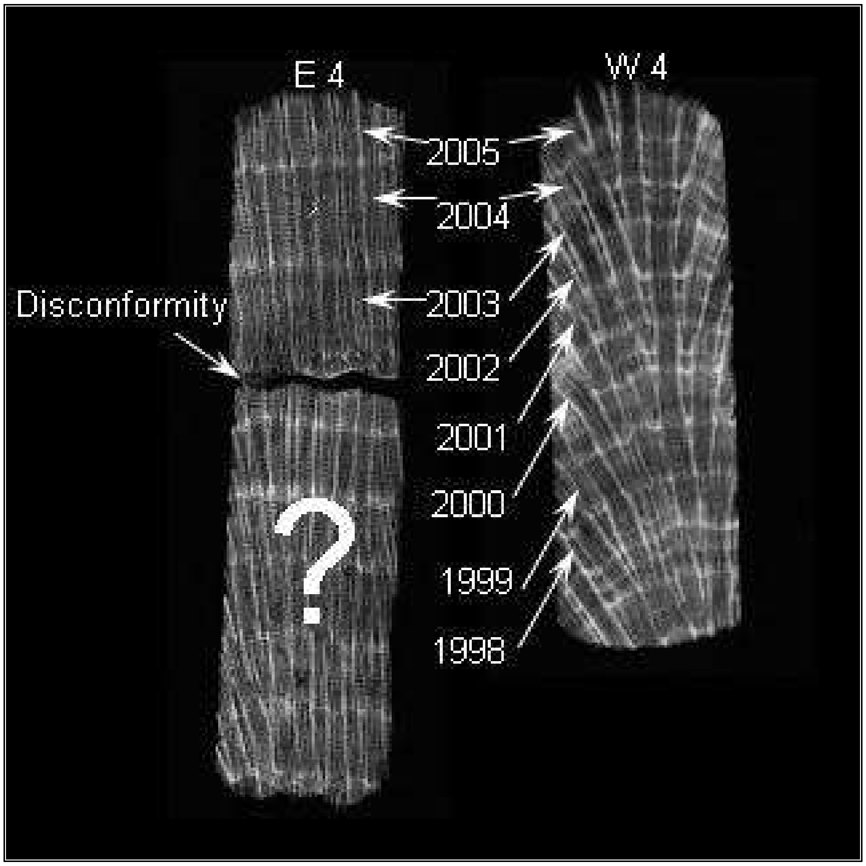


Figure 3.2.3. X-ray images of *Montastraea faveolata* cores from East (left) and West (right) Banks showing a disconformity (arrow) in accretionary growth sometime in 2002-2003.

3.3 Lateral Growth

The data were examined for conformity to the normality and homogeneity-of-variances assumptions of parametric statistics using the Anderson-Darling and Levene's tests, respectively. The raw data violated the assumption of normality for all combinations of Bank and Interval except the 2004-2005 data for the East Bank (for which the Anderson-Darling test gave $P=0.89$; $P<0.05$ in all other cases). The variances of the raw data were homogeneous (Levene's test, $P=0.262$). Because some of the colonies more than doubled in area during an interval, some of the proportional changes were greater than 1. As a result, the arcsine transformation could not be employed. The only transformation that conformed the data reasonably well to the assumptions of parametric statistics was $\{y = 1/(x+1)\}$. Even so, Anderson-Darling tests revealed that the transformed 2004-2005 data from the West Bank were not normally distributed ($P=0.008$). The data sets representing the three other combinations of Bank and Interval were normally distributed ($P>0.19$ in all cases). Levene's test showed that the variances of the four Bank-Interval combinations were homogeneous ($P=0.25$). Because ANOVA is robust to departures from normality, the non-normality of one cell was not considered a serious impediment to the analysis.

When pooling the data for the two Banks, colony area increased by 32% on average in 2003-2004 and 14% in 2004-2005. The repeated-measures ANOVA was designed as follows: Bank was a fixed factor, with *Diploria* stations (the blocks) nested within Banks. Interval was also fixed factor. Table 3.3.1 indicates a significant effect of both Bank, with overall growth at the West Bank greater than overall growth at the East Bank, and Interval, with overall growth in 2003-2004 having been greater than overall growth in 2004-2005. There was no significant effect of station, nor was there a significant interaction between Bank and Interval.

Paired t-tests were used to compare Intervals within Banks. For the West Bank, there was no significant difference between the two intervals (t=0.66, df=20, P=0.514). For the East Bank, growth was significantly greater in 2003-2004 than in 2004-2005 (t=2.63, df=23, P=0.015). In fact, the mean effect on the East Bank in 2004-2005 was negative growth (i.e., shrinkage; Figure 3.3.1). In addition, two-sample t-tests were used to compare Banks within Intervals. For 2003-2004, there was no significant difference in growth between the Banks (t=0.86, df=43, P=0.395), whereas in 2004-2005 growth was significantly greater on the West Bank than on the East Bank (t=2.64, df=43, P=0.011; Figure 3.3.1).

In summary, growth was variable, but net growth was positive over both years. Growth was higher on the West Bank, and it was higher in 2003-2004. The *Diploria strigosa* colonies as a group appear to be holding steady or increasing in size. See Appendix 3 for 2003 - 2005 lateral growth data.

Table 3.3.1.

Results of repeated-measures ANOVA on proportional change in areas of *Diploria* colonies, comparing the East and West Banks during the intervals 2003-2004 and 2004-2005. Data were transformed to 1/(x+1).

Source	df	SS	MS	F	P
Bank	1	0.4826	0.4826	10.12	0.003
Station(Bank)	42	1.9655	0.0468	0.37	0.999
Interval	1	0.5326	0.5326	4.26	0.045
Bank*Interval	1	0.1043	0.1043	0.83	0.366
Error	44	5.5007	0.1250		
Total	89	8.6322			

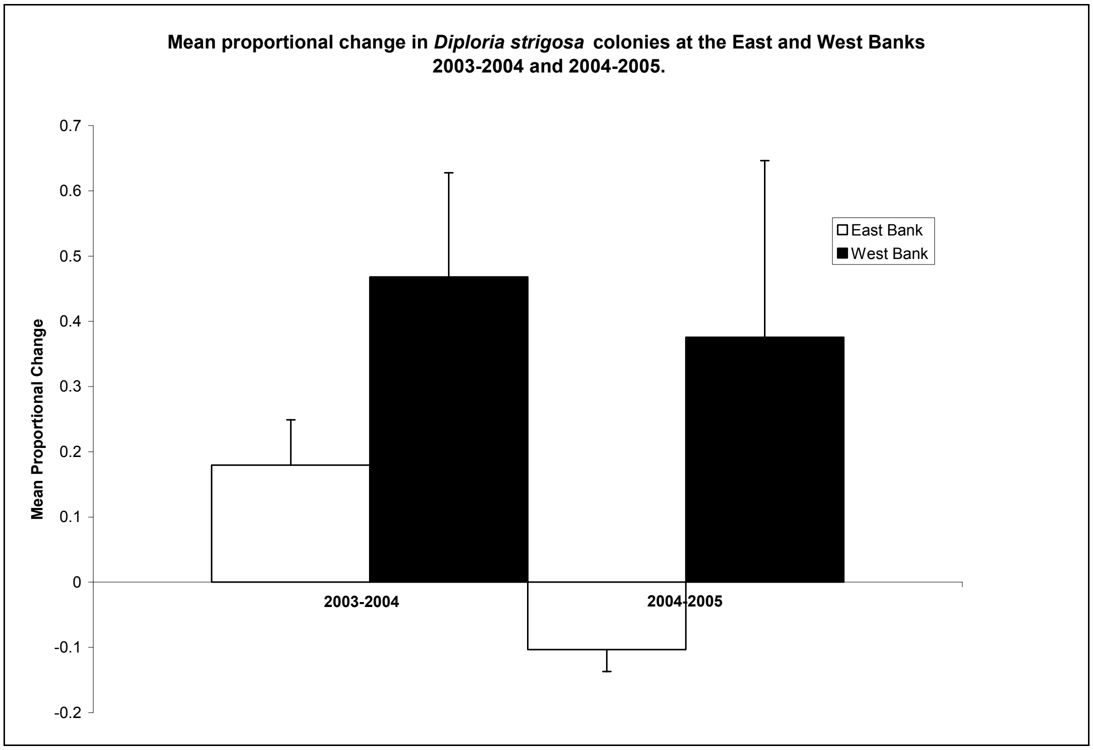


Figure 3.3.1. Mean proportional change in area of *Diploria strigosa* colonies, comparing the East and West Banks during the intervals 2003-2004 and 2004-2005. Error bars represent standard errors. Figure is based on untransformed data.

3.4. Repetitive Quadrats

3.4.1 Repetitive Quadrat Analysis

For percent cover data, a total of 58 quadrats were analyzed for 2004: 38 from the East Bank and 20 from the West Bank. A total of 61 quadrats were analyzed for 2005: 41 from the East Bank and 20 from the West Bank. In both 2004 and 2005 coral cover was high (Figure 3.4.1 and Figure 3.4.2). Macroalgae and CTB showed reciprocal patterns at both banks: macroalgae increased from 2004 to 2005, while CTB decreased during the same period. The incidences of bleaching, paling, and mortality from fish bites were low (Table 3.4.2). The coral assemblage remained stable at both banks in both years with dominant corals being the *Montastraea annularis* species complex, *Diploria strigosa* and *M. cavernosa* (Figures 3.4.3 and 3.4.4).

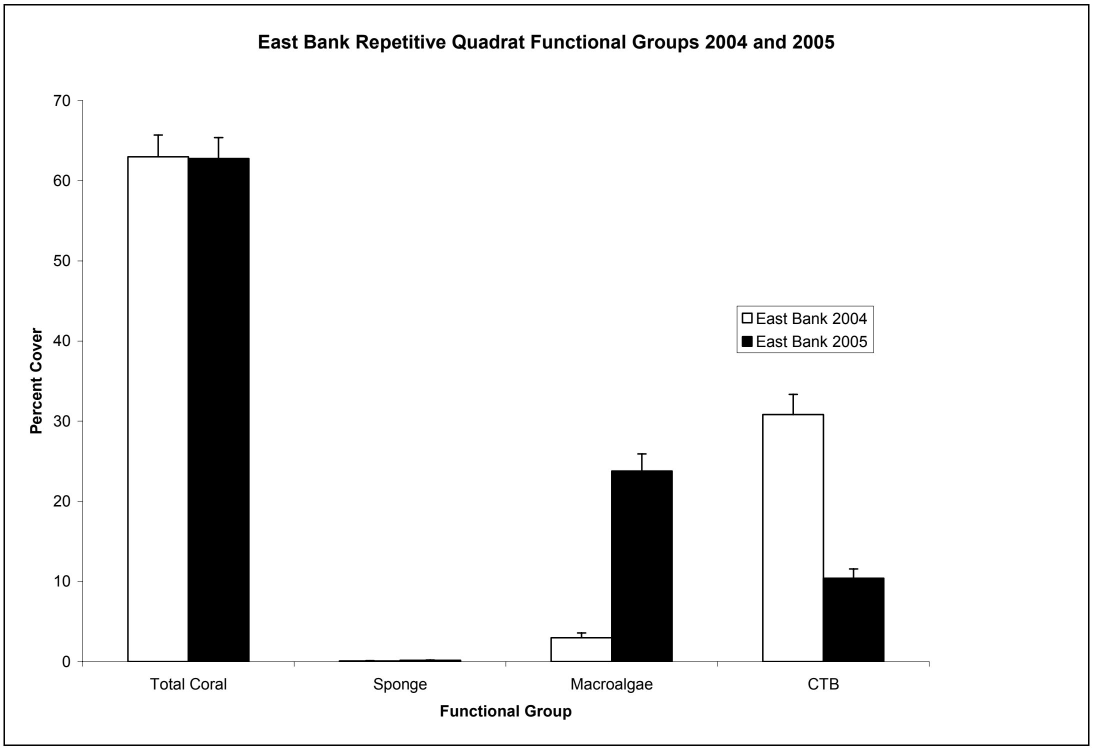


Figure 3.4.1. Four functional groups in the East Bank repetitive quadrats in 2004 and 2005. Abbreviation: CTB - crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turfs as well as fleshy macroalgae.

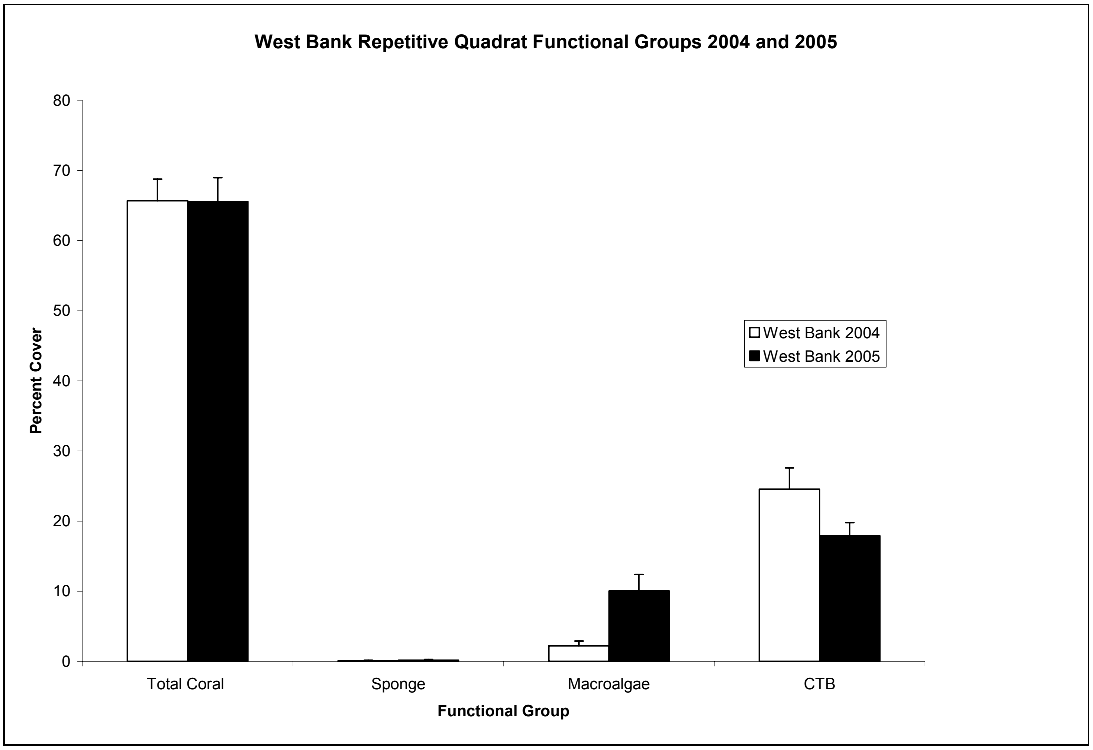


Figure 3.4.2. Four functional groups in the West Bank repetitive quadrats in 2004 and 2005. Abbreviation: CTB - crustose coralline algae, fine turf algae, and bare rock. Macroalgae includes thick turfs as well as fleshy macroalgae.

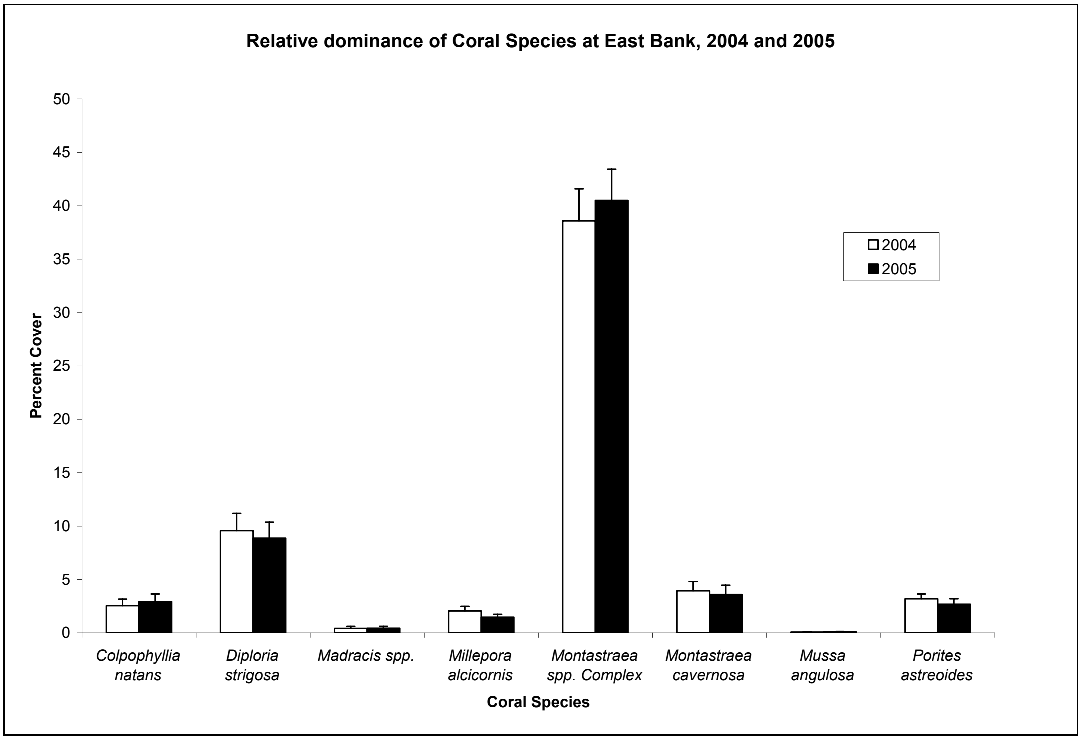


Figure 3.4.3. Relative dominance of coral taxa at the East Bank in 8 m^2 repetitive quadrats, expressed as percent cover + SE.

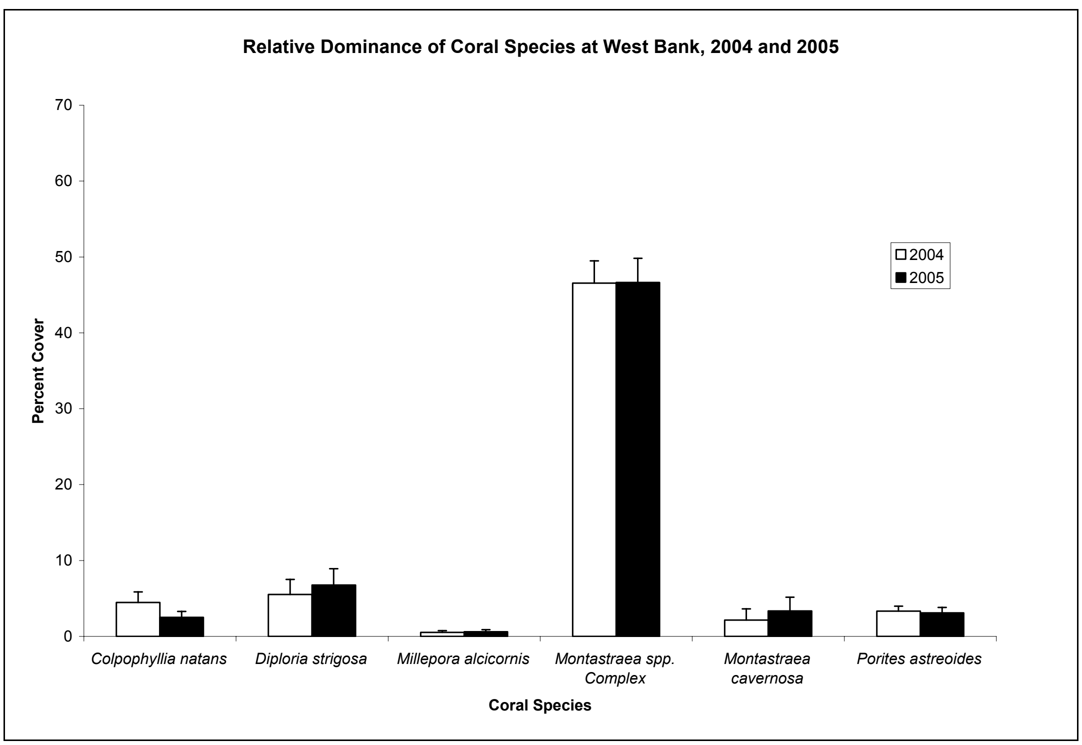


Figure 3.4.4. Relative dominance of coral species at the West Bank in 8 m^2 repetitive quadrats, expressed as percent cover + SE.

Coral disease was absent from the analyzed photographs at both banks in both years (Table 3.4.1); however, the identification of disease in photographs is not reliable because of the 2 m distance from the substrate (B. Zimmer, personal observation). Paling and bleaching were extremely low at both banks, ranging from 0-0.57% (Table 3.4.1). Concentrated fish biting and isolated fish biting were similarly low at each bank, ranging from 0.30-4.73% in both years (Table 3.4.1). Bleaching occurred most frequently on colonies of *Millepora alcicornis* at the East Bank in 2005 (Table 3.4.2). Paling was more frequent at the East Bank, mainly occurring on *Diploria strigosa* and *Montastraea annularis* complex. Fish biting occurred primarily on the *M. annularis* complex and appeared to be more common at the East Bank in both years (Table 3.4.2).

Table 3.4.1.

Percent paling, bleaching, concentrated fish biting, isolated fish biting, and disease (± SE), in 8 m^2 repetitive quadrats at the East and West Banks, 2004 and 2005.

Observation	East Bank 2004	East Bank 2005	West Bank 2004	West Bank 2005
Paling	0.2 ± 0.07	0.18 ± 0.06	0.06 ± 0.05	0.00
Bleaching	0.32 ± 0.08	0.57 ± 0.18	0.09 ± 0.07	0.03 ± 0.03
Concentrated Fish Biting	0.30 ± 0.12	0.31 ± 0.10	0.46 ± 0.22	0.65 ± 0.19
Isolated Fish Biting	2.72 ± 1.09	4.73 ± 1.40	0.77 ± 0.29	1.49 ± 0.53
Disease	0.00	0.00	0.00	0.00

Table 3.4.2.

Percent cover of isolated fish biting, concentrated fish biting, paling, and bleaching at the East and West Banks, 2004 and 2005. IFB= isolated fish biting, CFB= concentrated fish biting, P= paling, BL= bleaching, East Bank 2004 (n=6025) and 2005 (n= 6497), West Bank 2004 (n=3236) and 2005 (n = 3218) (random dot analysis). n = number of coral points within repetitive quadrats.

Observation	East Bank 2004				East Bank 2005				West Bank 2004				West Bank 2005			
	IFB	CFB	P	BL	IFB	CFB	P	BL	IFB	CFB	P	BL	IFB	CFB	P	BL
Colpophyllia natans	0.02	0.00	0.02	0.00	0.00	0.02	0.02	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coral (general)	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.05	0.03	0.06	0.00	0.00	0.00	0.00	0.00	0.00
Diploria strigosa	0.08	0.00	0.07	0.08	0.20	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00
Madracis decactis	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
Millepora alcicornis	0.00	0.00	0.00	0.13	0.03	0.00	0.00	0.43	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.03
Montastraea annularis complex	2.57	0.28	0.07	0.02	4.43	0.28	0.06	0.06	0.71	0.37	0.06	0.00	1.43	0.59	0.00	0.00
Montastraea annularis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.09	0.16	0.00	0.00
Montastraea cavernosa	0.02	0.00	0.03	0.00	0.05	0.02	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Montastraea faveolata	2.27	0.17	0.05	0.00	3.99	0.26	0.02	0.00	0.34	0.06	0.00	0.00	0.59	0.06	0.00	0.00
Montastraea franksi	0.30	0.12	0.02	0.02	0.45	0.02	0.05	0.06	0.31	0.31	0.06	0.00	0.75	0.37	0.00	0.00
Mussa angulosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Porites astreoides	0.02	0.02	0.02	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	**2.71**	**0.30**	**0.20**	**0.32**	**4.73**	**0.31**	**0.18**	**0.57**	**0.77**	**0.46**	**0.06**	**0.09**	**1.49**	**0.65**	**0.00**	**0.03**

3.4.2 Repetitive Quadrats Planimetry Analysis

Because *Montastraea annularis* species complex, *Diploria strigosa*, and *Colpophyllia natans* are dominant frame-building corals in the repetitive quadrats, we compared the change in cover of these taxa over the period 2003-2004 and 2004–2005 between banks (Figure 3.4.5; Appendix 4). For each repetitively-photographed quadrat, we calculated the average proportional change in planar area for the colonies that were measured. This procedure yielded 38 quadrats from the East Bank and 23 quadrats from the West Bank for 2003-2004. Thirty six quadrats from the East Bank and 20 quadrats from the West Bank were measured for 2004-2005.

The Anderson-Darling test showed that the data from the West Bank conformed to the normality assumption ($P=0.509$), but the data from the East Bank violated the normality assumption ($P<0.005$). Levene's test showed that the variances for the two banks were homogeneous ($P=0.860$). The normality problem could not be corrected by the arcsine transformation or other transformation. A one-way analysis of covariance (ANCOVA) was run on the untransformed proportional data, with Bank (East and West) as the fixed factor and average initial length (average largest horizontal dimension) of the *Montastraea* colonies in the quadrat as the covariate. The rationale for including the covariate was that a given absolute amount of growth represents a lower proportional increase of a larger colony (or a larger group of colonies) than a smaller colony (or group of colonies). The results (Table 3.4.3) showed no significant effect of either Bank or the covariate (Table 3.4.3). Therefore, the covariate was eliminated from the analysis. A two-sample t-test detected no significant difference between banks from 2003 to 2004 ($t=0.25$, $df=127$, $P=0.8$); or from 2004-2005 between banks ($t=1.45$, $df=46$, $P=0.154$). Likewise, the less powerful, non-parametric Mann-Whitney U-test, adjusted for ties, detected no significant difference between the banks ($W=821.5$, $P=0.185$).

The two banks display similar patterns with respect to change in the cover of colonies of *Montastraea annularis* species complex. The cover of *Montastraea* in the quadrats decreased at both banks from 2003 to 2004 and increased at both banks from 2004 to 2005, for a net increase over the three years at both banks (Figure 3.4.5).

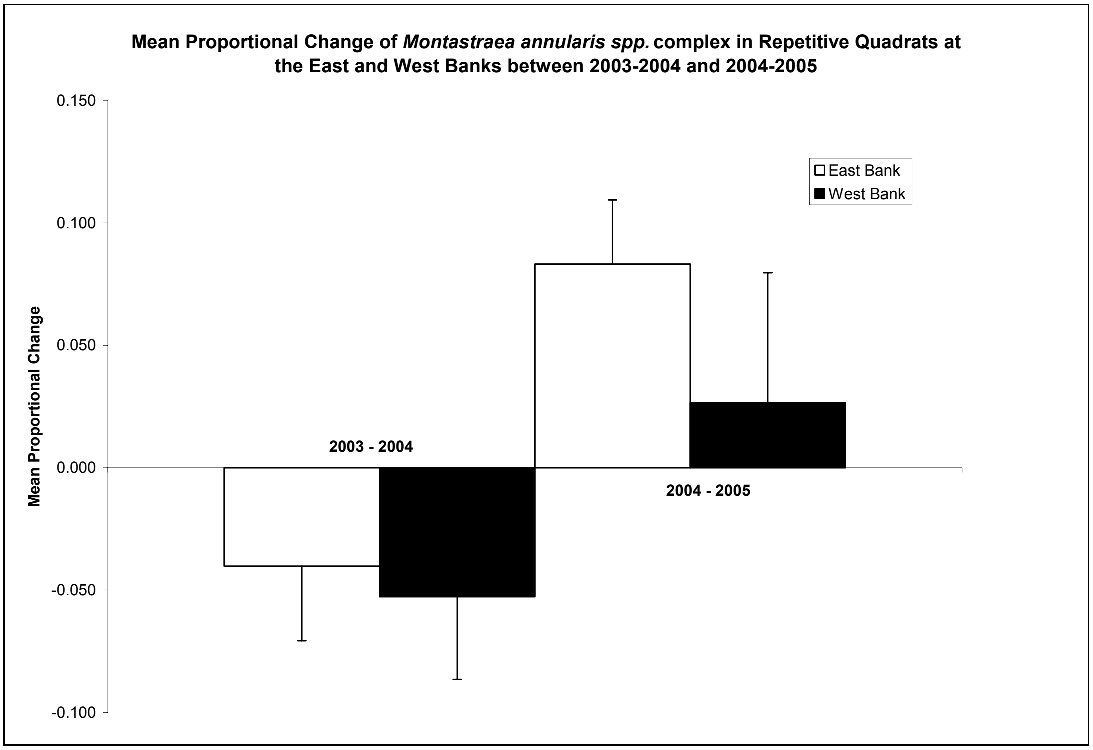


Figure 3.4.5. Mean proportional change + SE in *Montastraea annularis* species complex at the East and West Banks between 2003-2004 and 2004-2005.

Table 3.4.3.

Results of ANOVA on proportional change in planar area of colonies of *Montastraea annularis* species complex in the repetitive quadrats.

Source	**Sum of Squares**	***df***	**Mean Square**	***F*-ratio**	***P*-value**
Bank	0.0874	1	0.0874	2.18	0.147
Mean Initial Size	0.021	1	0.0211	0.53	0.472
Error	1.8075	45	0.0402		
Total	1.916	47			

3.4.3 Deep Repetitive Quadrat Analysis

The deep stations were analyzed for benthic cover type using random dot analysis (Figure 3.4.6). Coral cover was high at the deep stations, while algal cover consisted mostly of CTB. The *Montastraea annularis* species complex was consolidated for analysis and was the predominant coral group in addition to *M. cavernosa* (Figure 3.4.7). An example of a deep station repetitive quadrat is shown in Figure 3.4.8.

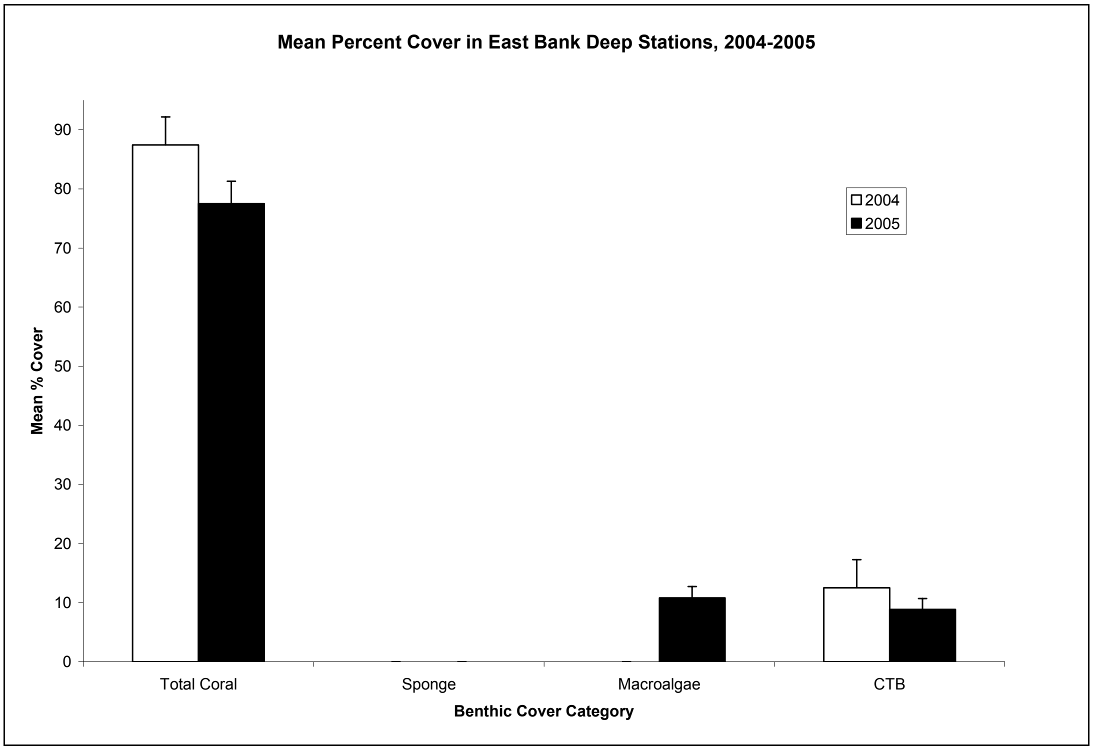


Figure 3.4.6. Percent cover (+ SE) data for four benthic categories in the East Bank deep repetitive quadrats in 2004 and 2005. Abbreviation: CTB - crustose coralline algae, fine turf algae, and bare rock. Macroalgae contains thick turf algae as well as macroalgal species.

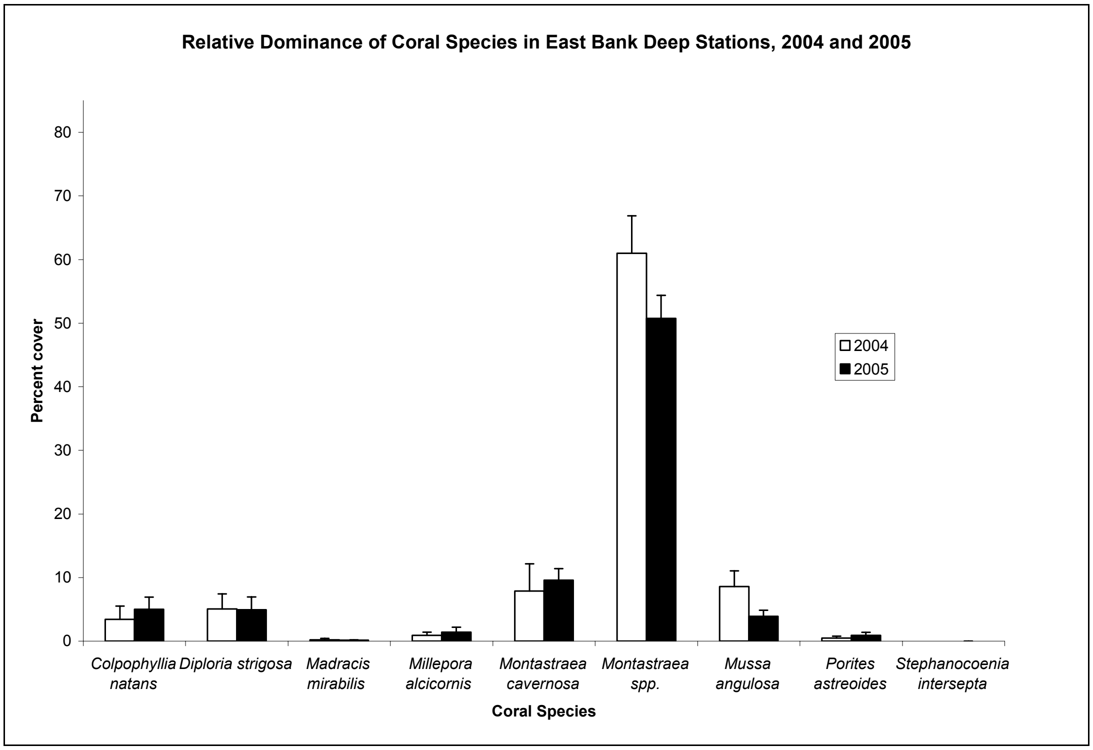


Figure 3.4.7. Relative dominance (+ SE) of coral species in the East Bank deep repetitive quadrats in 2004 and 2005. Abbreviation: CTB - crustose coralline algae, fine turf algae, and bare rock. Macroalgae contains thick turf algae as well as macroalgal species.

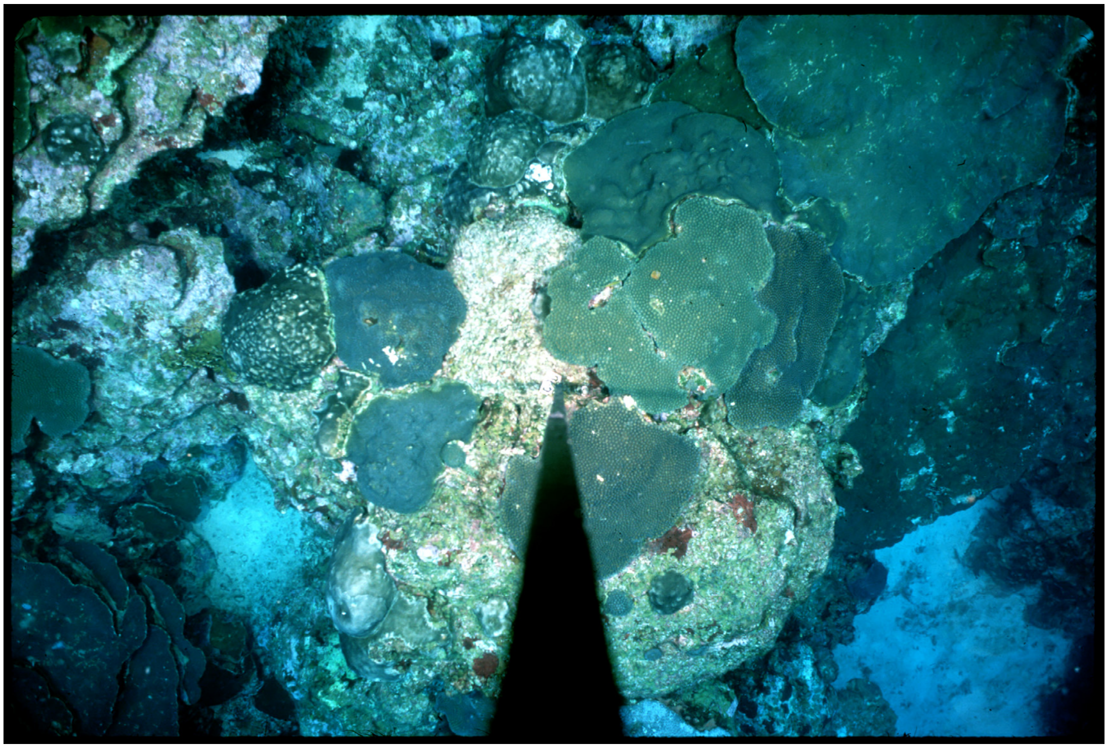


Figure 3.4.8. Deep repetitive 8 m^2 quadrat at the East Bank in June 2005.

3.4.4 Deep Repetitive Quadrat Planimetry Analysis

Because the *Montastraea annularis* species complex was the dominant substrate occupant in the deep station repetitive quadrats, we compared the change in cover of this taxon over the periods 2003-2004 and 2004-2005 at the East Bank (Figure 3.4.9). For each repetitively-photographed quadrat that contained one or more colonies of *M. annularis* species complex, we calculated the average proportional change in planar area for the colonies that were measured. This procedure yielded eight quadrats between 2003 and 2004 (only eight deep-station photographs were taken in 2003) and nine between 2004 and 2005.

A t-test assuming equal variance was used to compare lateral growth, as calculated through planimetry, of *Montastraea annularis* complex colonies from deep repetitive quadrats (Figure 3.4.9). There was no significant difference between the 2003-2004 and 2004-2005 lateral growth measurements ($t=1.2$, $df=31$, $P=0.23$).

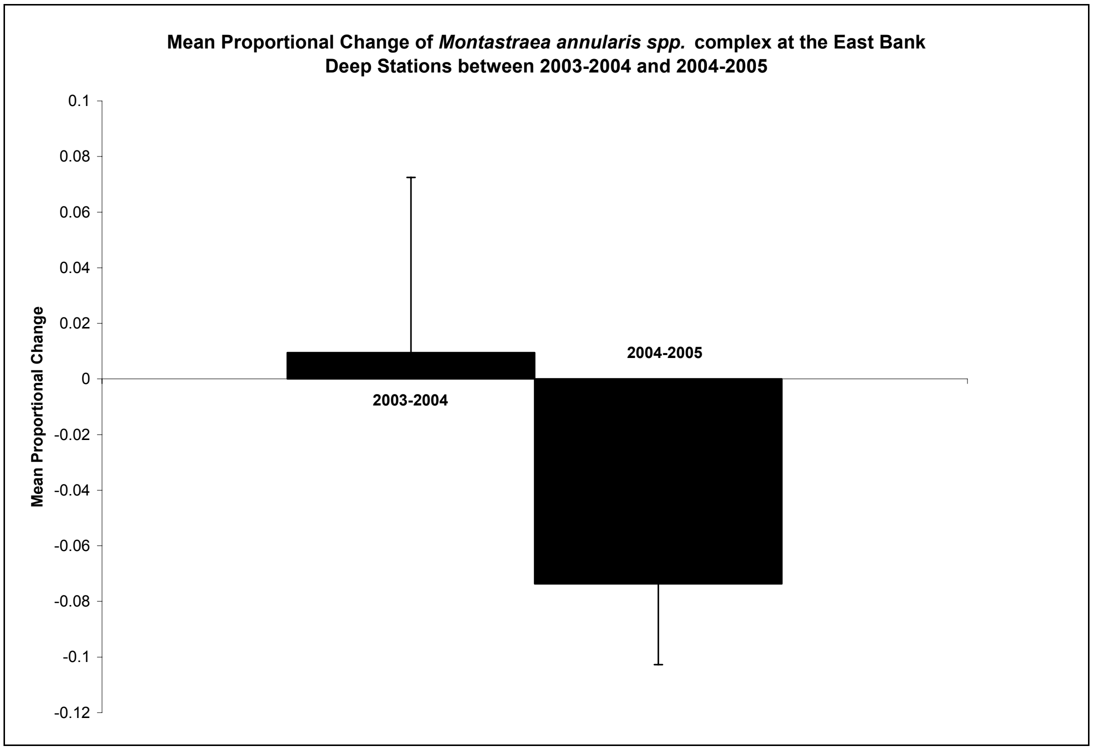


Figure 3.4.9. Mean proportional change + SE in *Montastraea annularis* species complex at East Bank deep stations, 2003-2004 and 2004-2005.

3.5. Perimeter Videography

Overall, the coral condition and fish population levels along the perimeters of the East and West Bank in 2004 and 2005 were comparable to past video perimeter lines. These areas displayed low levels of stress and high coral cover, and they were comparable to random transect footage, although no statistical comparisons were made. Most distressed corals were affected by fish biting, with fewer incidences of paling and bleaching. These results reflect the pattern found in the repetitive quadrat data. Furthermore, no evidence of disease was observed at either bank during 2004 or 2005, although, as mentioned above, disease is difficult to identify in photographic analysis. No other invertebrates were observed along the perimeter of either bank.

3.5.1 East Bank Perimeter Lines

At the East Bank in 2004, no incidences of disease were documented. Isolated fish biting (typical of damselfish) occurred on 11 colonies, followed by concentrated fish biting of 8 colonies (most likely due to the parrotfish), paling of 4 colonies, and bleaching of 2 colonies. *Montastraea faveolata* and *M. franksi* were the most impacted coral species (Table 3.5.1). The most abundant fish were the Creole wrasse, Creole fish, and damselfish (Table 3.5.2).

In 2005, no incidences of disease were observed at the East Bank. Stresses included isolated fish biting (13 colonies), concentrated fish biting (8 colonies), paling (2 colonies), and bleaching (2 colonies) (Table 3.5.1). In 2005, Brown chromis, damselfish, and the Bluehead wrasse were most abundant (Table 3.5.2).

Table 3.5.1.

Comparison of observations of the condition of coral colonies at the East Bank along perimeter lines and 360º panoramic views between 2004 (n≈660) and 2005 (n≈730). (CFB= Concentrated fish biting, IFB= Isolated fish biting, B= Bleaching, P= Paling, H= Healthy colony, ICFB= Increased tissue loss due to concentrated fish biting, IIFB= Increased tissue loss due to isolated fish biting, GI= Growth infilling [tissue regrowth], U= Unchanged condition, T= Surface replaced by turf algae, NP= not photographed).

Number of Colonies	Coral Species	East Bank 2004	East Bank 2005
1	*Colpophyllia natans*	B	H
1	*Colpophyllia natans*	P	H
2	*Diploria strigosa*	H	IFB
1	*Diploria strigosa*	CFB	T
1	*Diploria strigosa*	CFB	U
1	*Diploria strigosa*	P	U
1	*Diploria strigosa*	IFB	T
1	*Diploria strigosa*	P	H
1	*Montastraea annularis*	IFB	U
3	*Montastraea annularis*	IFB	IIFB
1	*Montastraea cavernosa*	IFB	IIFB
1	*Montastraea cavernosa*	H	IFB
2	*Montastraea faveolata*	CFB	NP
1	*Montastraea faveolata*	CFB	T
1	*Montastraea faveolata*	H	IFB
1	*Montastraea faveolata*	IFB	IIFB
1	*Montastraea faveolata*	H	P
1	*Montastraea faveolata*	CFB	GIF
1	*Montastraea faveolata*	IFB	NP
2	*Montastraea faveolata*	H	B
1	*Montastraea faveolata*	CFB	ICFB
1	*Montastraea faveolata*	P	H
2	*Montastraea franksi*	H	IFB
1	*Montastraea franksi*	B	NP
2	*Montastraea franksi*	NP	CFB
3	*Montastraea franksi*	H	CFB
2	*Montastraea franksi*	IFB	GIF
1	*Montastraea franksi*	IFB	IIFB
1	*Montastraea franksi*	CFB	ICFB

Table 3.5.2.

Fish species composition and individual counts for the East and West Banks in 2004 and 2005 along perimeter lines and 360º panoramic views at corner markers. * Represents those individuals belonging to the Labridae, Pomacentridae, "Scaridae" (= Labridae: Scarinae), and Serranidae that could only be identified to the family level.

SPECIES	COMMON NAME	EAST BANK 2004	EAST BANK 2005	WEST BANK 2004	WEST BANK 2005
Acanthurus bahianus	Ocean Surgeonfish	0	5	2	2
Acanthurus chirurgus	Doctorfish	3	0	3	0
Acanthurus coeruleus	Blue Tang	0	7	4	7
Canthidermis sufflamen	Ocean Triggerfish	0	3	0	0
Melichthys niger	Black Durgon	2	0	1	4
Caranx ruber	Bar Jack	4	0	0	2
Caranx lugubris	Black Jack	1	0	0	0
Chaetodon striatus	Banded Butterfly	0	0	0	2
Chaetodon aculeatus	Longsnout butterfly	0	0	0	1
Chaetodon ocellatus	Spotfin Butterfly	3	0	0	0
Chaetodon sedentarius	Reef Butterfly	0	4	1	0
Haemulon spp.	Grunt	2	0	0	0
Kyphosus sectatrix/incisor	Bermuda/Yellow Chub	0	20	0	1
Labridae	**Wrasses ***	0	12	6	0
Bodianus rufus	Spanish Hogfish	0	2	2	3
Clepticus parrae	Creole Wrasse	78	14	10	37
Halichoeres garnoti	Yellowhead Wrasse	0	0	1	0
Thalassoma bifasciatum	Bluehead Wrasse	17	43	12	25
Ocyurus chrysurus	Yellowtail Snapper	0	0	1	0
Mulloidichthys martinicus	Yellow Goatfish	13	0	0	2
Lactophrys triqueter	Smooth Trunkfish	1	0	0	0
Holacanthus ciliaris	Queen Angelfish	0	0	1	0
Pomacentridae	**Damselfishes ***	26	24	23	22
Abudefduf saxatilis	Sergeant Major	4	3	0	1
Chromis cyanea	Blue Chromis	20	16	8	10
Chromis multilineata	Brown Chromis	24	55	31	102
Microspathodon chrysurus	Yellowtail Damselfish	5	1	4	5
Stegastes partitus	Bicolor Damsel	5	15	20	6
Stegastes planifrons	Threespot damselfish	0	7	1	7
Stegastes variabilis	Cocoa Damselfish	0	5	3	0
Scaridae	**Parrotfishes ***	1	2	2	3
Scarus taeniopterus	Princess Parrotfish	0	7	0	5
Scarus vetula	Queen Parrotfish	5	11	6	16
Sparisoma viride	Stoplight Parrotfish	1	5	0	2
Serranidae	**Sea Basses***	0	0	2	1

Table 3.5.2. Fish species composition and individual counts for the East and West Banks in 2004 and 2005 along perimeter lines and 360º panoramic views at corner markers (continued).

SPECIES	COMMON NAME	EAST BANK 2004	EAST BANK 2005	WEST BANK 2004	WEST BANK 2005
Mycteroperca tigris	Tiger Grouper	0	2	0	0
Paranthias furcifer	Creole Fish	86	15	22	75
Sphyraena barracuda	Great Barracuda	0	0	1	1
Canthigaster rostrata	Sharpnose Puffer	0	1	0	4
Cantherhines macrocerus	Whitespotted Filefish	1	0	0	0
Total		**302**	**279**	**167**	**346**

3.5.2 East Bank 360° Panoramic Views

At the northwest corner, only one colony of *Montastraea* sp. exhibited concentrated fish biting in 2004, which appeared as fine turf or bare substrate in 2005. In 2004, only one school of Creole fish was visible, while in 2005, schools of Creole wrasse, Creole fish and chromis were present.

At the northeast corner in 2004, the only impacted coral was one colony of *Montastraea franksi*, which had large amounts of tissue loss due to concentrated fish biting. The species composition of fish was similar between years; however, there were larger schools of Creole fish and Creole wrasse in 2004 than in 2005.

At the southeast corner only one incidence of concentrated fish biting was recorded in 2004. During 2004 there were large schools of Creole wrasse, chromis and Creole fish. In 2005 there were fewer fish, although species such as Black durgon and Creole fish were present.

3.5.3 West Bank Perimeter Lines

At the West Bank in 2004, there were no recorded incidences of disease along the perimeter lines. Concentrated and isolated fish biting of 8 colonies were the most common stressors, followed by bleaching and paling of 4 colonies (Table 3.5.3). Due to the higher cover of *Montastraea faveolata* and *M. franksi*, these two species were the most impacted corals. The most abundant fish were the Creole wrasse, Brown chromis, and damselfish (Table 3.5.2).

In 2005, no incidences of disease were observed at the West Bank. Stresses included concentrated fish biting (3 colonies), bleaching (2 colonies), isolated fish biting (2 colonies) and paling (1 colony) (Table 3.5.3). As in 2004, *Montastraea faveolata* and *M. franksi* were the most affected coral species. During this year, Brown chromis, Creole wrasse, and Creole fish were most abundant (Table 3.5.2).

Table 3.5.3.

Comparison of observations of the condition of coral colonies at the West Bank along perimeter lines and 360º panoramic views between 2004 (n≈955) and 2005(n≈ 825). (CFB= Condensed fish biting, IFB= Isolated fish biting, B= Bleaching, P= Paling, H= Healthy colony, ICFB=Increased tissue lost to concentrated fish biting, IIFB= Increased tissue lost to isolated fish biting, GI=Growth infilling [tissue regrowth], U=Unchanged condition, T=Surface replaced by turf algae).

Number of Colonies	Coral Species	West Bank 2004	West Bank 2005
1	*Diploria strigosa*	P	U
1	*Millepora alcicornis*	H	B
1	*Montastraea cavernosa*	P	GI
1	*Montastraea cavernosa*	B	U
1	*Montastraea faveolata*	CFB	ICFB
2	*Montastraea faveolata*	H	CFB
1	*Montastraea faveolata*	CFB	T
1	*Montastraea franksi*	IFB	U
1	*Montastraea franksi*	B	GI
3	*Montastraea franksi*	IFB	GI
1	*Montastraea franksi*	H	IFB
1	*Porites astreoides*	CFB	GI
1	*Siderastrea siderea*	CFB	GI

3.5.4 West Bank 360° Panoramic Views

Two *Montastraea* sp. colonies showed isolated fish biting at the southeast corner in 2004. In 2005, both colonies had increased incidences of isolated fish biting. More fish were videotaped in 2005 than 2004. Creole fish, damselfish, Black durgon, and a barracuda were seen in 2004. In 2005, schools of Creole fish were observed, as well as damselfish, Spanish hogfish and surgeonfish.

At the southwest corner coral colonies exhibited normal coloration in 2004. In 2005, several *Montastraea* sp. colonies showed signs of isolated and concentrated fish biting. The fish population in 2004 consisted of wrasses, Creole fish and the occasional damselfish. In 2005, the increased fish population consisted of Creole wrasse and schools of chromis and Creole fish.

Two *Montastraea* sp. colonies showed new tissue loss due to concentrated fish biting in 2005. Again, in 2005, fish abundance increased from the 2004 level. In 2004, there was a relatively small school of Creole fish and the occasional damselfish. In 2005, Creole wrasse, schools of Creole fish and Brown chromis, and the occasional wrasse were observed.

3.6 WATER QUALITY

3.6.1 YSI Water Quality

Water quality data collected on the reef caps by the YSI datasondes were carefully reviewed to verify the validity of measurements. After a prolonged deployment in a marine environment (more than 15 days), the YSI sondes typically fail post-deployment calibration; therefore, data collected toward the end of extended deployments are usually suspect. This is generally caused by biofouling. In some cases, however, the data collected may be erroneous from the beginning of the data collection. To validate the water quality data collected here, we looked for data consistency and credibility by comparing the acquired data with published values of each water quality parameter (Pickard and Emery 1982; Valiela 1984; Gittings et al. 1992; Sorokin 1995; Lugo-Fernández 1998; Nowlin et al. 1998; Kleypas et al. 1999; Dokken et al. 2003; Precht et al. 2006). We also had YSI technicians examine probes and some of the data. Alternative hardware considerations would probably improve the amount and accuracy of the data collected.

The YSI datasondes were deployed from 03/11/2004 to 11/02/2005 (599 calendar days) at the East Bank and from 03/11/2004 to 10/11/2005 (580 calendar days) at the West Bank. The data collected during this time contained sizeable series of erroneous data, which in turn led to substantial data gaps. The parameters with the greatest amounts of credible records were depth, temperature, and pH (Table 3.6.1). Sensors produced fewer credible data for the remaining parameters, particularly turbidity and PAR.

Table 3.6.1.

Summary of YSI water quality records collected at the East and West Bank reef caps from March 2004 to November 2005.

Site	Statistic	Depth (m)	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/l)	pH	Turbidity (NTU)	PAR (µeinst s^{-1} m^{-2})
East Bank	Minimum	19.38	21.46	34.78	3.22	7.45	0.50	1.26
	Maximum	23.57	30.93	37.08	12.36	8.97	196.92	258.13
	Mean	21.98	26.60	36.39	5.32	8.18	20.22	58.51
	SE	0.08	0.13	0.03	0.12	0.02	5.25	3.73
	n	349	349	153	119	349	53	84
West Bank	Minimum	23.96	21.11	33.20	5.90	7.31	5.50	6.85
	Maximum	29.20	30.45	35.93	7.36	8.24	5.92	104.86
	Mean	27.54	24.62	34.88	6.89	7.81	5.80	57.38
	SE	0.06	0.14	0.06	0.03	0.01	0.03	2.14
	n	430	304	80	95	350	13	79

3.6.2 East Bank YSI Reef Cap Data Review

Six files of YSI water quality data were acquired at the East Bank reef cap during the reporting period: 03/11/2004 to 07/15/2004 (127 days), 07/15/2004 to 02/25/2005 (226 days), 05/11/2005 to 06/08/2005 (29 days), 06/08/2005 to 08/27/2005 (83 days), 08/27/2005 to 10/12/2005 (47 days), and 10/12/2005 to 11/02/2005 (22 days). Note that the YSI sonde deployed at the East Bank from 02/25/2005 to 05/11/2005 failed. YSI technicians found that the turbidity probe failed upon deployment, which affected the recording of all other parameters. The turbidity probe flooded, causing a surge of current into its circuit board and a substantial drop in current to the other probes. This caused wide fluctuations in readings for all parameters. None of the water quality data are reliable for these 76 days.

File East Bank YSI 03/11/2004 to 07/15/2004:

- Depth data are credible and consistent.
- Temperature data are credible.
- Specific conductivity data were collected, but no salinity were recorded in parts per thousand.
- Dissolved oxygen data are suspicious starting from the beginning of the record. There is a series of negative values in the record and some very high values toward the end followed by lower values.
- pH data are credible.
- Turbidity data appear to be credible from 03/12/2004 to 03/23/2004. After that, the data set contains many unusually high values.
- PAR data are faulty. There are many negative values starting from the beginning of the record.

File East Bank YSI 07/15/2005 to 02/25/2005

- Battery voltage went from 13 volt to 10 volt from 07/16/2004 to 10/22/2004, then from 10 volt to about 7 volt from 10/22/2004 to 12/03/2004.
- Depth data seem accurate.
- Temperature data are credible.
- Salinity data are faulty.
- Dissolved Oxygen data are faulty.
- pH data are credible.
- Turbidity readings are faulty. Negative values right from the start.
- PAR readings are faulty.

File East Bank YSI 05/11/2005 to 06/08/2005

- Battery voltage began at 13.4 volt and ended at 12.1 volt.
- Depth data are credible.
- Temperature data are credible.
- Salinity data are credible. The mean salinity on the bottom seems to be very high at 36.59.
- DO readings are credible.
- pH data seem credible.
- Turbidity records are faulty. Turbidity values are negative right from the start.
- PAR readings are credible.

File East Bank YSI 06/08/2005 to 08/27/2005

- Voltage was stable throughout the data recording.
- Depth data are credible.
- Temperature data are credible.
- Salinity records for the most part seemed credible. There were a few faulty data points, but more importantly, this file contains evidence that freshwater reached the reef cap. Eight data points were deleted because they were isolated (immediately surrounded by substantially higher values) and too low to be real: 08/06/2005 at 0530 hrs: 23.23 ppt; 08/06/2005 at 1030 hrs: 25.04 ppt; 08/06/2005 at 1330 hrs: 23.4 ppt; 08/06/2005 at 2330 hrs: 23.5 ppt; 08/09/2005 at 0430 hrs: 21.38 ppt; 08/11/2005 at 1900 hrs: 21.90 ppt; 08/15/2005 at 0630 hrs: 11.68 ppt; and 08/15/2005 at 2330: 12.55 ppt. The freshwater on the reef occurred from 06/21/2005 0130 hrs to 6/21/2005 1100 hrs: 32.55 to 34.38 ppt.
- Dissolved oxygen data are difficult to dissect. Dissolved oxygen seems credible from 06/08/2005 to 06/14/2005. After that the data include unusually high values (> 9 mg/l) mixed with low values. Dissolved oxygen data recorded after 06/14/2005 were deleted to conservatively eliminate faulty data.
- pH data are credible.
- The turbidity data are difficult to dissect. The data seem real from 06/08/2005 to 06/26/2005 0930 hrs. After that the values jump around. The credible data were kept and the rest were deleted.
- PAR values seem credible from 06/08/2005 to 06/14/2005, 2000 hrs. After that there are negative values that are meaningless.

File East Bank YSI 08/27/2005 to 10/12/2005

Upon retrieval of the YSI on October 12, we found that the datasonde had undergone significant abrasion as evidenced by abundant scratches on the housing. The dissolved oxygen (DO) membrane was torn and the DO electrolyte cavity was filled with sediment. The entire railroad wheel (equipment base) was covered with sediment, only exposing the angle-iron attachment arms. The abrasions, the impacted DO probe, and the evidence of sedimentation were probably caused by Hurricanes Katrina (August 28 and 29) and Rita (September 23 and 24).

- Voltage was stable throughout the data recording.
- Depth data are credible. There are some jumps in depth on 09/23/2005 and 09/24/2005 which are probably due to Hurricane Rita.
- Temperature data are credible.
- Salinity data look good except for two values: 09/23/2005 1200hrs: 20.24 ppt, and on 09/23/2005 1230 hrs: 24.76 ppt. These data were deleted.
- Dissolved oxygen data appear to be credible from 08/27/2005 to 09/23/2005 1430 hrs. After that the data start to jump around and include extreme values (0.90; 11.43) that seem faulty.
- pH data are credible.
- Turbidity data are faulty.
- PAR data are credible from 08/27/2005 0130 hrs to 09/23/2005 1330 hrs. After that there are negative values. Everything after 09/23/2005 1330 hrs was deleted. The PAR sensor was probably affected by the passage of Hurricane Rita.

File East Bank YSI 10/12/2005 to 11/02/2005

- Voltage dropped from 12.9 volt at the beginning of the record to 10.1 volt by 10/20/2005. Then the voltage dropped by 1.7 volt in one day, then 0.4 volt the next day and 1.7 volt the day after that. Data recorded after 10/20/2005 are potentially suspicious.
- Depth data all appear credible.
- Temperature data are credible.
- Salinity data are all too high and were discarded (38.3 to 39.8 ppt).
- Dissolved oxygen data seem credible except for the first few data points, which seem unusually high compared to the rest of the record.
- pH data are credible.
- Turbidity data are faulty (all negative values).
- PAR data are credible.

3.6.3 West Bank YSI Reef Cap Data Review

Five files of YSI water quality data were acquired at the West Bank reef cap during the reporting period: 03/11/2004 to 07/15/2004 (127 days), 07/15/2004 to 11/19/2004 (128 days), 11/19/2004 to 02/23/2005 (97 days), 05/09/2005 to 06/07/2005 (30 days), and 06/07/2005 to 08/25/2005 (79 days). YSI data acquired from 02/23/2005 to 05/09/2005 (76 days) were faulty. YSI technicians found that the turbidity probe failed upon deployment, which affected the recording of all other parameters. No data were collected from 08/25/2005 to 10/11/2005 (50 days) as a result of hurricane damage to the datasonde.

File West Bank YSI 03/11/2004 to 07/15/2004

- The depth sensor recorded values ranging from 23 to 28 m.
- Temperature data are credible.
- Salinity measurements are faulty.
- Dissolved oxygen values are all over the place. It appears that the DO sensor may have functioned for 15 days but even during those 15 days the data seem odd.
- pH data are credible.
- Turbidity values are faulty. Values also all over the place particularly toward the end of the record.
- PAR data collected here are not reliable.

File West Bank YSI 07/15/2004 to 11/19/2004

- Voltage was steady throughout the recording.
- Date changes are out of synchrony with times.
- Depth data seem credible.
- Temperature data are faulty.
- Salinity data are faulty.
- DO data are faulty
- pH data seem credible
- Turbidity data are faulty
- PAR data are faulty

File West Bank YSI 11/19/2004 to 02/23/2005

- Depth data are credible.
- Temperature data are credible.
- Salinity measured as specific conductivity.
- Dissolved oxygen data appear credible up until 02/21/2005 1400 hrs. After that, there is a sudden and unexplained drop.
- pH data are credible.
- Turbidity data are suspicious. Up until 12/01/2004, 2100 hrs average turbidity is 5.8 NTU. At 2130 hrs, there is a sudden jump to 1395 NTU. Thereafter the jumps are more frequent.
- PAR data are suspicious. There are relatively high values occurring during the nighttime. There is no clear daily cycle.

File West Bank YSI 05/09/2005 to 06/07/2005 (Data were recorded in a water depth of 38 m)

- Voltage was steady.
- Depth data were consistent. The average depth, however, was 38 m.
- Temperature data are credible.
- The dissolved oxygen data contained some unusually high values (> 9 mg/l). Typical values near the sea surface range from 6 to 8 mg/l (Pickard and Emery 1982). Aside from the questionable values, the sensor picked up a daily cycle in DO concentrations.
- Salinity data are credible. The values are somewhat high but consistent throughout.
- Turbidity data look faulty.
- PAR data are credible.

File West Bank YSI 06/07/2005 to 08/25/2005

- Voltage was steady.
- Depth data are credible.
- Temperature records are credible.
- Salinity records are credible.
- DO data are faulty.
- pH data are credible.
- Turbidity data are suspicious. They contain numerous outliers.
- PAR data are credible.

3.6.4 YSI Water Quality – Reef Cap

Temperature. Temperature ranged from 21.46 to 30.93 °C (mean = 26.60 °C ± 0.13 SE, n = 349) at the East Bank and 21.11 to 30.45 °C (mean = 24.62 °C ± 0.14 SE, n = 304) at the West Bank (Appendix 5). In June and July 2005, seawater temperature at the East Bank and West Bank oscillated between 25 °C and 28 °C before increasing steadily to reach peak annual temperatures in August.

The temperature threshold for bleaching at the Flower Garden Banks is 30 °C (Hagman and Gittings 1992). Seawater temperature exceeded 30 °C on the reef caps of both banks in 2005 (Appendix 5). At the East Bank average daily temperature was greater or equal to 29.5 °C from

07/29/2005 to 09/19/2005 (53 consecutive days; Appendix 5). During that time, temperature exceeded 30 °C during 29 days (including 16 consecutive days). At the West Bank, temperature on the reef cap was equal to or exceeded 29.5 °C from 07/26/2005 to 08/22/2005 (29 days) and temperature exceeded 30 °C during seven days from 08/06/2005 to 08/21/2005.

During the passage of Hurricane Katrina (28 and 29 August 2005) temperature on the reef cap exceeded 30 °C at the East Bank and no temperature was acquired at the West Bank. During the passage of Hurricane Rita (23 and 24 September 2005), temperature on the reef cap was 29.1 °C and 28.3 °C at the East Bank. No temperature data were gathered at the West Bank.

Salinity. Few reliable salinity data were gathered during the reporting period. Salinity on the reef cap was documented from May to October 2005 at the East Bank and from June to August at the West Bank. At the East Bank mean daily salinity ranged from 34.8 to 37.1 ppt (mean = 36.4 ppt ± 0.03 SE, n = 153) (Table 3.6.1). At the West Bank mean daily salinity ranged from 33.2 to 35.9 ppt (mean = 34.9 ppt ± 0.06 SE, n = 80) (Table 3.6.1). Salinity (arcsine-transformed) was significantly different between banks during coinciding sampling periods (6/9/05 to 8/25/05) (two-tailed paired-sample *t* test; $t = -16.46$, df = 88 $P>0.05$). The salinity at the West Bank was significantly different than the salinity at the East Bank. The salinity minimum at the East Bank (34.78 ppt) occurred on 21 June 2005 and the salinity minimum at the West Bank (33.20 ppt) occurred on 13 July 2005.

During the passage of Hurricane Katrina (28 and 29 August 2005), mean daily salinity on the reef cap at the East Bank was 36.5 ppt. No water quality data are reported at the West Bank past 25 August 2005. During the passage of Hurricane Rita (23 and 24 September 2005), mean daily salinity at the East and West Banks were 36.3 ppt and 35.7 ppt, respectively.

Dissolved Oxygen. The West Bank dissolved oxygen (DO) data gathered from November 2004 to February 2005 ranged from 5.9 to 7.4 mg/l (mean = 5.32 mg/l ± 0.03 SE, n = 95; Appendix 5). These data seem reliable when compared with the 4.94 to 7.78 mg/l DO range reported by Gittings et al. (1992). The DO concentrations at the East Bank in March and April 2004 ranged from 3.2 to 12.4 mg/l (03/12/2005 to 04/14/05). The DO concentration rose above 9 mg/l during three days during this sampling period. The remainder of the DO records at the East Bank from May to November 2005 ranged from 3.2 to 7.0 mg/l with minima occurring in May, June, and September.

On 28 and 29 August 2005, when Hurricane Katrina crossed the northern Gulf of Mexico, mean daily DO on the reef cap at the East Bank was 5.8 mg/l and 5.6 mg/l. No water quality data are reported at the West Bank past 25 August 2005. When Hurricane Rita passed near the Flower Garden Banks on 23 and 24 September 2005, the last measurements the DO probe captured on September 23 averaged 4.7 mg/l.

pH. Hydrogen ion concentration (pH) in seawater typically ranges from 7.5 to 8.4 (Sverdrup et al. 1970). Mean daily pH ranged from 7.5 to 9.0 at the East Bank and from 7.3 to 8.2 at the West Bank (Table 3.6.1). Although the pH data gathered seem credible, the East Bank June to December 2004 data were probably flawed by a gradually decreasing voltage in the YSI instrument.

Turbidity. There were very few data collected during the reporting period that were usable or credible. The few data the turbidity probe managed to collect indicate that turbidity may have been unusually high (~ 200 NTU) at one point in late March 2004 at the East Bank. Otherwise turbidity was less than 10 NTU. No turbidity data was collected during the passages of Hurricanes Katrina or Rita.

Photosynthetically Active Radiation. The PAR data retained for the reporting period were concentrated in 2005 (Appendix 5). At the East Bank, mean daily PAR ranged from 1 to 258 µeinst s^{-1} m^{-2} (n = 84). At the West Bank, PAR ranged from 7 to 105 µeinst s^{-1} m^{-2} (n = 79). The West Bank PAR record from June to August 2005 is credible and shows a decline in PAR around mid-July followed by an increase. The drop in PAR coincides with the drop of salinity. The decreased PAR on the reef cap may have been caused by reduced light penetration to the seafloor caused by a turbid and low salinity sea surface layer (Deslarzes and Lugo-Fernández 2006).

3.6.5 Water Quality – Vertical Profiles

While we conducted the annual monitoring of the coral reefs at the Flower Garden Banks in June 2005, we noticed a discolored sea surface layer and decided to document water quality along vertical profiles using the YSI sonde. We collected water quality data (temperature, salinity, dissolved oxygen, pH, and turbidity) at 431 points along the vertical profile (Appendix 5). These data points were averaged at 0.5 m depth increments, resulting in 38 averaged data points.

The turbidity probe showed that the discolored layer near the sea surface was indeed more turbid than the underlying water and that the turbid layer reached down to an approximate depth of 7.5 m (Figure 3.6.6; Appendix 5). From the sea surface to a depth of 7.5 m, turbidity decreased from 0.9 to 0.6 NTU. From 7.5 m to the reef cap (~20 m) the turbidity remained at 0.6 NTU. Furthermore, the turbid layer was fresher and warmer than the underlying water (Figure 3.6.7; Appendix 5). While the turbidity data showed a clear break between a surface layer and the underlying water, salinity and temperature values did not. There was a salinity and temperature cline in a depth range of 7.5 m to 10.5 m. The salinity of the upper 7.5 m ranged from 32 ppt to 33 ppt. In the interface, salinity changed from 33 ppt to 36 ppt. Below the interface, salinity was approximately 36 ppt. Temperature ranged from 28.0 °C to 28.4 °C in the upper layer. In the cline, water temperature dropped from 28.0 °C to 27.2 °C and then continued to decline with increasing depth to 26.2 °C on the reef cap.

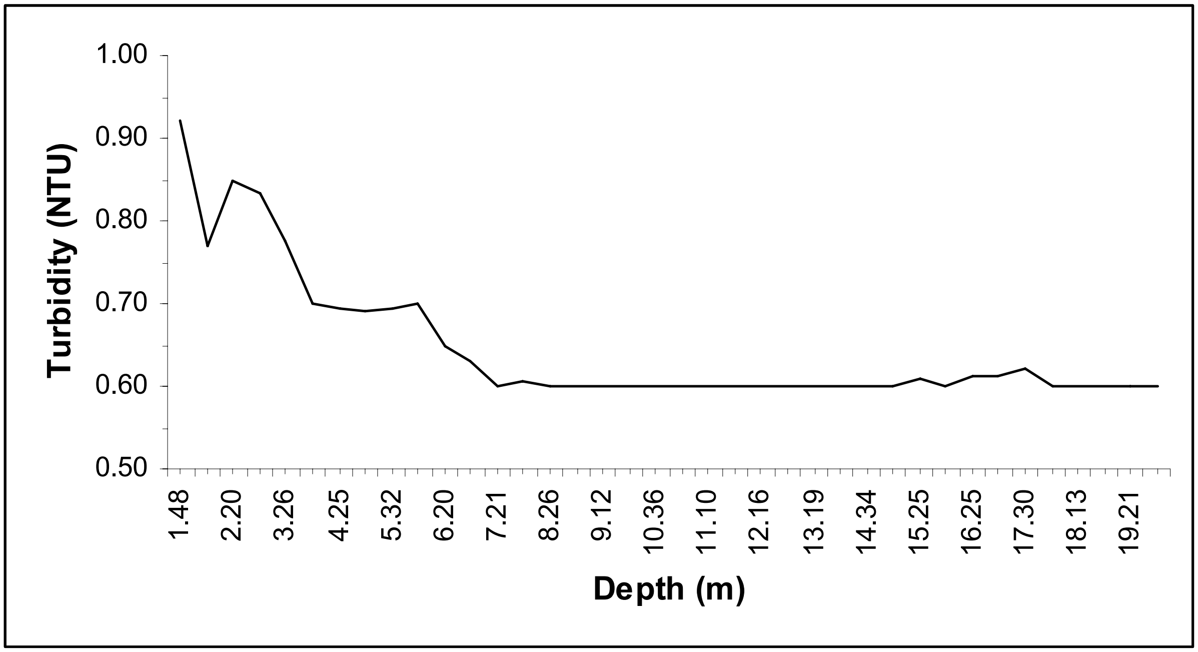


Figure 3.6.6. Vertical profile of turbidity at the East Bank study site (8 June 2005).

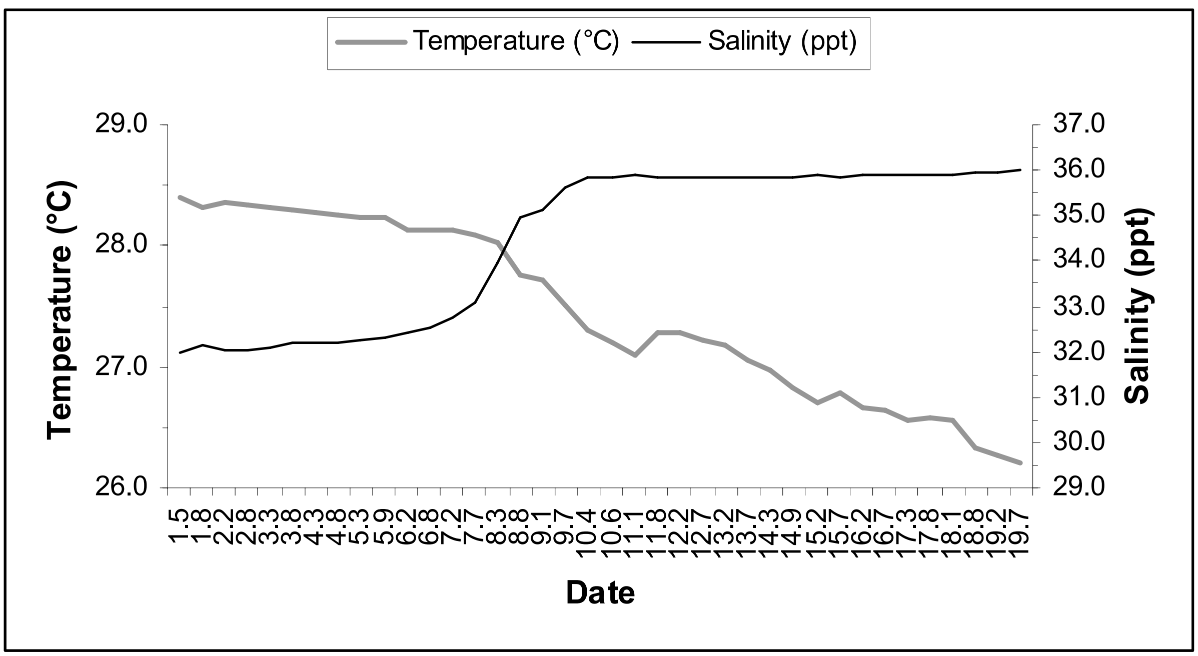


Figure 3.6.7. Vertical profiles of temperature and salinity at the East Bank study site (8 June 2005).

3.6.6 HoboTemp Temperature

HoboTemp thermographs were used to collect temperature data as comparison data and/or back up data to the YSI collected temperature data. Generally, HoboTemp thermographs worked well but were occasionally lost due to weather, faunal interference, or diver interference.

3.6.7 HoboTemp Data Review

Five files of HoboTemp data were collected at the East Bank and four files were collected at the West Bank during the reporting period. The HoboTemp thermographs were deployed with the YSI instruments and therefore HoboTemp temperature records generally overlap those gathered by the YSI temperature sonde.

The East Bank HoboTemp data were collected from 03/11/2004 to 11/14/2005. Data gaps at the East Bank occurred from 11/19/2004 to 05/11/2005 and from 08/26/2005 to 10/12/2005. The first data gap was caused by a loss of the HoboTemp thermograph from the YSI datasonde. The second data gap was most likely caused by Hurricane Rita.

File East Bank 03/11/2004 to 07/15/2004

- Data are credible.

File East Bank 07/15/2004 to 11/19/2004

- Data are credible.

File East Bank 05/11/2005 to 06/08/2005

- Data are credible.

File East Bank 06/08/2005 to 08/26/2005

- Data are credible.

File East Bank 10/12/2005 to 11/14/2005

- Data are credible.

The West Bank HoboTemp data were gathered from 03/11/2004 to 10/11/2005. Data gaps occurred from 11/19/2004 to 05/07/2005 as a result of the loss of the HoboTemp thermograph from the YSI datasonde.

File West Bank 03/11/2004 to 07/15/2004

- Data are credible.

File West Bank 07/15/2004 to 11/19/2004

- Data are credible.

File West Bank 05/07/2005 to 06/07/2005

- Data are credible.

File West Bank 06/07/2005 to 08/25/2005

- Data are credible.

File West Bank 08/25/2005 to 10/11/2005

- Data are credible.

Seawater temperature on the reef cap of the East Bank was measured during 269 days from 03/11/2004 to 11/14/2005 and ranged from 20.7 °C to 30.5 °C (mean = 25.7 °C ± 0.20 SE; Table 3.6.7; Figure 3.6.8). At the West Bank, HoboTemp thermistors measured seawater temperature on the reef cap during 381 days from 03/11/2004 to 10/11/2005. Temperature on the West Bank ranged from 20.8 °C to 30.5 °C (mean = 26.7 °C ± 0.1 SE; Table 3.6.7; Figure 3.6.8).

The seasonal (spring to summer) warming over the reef cap is very apparent in Figure 3.6.8. In 2004 and 2005, after a steady increase in temperature during the spring, seawater temperature began to oscillate in June and July. Comparing 2004 and 2005, the temperature continued to oscillate from July through August in 2004 whereas in 2005 the temperature ceased to oscillate toward the end of July and instead increased steadily toward the summer maximum. Following the summer maximum, temperature began to decline around mid-September in both 2004 and 2005.

Table 3.6.7.

Summary of temperature data collected at the East and West Bank reef caps using HoboTemp thermographs from March 2004 to November 2005.

Site	Statistic	Temperature (ºC)
East Bank	Minimum	20.7
	Maximum	30.5
	Mean	25.7
	SE	0.2
	n	269
West Bank	Minimum	20.8
	Maximum	30.5
	Mean	26.7
	SE	0.1
	n	381

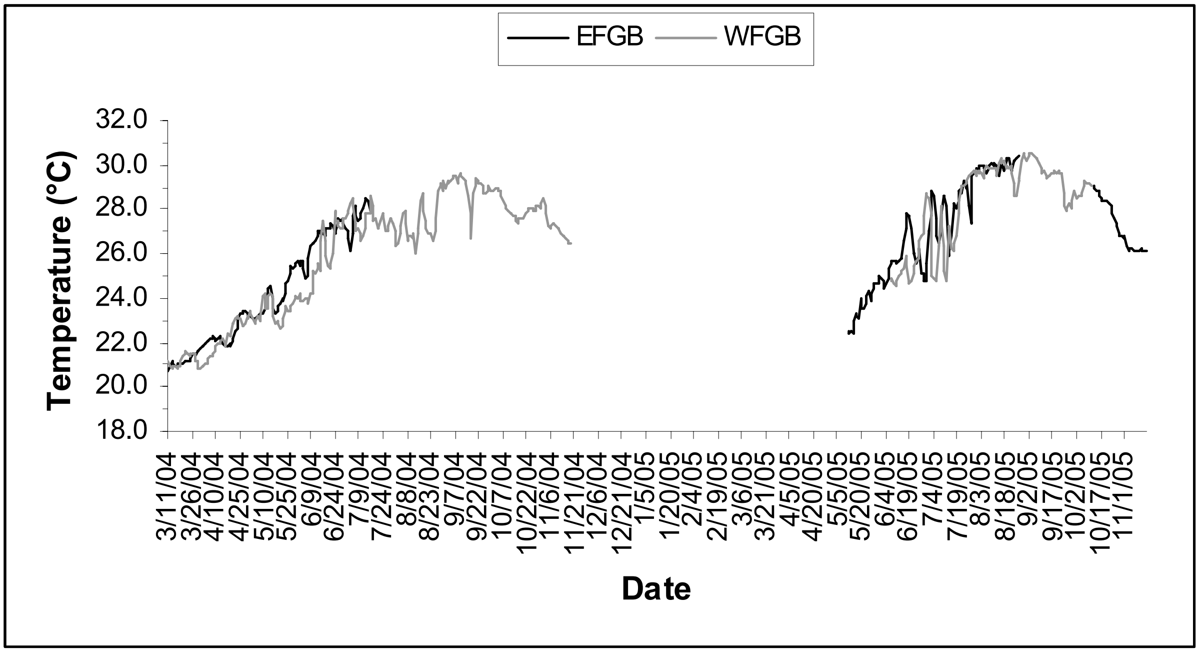


Figure 3.6.8. Mean daily temperature measured at the East and West Bank reef caps using HoboTemp thermographs.

A comparison of the overlapping temperature records (arc sine-transformed) at the East Bank and West Bank showed that temperatures are significantly different between banks from 03/11/2004 to 07/15/2004 (two-tailed paired-sample *t*-test; $t = 6.07$; df = 126; P>0.05). From 06/07/2005 to 08/26/2005, temperatures (arc sine-transformed) were also significantly different between banks (two-tailed paired-sample *t*-test; $t = 2.68$; df = 80; P>0.05). In both cases the East Bank temperature on the reef cap was greater than that on the West Bank.

As mentioned earlier, the temperature threshold for coral bleaching at the Flower Garden Banks is 30 °C (Hagman and Gittings 1992). At the East Bank seawater temperature was greater than or equal to 29.5 °C starting on 28 July 2005 and ending on the last recording day on 26 August 2005 (30 consecutive days). During that time temperature was greater than 30 °C during 15 days. At the West Bank seawater temperature rose above 29.5 °C during the period 07/26/2005 to 09/22/2005 (59 days). During that time, temperature was greater than 29.5 °C from 07/26/2005 to 08/03/2005 (9 days), 08/05/2005 to 08/22/2005 (18 days), 08/28/2005 to 09/12/2005 (16 days), and 09/14/2005 to 09/22/2005 (9 days). Temperature was greater than 30 °C during a total of 18 days and during 12 consecutive days (08/28/2005 to 09/08/2005). Corals on the reef caps of both banks were, therefore, exposed to prolonged thermal stress known to induce bleaching at the Flower Garden Banks.

3.6.8 Water Samples

Water samples were taken to identify chlorophyll *a* and nutrients at the sea surface, in mid-water, and at surface of the reef cap on monitoring cruises between March and November 2004 and February to October 2005 (Table 2.7.4.).

3.6.9 Chlorophyll *a*

Chlorophyll *a* was not detected (< 1 mg/m^3) in any of the water samples (surface, midwater, and reef cap) collected between March 2004 and October 2005 (Table 2.7.4.).

3.6.10 Nutrients

Water samples taken at the sea surface, in midwater, and on the reef cap between March 2004 and October 2005 (Table 2.7.4.) were analyzed for ammonia, nitrate and nitrite, soluble reactive phosphorous and total Kjeldahl nitrogen. The detection limit for nitrate and nitrite is 0.15 mg/l and that for soluble reactive phosphorous is 0.40 mg/l. Nitrite and soluble reactive phosphorous were each below detection limits; however, in June 2005, 0.20 mg/l of nitrate was recorded in the surface water of the West Bank. Ammonia and total Kjeldahl nitrogen (sum of organic nitrogen and ammonia) were present above minimum detection limits at the East and West Banks (Table 3.6.10; Table 3.6.11). Ammonia concentrations at the East Bank ranged from 0.03 mg/l to 0.26 mg/l throughout the water column in 2004 and 2005. At the West Bank between 2004 and 2005, ammonia concentrations ranged from 0.03 mg/l to 0.13 mg/l (Table 3.6.10; Table 3.6.11). Total Kjeldahl nitrogen levels ranged from 0.33 mg/l to 2.24 mg/l in the surface waters of the East Bank during July 2004 and October 2005, respectively. At the West Bank, total Kjeldahl levels ranged from 0.19 mg/l (measured at the surface and reef cap in July 2004) to 2.01 mg/l (measured in midwater in October 2005; Table 3.6.10; Table 3.6.11). No patterns were detected, generally concentrations were close to or below detection limits.

Table 3.6.10.

Nutrient concentrations in water samples taken at the East and West Banks in 2004. Abbreviation ND: not detectable.

Ammonia (mg/l) (Detection limit: 0.03 mg/l)	**3/11/2004**	**7/15/2004**	**7/16/2004**	**9/21/2004**	**11/19/2004**
EFGB Surface	0.26	No sample	ND	0.03	No sample
EFGB Midwater	0.25	No sample	0.04	0.03	No sample
EFGB Reef cap	0.16	No sample	0.03	0.03	No sample
WFGB Surface	0.13	0.04	No sample	No sample	0.03
WFGB Midwater	0.1	ND	No sample	No sample	0.03
WFGB Reef cap	0.12	ND	No sample	No sample	0.03
Total Kjeldahl Nitrogen (mg/l) (Detection limit: 0.10 mg/l)	**3/11/2004**	**7/15/2004**	**7/16/2004**	**9/21/2004**	**11/19/2004**
EFGB Surface	0.42	No sample	0.33	0.75	No sample
EFGB Midwater	0.51	No sample	ND	0.84	No sample
EFGB Reef cap	0.37	No sample	ND	0.65	No sample
WFGB Surface	0.19	ND	No sample	No sample	0.7
WFGB Midwater	ND	ND	No sample	No sample	0.89
WFGB Reef cap	0.19	ND	No sample	No sample	0.75

Table 3.6.11.

Nutrient concentrations in water samples taken at the East and West Banks in 2005.

Ammonia (mg/l) (Detection limit: 0.03 mg/l)	**2/23/2005**	**5/10/2005**	**5/11/2005**	**6/7/2005**	**6/8/2005**	**8/25/2005**	**8/26/2005**	**10/11/2005**	**10/12/2005**
EFGB Surface	0.04	No sample	0.03	No sample	0.03	No sample	0.03	No sample	0.03
EFGB Midwater	0.04	No sample	0.03	No sample	0.03	No sample	0.04	No sample	0.03
EFGB Reef cap	0.04	No sample	0.03	No sample	0.03	No sample	0.05	No sample	0.03
WFGB Surface	0.05	0.04	No sample	0.03	No sample	0.03	No sample	0.03	No sample
WFGB Midwater	0.05	0.03	No sample	0.04	No sample	0.04	No sample	ND	No sample
WFGB Reef cap	0.04	0.03	No sample	0.04	No sample	0.04	No sample	0.03	No sample
Total Kjeldahl Nitrogen (mg/l)l) (Detection limit: 0.10 mg/l)	**2/23/2005**	**5/10/2005**	**5/11/2005**	**6/7/2005**	**6/8/2005**	**8/25/2005**	**8/26/2005**	**10/11/2005**	**10/12/2005**
EFGB Surface	0.98	No sample	0.7	No sample	1.07	No sample	0.56	No sample	2.24
EFGB Midwater	1.03	No sample	0.79	No sample	0.75	No sample	1.17	No sample	2.01
EFGB Reef cap	0.98	No sample	0.61	No sample	0.61	No sample	1.35	No sample	1.96
WFGB Surface	1.26	0.89	No sample	0.65	No sample	0.61	No sample	1.68	No sample
WFGB Midwater	1.12	0.84	No sample	0.7	No sample	1.21	No sample	2.01	No sample
WFGB Reef cap	1.07	0.93	No sample	0.84	No sample	1.4	No sample	1.96	No sample

3.7. FISH SURVEYS

A mean of 21.5 diver surveys/samples (± 6.56 SD) were conducted during the 2004-2005 Flower Garden Banks survey efforts. Surveys were conducted during the day from 0700 through dusk. The 2004 data was gathered in September (East Bank) and November (West Bank). Data in 2005 was collected in June. The highest number of diver surveys/samples was conducted in 2004 at the West Bank, while the lowest occurred at the East Bank in 2004 (Table 3.7.1). Unfavorable weather conditions hampered survey efforts in 2004 and were the reason for low number of fish surveys at the East Bank in 2004. An average of 38% of the 100 x 100 m study sites was visually surveyed during 2004-2005.

Table 3.7.1.

Visual fish survey sampling statistics for the East and West Banks in 2004 and 2005.

	EB 2004	**WB 2004**	**EB 2005**	**WB 2005**
Number Samples (n)	12	27	24	23
% area of study site sampled	21%	48%	42%	41%
Fish cylinder sample area (m^2)	177	177	177	177
Area sampled (m^2)	2,124	4,779	4,248	4,071
Total Fish Abundance	5,331	1,876	3,928	3,252

A mean of 57 fish species (± 6.0 SD) were observed during the 2004-2005 surveys. This is an increase from the 51 (± 3.5 SD) mean fish species recorded during the 2002-2003 surveys. A total of 85 fish species were recorded for all survey efforts combined at the Flower Garden Banks in 2004 and 2005 (Table 3.7.6; Appendix 6). Species richness (number of species recorded per diver survey/sample) comparisons between banks and years showed a similar pattern to fish abundance, with a significant difference between banks in 2004 but not in 2005 and a significant difference at East Bank, but not at West Bank, between 2004 and 2005. The highest mean richness recorded per diver survey was at East Bank in 2004 (mean richness = 22 species per diver survey; Table 3.7.2).

Table 3.7.2.

Species and family richness and density values for the East and West Banks recorded during 2004 and 2005 survey efforts.

	EB 2004	WB 2004	EB 2005	WB 2005
Total Species (Species Richness)	55	50	64	60
Total Families (Family Richness)	18	19	22	21
Mean Abundance/Survey	444.25	69.48	163.66	141.39
^SD	275.36	35.62	101.64	79.29
Mean Abundance/ m^2	2.51	0.39	0.97	0.80
Mean Species Richness/Survey	22	14.96	17.21	16.61
^SD:	4.22	6.15	2.75	3.07
Mean Spp Richness/ m^2	0.12	0.08	0.10	0.09
Mean Family Richness	11.5	8.71	9.79	9.74
^SD	2.11	2.88	1.91	1.79
Mean Family Richness/ m^2	0.07	0.049	0.06	0.06

Mean fish abundance per area ranged from a high at the East Bank in 2004 of 251.39 per 100 m^2 to a low at the West Bank in 2004 of 39.32 per 100 m^2 (Table 3.7.2). Mean density values in 2005 were 96.64 and 80.01 per 100 m^2 respectively. In previous survey years, the mean density value for the East Bank has fluctuated from 82.78 per 100 m^2 in 2002 to 157.53 per 100 m^2 in 2003. Previous mean density values recorded in 2002 and 2003 at the West Bank were 73.29 and 84.62 per 100 m^2 respectively.

Fish abundances (mean fish abundances recorded per diver survey) showed a significant difference ($t=7.056$, $df=37$, $P=2.38E-08$) between the East and West Banks in 2004 but not in 2005. The East Bank showed a significant difference ($t=4.470$, $df=34$, $P=8.26E-05$) in fish abundances between the years 2004 and 2005 but no inter-year difference was found at the West Bank. The high density value for the East Bank in 2004 is attributed to the high numbers of the small schooling Inermiidae species, *Emmelichthyops atlanticus.* The mean observed abundance for *E. atlanticus* was 266.67 fish per diver survey (± 271.64 SD), corresponding to a mean density value of 150.9 fish per 100 m^2. *Clepticus parrae, Chromis multilineata,* and *Paranthias furcifer* were also observed in high densities at the East Bank in 2004 with mean density values of 20.37, 19.38, and 13.06 per 100 m^2 respectively. Density values of *C. multilineata* and *C. parrae*, which ranked as the top two most abundant species at the East Bank in 2005, were 37.87 and 9.41 per 100 m^2 respectively. Also ranked as the top two most abundant species at the West Bank in 2005, their density values there were 34.08 and 9.87 per 100 m^2.

Chromis multilineata and *Clepticus parrae* were consistently the two most abundant species in 2004 and 2005 except at the East Bank in 2004 when *Emmelichthyops atlanticus* was recorded in greater numbers than both of these. Additionally, *P. furcifer, Thalassoma bifasciatum,* and *Stegastes partitus,* were regularly ranked among the top five most abundant species as well.

The sighting frequency of fish species varied between years and banks as they did during the 2002-2003 surveys. However, the species most frequently recorded per diver survey/sample throughout the 2004-2005 surveys were *C. multilineata, S. planifrons, S. partitus, S. vetula, T. bifasciatum, Acanthurus coeruleus*, and *C. parrae.*

Fish species recorded fell into a mean of 20 fish families (±1.83 SD) per bank and year. This is a decrease of one family from the 2002-2003 surveys, when there were 21 families (±0.82 SD) recorded. The most abundant families observed were the Labridae, Pomacentridae, Serranidae, and "Scaridae" (more properly Labridae: Scarinae). The Inermiidae were the most abundant family observed in 2004 at the West Bank and the Carangidae were recorded in high numbers (within the five most abundant families) at both banks in 2005. Mean densities of Labridae (excluding Scarinae) recorded per survey ranged from 8.80 to 31.60 per 100 m^2 at the West and East Banks, respectively, in 2004. Pomacentridae densities ranged from 15.50 per 100 m^2 at the West Bank in 2004 to 49.51 per 100 m^2 at the East Bank in 2005. "Scaridae" ranged in density from 2.73 per 100 m^2 at the West Bank in 2005 to 7.40 per 100 m^2 at the East Bank in 2004.

Families represented by the most species were the Pomacentridae, Labridae, Serranidae, and "Scaridae." The most species of Pomacentridae were recorded in 2005 at the East Bank with 12 representatives, and the fewest were recorded in 2004 at the East Bank with 8 representative species. The greatest number of species of Serranidae were observed in 2005 at the West Bank with 9 species. The number of "Scaridae" species was consistent, ranging from 5 recorded in 2004 at the West Bank to 7 at the East Bank in 2005. The Labridae were generally represented by 7 species.

The Pomacentridae were represented by a mean of 4.00 to 4.58 species per survey at the West Bank in 2005 and the East Bank in 2004, respectively. The most common representatives of the Pomacentridae were *C. mulitilineata*, *S. partitus*, *Chromis cyanea*, and *Stegastes planifrons*. The Labridae were represented by a mean of 2.65 to a 3.67 species per survey at the West Bank in 2005 and the East Bank in 2004, respectively. The most common representatives of the Labridae were *C. parrae*, *T. bifasciatum*, and *Bodianus rufus*. The "Scaridae" were represented by a mean of 1.78 to 3.00 species per survey at the West Bank in 2004 and at the East Bank in 2004, respectively. The most common representatives of the "Scaridae" were *Scarus vetula, Sparisoma viride, Scarus taeniopterus,* and *Sparisoma aurofrenatum*. The Serranidae were represented by a mean of 0.63 to 1.83 species per survey at the West Bank in 2004 and at the East Bank in 2004, respectively. *Paranthias furcifer* was by far the most common representative of the Serranidae; however, others included *Cephalopholis cruentata, Epinephelus adscensionis,* and *Mycteroperca tigris*.

The Acanthuridae are important herbivores on coral reefs and are represented at the Flower Garden Banks (and the rest of Florida, the Bahamas, and the Caribbean) by 3 species. The Acanthuridae were represented by a mean of 0.93 to a 1.92 species per survey at the West Bank in 2004 and at the East Bank in 2004, respectively. The species representing Acanthuridae are *Acanthurus coeruleus*, *A. chirurgus*, and *A. bahianus*.

Shannon-Weiner diversity indices were similar between the East and West Banks in 2005 while those of 2004 varied from each other and from those of 2005 (Table 3.7.3). The greatest diversity was calculated for the West Bank in 2004 and the lowest for the East Bank in 2004. Higher sampling effort (larger n) appears to have had a positive effect on diversity and evenness calculations.

Table 3.7.3.

Fish diversity and evenness values calculated for fish communities surveyed at the East and West Banks in 2004 and 2005.

	EB 2004	WB 2004	EB 2005	WB 2005
Number of Samples (n)	12	27	24	23
Diversity (log10)	0.77	1.30	1.06	1.04
Evenness	0.44	0.76	0.58	0.58

The families of large-sized fish (visually estimated fork lengths) at the Flower Garden Banks were the Carangidae, Serranidae, Sphyraenidae, and Lutjanidae. Other families with large individuals included the "Scaridae," Ballistidae, Pomacanthidae, and Kyphosidae. *Sphyraena barracuda* weighted mean lengths ranged from 50 cm at the East Bank in 2005 to 88 cm at the West Bank in 2004. *Mycteroperca tigris* (90 cm weighted mean length), *Mycteroperca bonaci* (90 cm weighted mean length), *Lutjanus jocu* (83 cm weighted mean length), and *Mycteroperca interstitialis* (50 cm weighted mean length) were the largest species, aside from *S. barracuda,* at the Flower Garden Banks during the 2004-2005 surveys (Table 3.7.4).

Table 3.7.4.

Weighted mean sizes (visual estimation of fork length) of the top five largest carnivore species at the East and West Banks in 2004 and 2005.

East Bank 2004		West Bank 2004		East Bank 2005		West Bank 2005	
Fish Species	**(cm)**	**Fish Species**	**(cm)**	**Fish Species**	**(cm)**	**Fish Species**	**(cm)**
Sphyraena barracuda	**56**	*Mycteroperca tigris*	**90**	*Lutjanus jocu*	**83**	*Mycteroperca bonaci*	**90**
Mycteroperca interstitialis	**50**	*Serioloa lalandi*	**90**	*Caranx latus*	**60**	*Gymnothorax moringa*	**80**
Caranx lugubris	**49**	*Sphyraena barracuda*	**88**	*Caranx hippos*	**52**	*Caranx lugubris*	**73**
Canthidermis sufflamen	**45**	*Caranx latus*	**70**	*Sphyraena barracuda*	**50**	*Sphyraena barracuda*	**66**
Epinephelus adscensionis	**40**	*Lutjanus griseus*	**55**	*Diodon hystrix*	**50**	*Caranx latus*	**65**

Species in the families Acanthuridae and "Scaridae," as well as the pomacentrid *Microspathodon chrysurus*, can be grouped in an herbivore category comprised of algae-scrapers and -denuders (Steneck 1988; Pattengill-Semmens and Gittings 2003). Three species of Acanthuridae and seven species of "Scaridae" were recorded in the surveys making a total of 11 species in this herbivore group. The mean number of herbivore species per survey ranged from 2.85 at the West Bank in 2004 to 5.07 at the East Bank in 2004. The mean number of herbivore species in 2005 was 3.75 at the East Bank and 3.35 at the West Bank. There was a significant difference ($t=3.627$, $df=37$, $P=0.0009$) in herbivore species richness between the East Bank and the West Bank in 2004, as well as between 2004 and 2005 at the East Bank ($t=3.068$, $df=34$, $P=0.0002$). Mean fish densities of the herbivore group ranged from 5.14 to 10.47 per 100 m^2 at the West Bank in 2005 and the East Bank in 2004, respectively. Densities at the East Bank in 2005 were 6.74 per 100 m^2 and at the West Bank in 2004 were 6.33 per 100 m^2. The only significant difference in mean densities of the herbivore group was found between the East and West Banks in 2004 ($t=6.639$, $df=37$, $P=8.62E-08$) (Table 3.7.5). *Scarus vetula* and *Acanthurus coeruleus* were the most frequent species in the herbivore group.

The size-frequency distributions of the herbivorous fishes are normal curves for all years at both banks. The curves for both banks in 2004 are shifted to the lower end of the size ranges and those of West Bank in 2004 shows a more exaggerated (less dispersed) pattern. The curves for 2005 are more evenly dispersed and are shifted more toward the larger sizes (Figure 3.7.1).

Select species are grouped here as a carnivore category. These include serranids in the genera *Epinephelus, Cephalopholis, Mycteroperca,* and *Dermatolepis* as well as all species of lutjanids (Claro and Cantelar Ramos 2003; Pattengill-Semmens and Gittings 2003). A total of twelve species were observed in this group: two Lutjanidae and ten Serranidae (three more species than were observed in the 2002-2003 surveys). Although present in large numbers, the serranid *P. furcifer* is not included in the carnivore group. The mean carnivore species richness recorded per survey ranged from 0.63 at the East Bank in 2005 to 1.09 at the West Bank in 2005. Mean species richness recorded in 2004 was 0.74 at the West Bank and 0.83 at the East Bank. No significant differences were found in mean species richness between banks or years. Mean densities of the carnivore group ranged from 0.38 per 100 m^2 at the East Bank in 2005 to 0.66 per 100 m^2 at the West Bank in 2005. Mean densities recorded for 2004 were 0.46 per 100 m^2 at the West Bank and 0.57 per 100 m^2 at the East Bank (Table 3.7.5). No significant differences were found in mean carnivore densities per survey between years or banks. *Mycteroperca tigris* and *Lutjanus jocu* were among the most frequently recorded species in the carnivore group.

The size-frequency distributions of the carnivorous fishes were generally non-normal. Similarly, they were not normal in the 2002-2003 surveys. The distribution of carnivorous fish sizes appeared with two peaks for each bank in both years, with the larger peak occurring in the smaller size range at the East Bank in 2004 and in the larger sizes for the other banks and years. The diminished size range was primarily that of the 31-40 cm range and to a lesser degree the 21-30 cm range. The exception was the West Bank in 2004 with the most fishes in the 31-40 cm range. No carnivorous fishes were recorded in the ranges of 0-5 or 6-10 cm at either bank in either year (Figure 3.7.2).

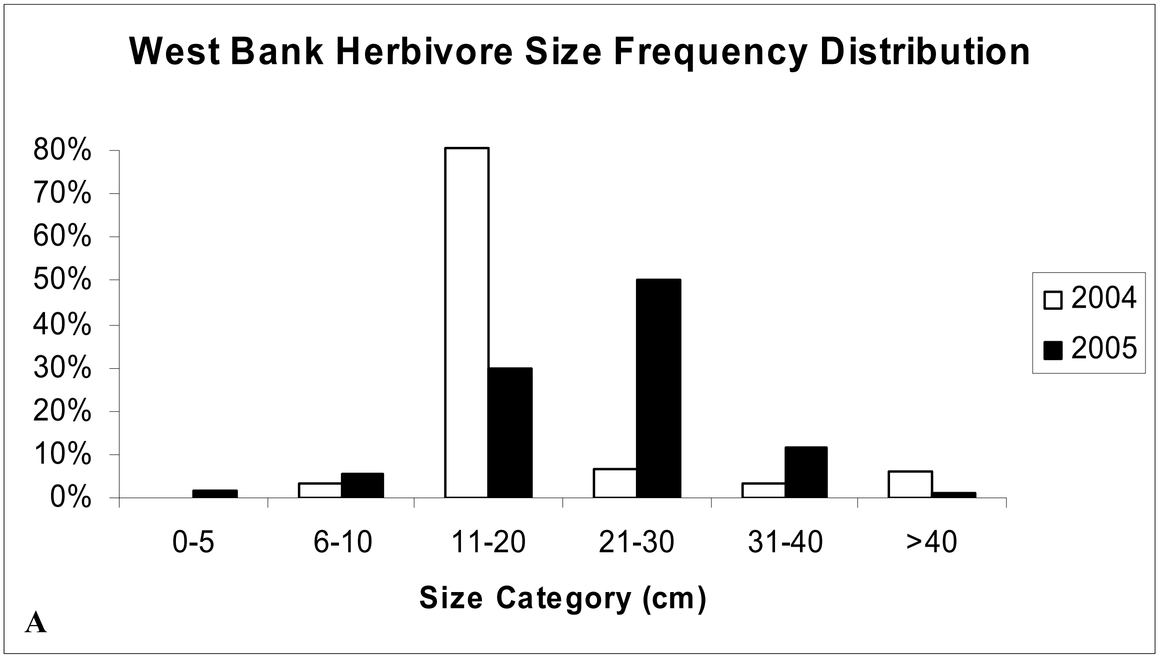
Analysis of selected species showed some differences in abundances between banks and years. A significant difference ($t=2.213$, $df=48$, $P=0.03$) in *Sphyraena barracuda* was found between 2004 and 2005 at the West Bank. The opposite was found during the 2002-2003 surveys, with significant differences occurring between banks but not years. A significant difference ($t=2.422$, $df=34$, $P=0.02$) was found for *Kyphosus sectator/incisor* between 2004 and 2005 at East Bank

(Table 3.7.5). During the 2002-2003 surveys, significant differences were found between banks but not between years.

Table 3.7.5.

Mean densities of fishes recorded per survey at the Flower Garden Banks during the 2004-2005 surveys (densities in numbers of fish per 100 m^2).

Category	**2004**		**2005**	
	East Bank	**West Bank**	**East Bank**	**West Bank**
Herbivores	10.47	6.33	6.74	5.14
Carnivores	0.57	0.46	0.38	0.66
Sphyraena barracuda	0.85	2.81	1.91	1.51
Kyophus sectator	1.84	1.45	0.31	0.54



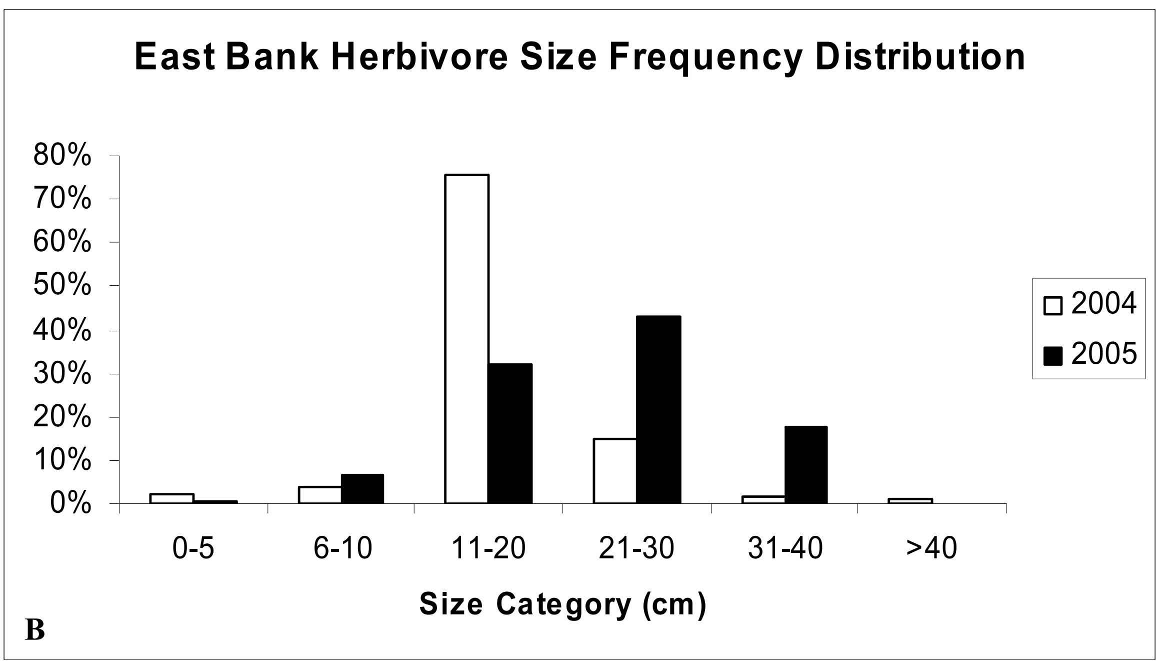
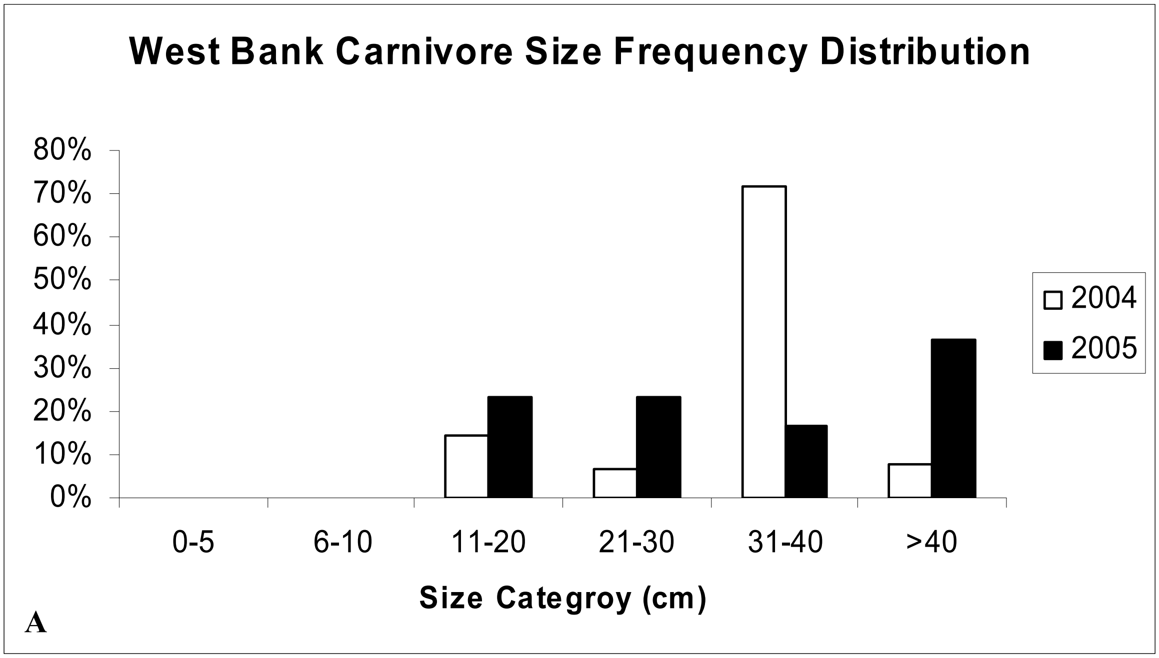


Figure 3.7.1. Herbivore size-frequency distributions at West (A) and East Banks (B) recorded during 2004 and 2005.



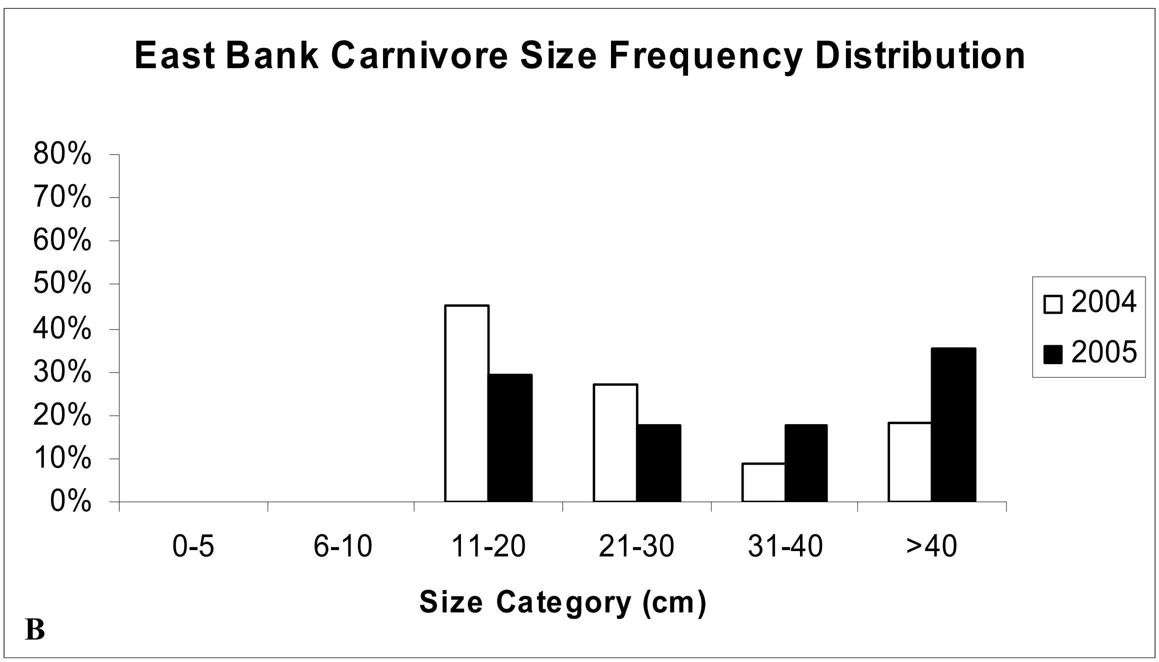


Figure 3.7.2. Carnivore size-frequency distributions at West (A) and East Banks (B) recorded during 2004 and 2005.

Table 3.7.6.

Species list of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005.

Fish Species	**Fish Common Names**	**Family Name**	**Trophic Guild**	**Number Observed**
Acanthurus bahianus	Ocean surgeonfish	Acanthuridae	Herbivore	75
Acanthurus chirurgus	Doctorfish	Acanthuridae	Herbivore	51
Acanthurus coeruleus	Blue tang	Acanthuridae	Herbivore	195
Melichthys niger	Black durgon	Balistidae	Omnivore	160
Canthidermis sufflamen	Ocean triggerfish	Balistidae	Omnivore	119
Parablennius marmoreus	Seaweed blenny	Blenniidae	Omnivore	8
Malacoctenus triangulatus	Saddled blenny	Blenniidae	Omnivore	13
Ophioblennius atlanticus	Redlip blenny	Blenniidae	Omnivore	28
Caranx hippos	Crevalle jack	Carangidae	Carnivore	159
Caranx latus	Horse-eye jack	Carangidae	Carnivore	19
Caranx lugubris	Black jack	Carangidae	Carnivore	12
Seriola dumerili	Amber jack	Carangidae	Carnivore	12
Caranx ruber	Bar jack	Carangidae	Carnivore	189
Elagatis bipinnulata	Rainbow runner	Carangidae	Carnivore	8
Chaetodon aculeatus	Longsnout butterflyfish	Chaetodontidae	Herbivore	28
Chaetodon ocellatus	Spotfin butterflyfish	Chaetodontidae	Herbivore	45
Chaetodon sedentarius	Reef butterflyfish	Chaetodontidae	Herbivore	57
Chaetodon striatus	Banded butterflyfish	Chaetodontidae	Herbivore	17
Amblycirrhitus pinos	Redspotted hawkfish	Cirrhitidae	Carnivore	7
Diodon hystrix	Porcupinefish	Diodontidae	Carnivore	2
Gnatholepis thompsoni	Goldspot goby	Gobiidae	Omnivore	4
Gobiosoma oceanops	Neon goby	Gobiidae	Omnivore	77
Holocentrus adscensionis	Squirrelfish	Holocentridae	Carnivore	8
Holocentrus rufus	Longspine squirrelfish	Holocentridae	Carnivore	3
Inermia vittata	Boga	Inermiidae	Planktivore	101
Emmelichthyops atlanticus	Bonnetmouth	Inermiidae	Planktivore	3200
Kyphosus sectator/incisor	Bermuda/Yellow chub	Kyphosidae	Omnivore	148
Halichoeres garnoti	Yellowhead wrasse	Labridae	Carnivore	61
Halichoeres radiatus	Puddingwife	Labridae	Carnivore	5
Halichoeres maculipinna	Clown wrasse	Labridae	Carnivore	207
Clepticus parrae	Creole wrasse	Labridae	Carnivore	1442
Bodianus rufus	Spanish hogfish	Labridae	Carnivore	99
Thalassoma bifasciatum	Bluehead	Labridae	Carnivore	711
Bodianus pulchellus	Spotfin hogfish	Labridae	Carnivore	40
Lutjanus jocu	Dog snapper	Lutjanidae	Carnivore	9
Lutjanus griseus	Gray snapper	Lutjanidae	Carnivore	4
Aluterus schoepfi	Orange filefish	Monocanthidae	Herbivore	1
Cantherhines pullus	Orangespotted filefish	Monocanthidae	Herbivore	2
Cantherhines macrocerus	Whitespotted filefish	Monocanthidae	Herbivore	4

Table 3.7.6. Species lists of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	Number Observed
Mulloidichthys martinicus	Yellow goatfish	Mullidae	Carnivore	76
Gymnothorax moringa	Spotted moray	Muraenidae	Carnivore	1
Lactophrys triqueter	Smooth trunkfish	Ostraciidae	Omnivore	14
Acanthostracion polygonius	Honeycomb cowfish	Ostraciidae	Omnivore	3
Lactophrys bicaudalis	Spotted trunkfish	Ostraciidae	Omnivore	1
Holacanthus tricolor	Rock beauty	Pomacanthidae	Herbivore	19
Holacanthus ciliaris	Queen angelfish	Pomacanthidae	Herbivore	11
Pomacanthus paru	French angelfish	Pomacanthidae	Herbivore	6
Stegastes adustus	Dusky damselfish	Pomacentridae	Herbivore	29
Chromis scotti	Purple reeffish	Pomacentridae	Planktivore	1
Chromis insolata	Sunshinefish	Pomacentridae	Planktivore	4
Chromis cyanea	Blue chromis	Pomacentridae	Carnivore	326
Abudefduf saxatilis	Sergeant major	Pomacentridae	Herbivore	30
Chromis multilineata	Brown chromis	Pomacentridae	Carnivore	3599
Stegastes diencaeus	Longfin damselfish	Pomacentridae	Herbivore	2
Stegastes leucostictus	Beaugregory	Pomacentridae	Herbivore	16
Stegastes partitus	Bicolor damselfish	Pomacentridae	Herbivore	494
Stegastes planifrons	Threespot damselfish	Pomacentridae	Herbivore	439
Microspathodon chrysurus	Yellowtail damselfish	Pomacentridae	Herbivore	62
Stegastes variabilis	Cocoa damselfish	Pomacentridae	Herbivore	61
Sparisoma rubripinne	Redfin parrotfish	Scaridae	Herbivore	1
Scarus taeniopterus	Princess parrotfish	Scaridae	Herbivore	148
Scarus vetula	Queen parrotfish	Scaridae	Herbivore	229
Sparisoma atomarium	Greenblotch parrotfish	Scaridae	Herbivore	1
Sparisoma chrysopterum	Redtail parrotfish	Scaridae	Herbivore	2
Sparisoma viride	Stoplight parrotfish	Scaridae	Herbivore	149
Sparisoma aurofrenatum	Redband parrotfish	Scaridae	Herbivore	62
Scarus iseri	Striped parrotfish	Scaridae	Herbivore	71
Scarus coelestinus	Midnight parrotfish	Scaridae	Herbivore	2
Equetus punctatus	Spotted drum	Sciaenidae	Carnivore	1
Mycteroperca tigris	Tiger grouper	Serranidae	Carnivore	48
Liopropoma eukrines	Wrasse bass	Serranidae	Carnivore	1
Mycteroperca bonaci	Black grouper	Serranidae	Carnivore	1
Mycteroperca interstitialis	Yellowmouth grouper	Serranidae	Carnivore	6
Epinephelus morio	Red grouper	Serranidae	Carnivore	2
Epinephelus guttatus	Red hind	Serranidae	Carnivore	6
Mycteroperca venenosa	Yellowfin grouper	Serranidae	Carnivore	4
Dermatolepis inermis	Marbled grouper	Serranidae	Carnivore	1
Serranus phoebe	Tattler bass	Serranidae	Carnivore	1
Paranthias furcifer	Creole fish	Serranidae	Carnivore	744
Cephalopholis cruentata	Graysby	Serranidae	Carnivore	15

Table 3.7.6. Species lists of fishes recorded in stationary visual surveys conducted at East and West Banks in 2004 and 2005 (continued).

Fish Species	Fish Common Names	Family Name	Trophic Guild	Number Observed
Cephalopholis fulva	Coney	Serranidae	Carnivore	1
Epinephelus adscensionis	Rock hind	Serranidae	Carnivore	15
Sphyraena barracuda	Barracuda, great	Sphyraenidae	Carnivore	297
Canthigaster rostrata	Sharpnose puffer	Tetraodontidae	Omnivore	130
Diodon holocanthus	Balloonfish	Tetraodontidae	Carnivore	1

3.8 Sea Urchin and Lobster Surveys

In 2004 at the East Bank, 0.005 individuals/m^2 of *Diadema antillarum* and two *Echinometra lucunter* were documented along the northern and eastern perimeter lines. At the West Bank in 2004, the southern and western lines were monitored for urchins and lobsters, and 0.11 individuals/m^2 (44 individuals) of *D. antillarum* were documented. This is a dramatic increase from previous monitoring results. Two *Panulirus argus* were also documented.

In 2005 at the East Bank, the northern and eastern perimeter lines were surveyed for urchin and lobster abundance. Urchin density at the East Bank in 2005 was 0.005 individuals/$m^{2.}$ One *Panulirus argus* was documented. At the West Bank, the southern and western lines revealed 0.013 individuals/m^2 of *Diadema antillarum* and one *Echinometra lucunter.* All transects were 2 m x 200 m.

4.0 DISCUSSION

4.1. CORAL

4.1.1 General

The East and West Flower Garden Banks, located 193 km and 172 km offshore from Galveston, Texas are reef communities situated at the northernmost range of Atlantic coral reefs. The first coral reef assessment of the Flower Garden Banks took place at the West Bank in 1972 (Bright and Pequegnat 1974). In 1973, the MMS (then Bureau of Land Management) instituted a Topographic Features Stipulation to protect topographic features in the Northwestern Gulf of Mexico (NWGOM) such as the Flower Garden Banks, from oil and gas activities (exploration and development) and in particular from the discharge of drilling effluents. The stipulations developed for the Flower Garden Banks consist of a No Activity Zone outside of the 100 m isobath based on the ¼, ¼, ¼, system (USDOI, MMS 1998). Additionally, a 4-Mile Zone was implemented around the East and West Banks, such that shunting of drilling effluents is restricted to within 10 m of the seafloor. In 1978, exploratory drilling began 1.7 km southeast of the East Bank (Gittings 1998). As a result, the MMS required that the benthic communities of East Bank be formally surveyed and monitored. Monitoring at the East Bank lasted until 1983. In 1983, NOAA funded a survey of anchoring damage at the East Bank (Gittings and Bright 1986). From 1988 to 1995, the MMS funded the annual monitoring of the East and West Flower Gardens. Congress designated the Flower Garden Banks as a National Marine Sanctuary in 1992. The NOAA Sanctuary office began co-sponsoring the long-term monitoring with MMS in 1996. Since 1988, the Flower Garden Banks coral reefs have changed little in terms of coral cover, dominance and diversity, prevalence of coral disease, condition of water quality, and fish population dynamics. Results from the 2004-2005 monitoring data indicate continuation of that stability.

The Flower Garden Banks coral reefs exhibited high coral cover during the 2004-2005 monitoring period (Table 4.1.1). The *Montastraea annularis* complex and *Diploria strigosa* continued to be the dominant coral species at both banks. Crustose coralline algae, fine turf algae, and bare rock (CTB) was in general the most abundant non-coral category of substratum cover, ranging from ~12-21%. The exception was the East Bank in June 2005 (34%), when macroalgae increased, most likely due to seasonal factors. Crustose coralline algae, a component of CTB, is thought to be a cue for settlement of coral recruits, and all components of CTB are indicative of high herbivory (Morse et al. 1988, Aronson and Precht 2000). Macroalgae were less abundant, ranging from ~12-34%, with an increase from 2004 to 2005 at the East and West Banks (Figure 3.1.3). High levels of herbivory are known to occur at the Flower Garden Banks, with robust herbivorous fish populations and the occurrence of fish biting on hard corals. Disease and bleaching were not measured in random transect videography, and the repetitive quadrat data also showed extremely low levels of bleaching (<0.57%) and disease (0%) for both years. Low levels of macroalgae, high cover of CTB, high coral cover, and low levels of coral disease and bleaching are all indications of the excellent condition of the coral reefs at the Flower Garden Banks.

Coral accretion was measured through the coring of *Montastraea faveolata* at the Flower Garden Banks. Sclerochronology results revealed growth rates comparable to growth rates of past observations at both banks (Dokken et al. 2003). Six out of eight cores at each bank showed an interruption in linear extension. Further investigation into the disconformity found within the *M. faveolata* cores will be conducted in the future. To study the lateral growth of an important contributor to coral cover at the banks, the margins of colonies of *Diploria strigosa* were photographed. Photographs of *D. strigosa* showed lateral growth from 2003 to 2004, and continued growth at the West Bank from 2004 to 2005, while at the East Bank the *D. strigosa* margins receded slightly between 2004 and 2005. For the period 2003-2005 overall, there was an increase in *D. strigosa* margins.

Water quality parameters indicated good water quality when measurements were valid. Numerous problems occurred with YSI datasondes failing, creating uncertainty in the quality of data. We recommend refurbishing datasondes and/or datasonde probes as well as exploring the use of other technologies to improve water quality measurement.

Fish surveys showed robust fish assemblages that were dominated by herbivorous fish and included healthy carnivore populations. Urchin surveys detected low densities of *Diadema antillarum,* except at the West Bank in 2004 where 0.11 individuals/m^2 were recorded. The following year, abundance declined to 0.013 individuals/m^2. These populations have not recovered to pre-1984 levels, which ranged from 0.54-1.63 individuals/m^2 between 1970 and 1983 (Bright and Pequegnat 1974; CSA 1984).

GIS-based maps using the four known geographic corner locations of the study sites at East and West Banks are being developed. Using photographs of the repetitive quadrat markers and lateral growth station markers and their known relative positions, we are creating a photomosaic for each site. This photomosaic will have considerable gaps between photostations, but each successive year can be added to the map and in this way a user will be able see a map of the repetitive and lateral growth stations for any given year. Eventually, each repetitive and lateral station will be mapped using GPS to obtain the exact and true geographic location. It would be possible, although costly, to georeference random transects, and in this way gradually develop a complete visual map of the coral reefs within the 10,000 m^2 study sites at the East and West Banks.

Table 4.1.1.

Percent coral cover (± SE) at both banks for both sampling years from random transect videography data.

East Bank 2004	East Bank 2005	West Bank 2004	West Bank 2005
64.13 ± 2.70	49.55 ± 3.01	60.41 ± 2.94	54.41 ± 3.13

4.1.2 Random Transects

The Flower Garden Banks continue to have high coral cover compared to other reefs of the western Atlantic (Aronson et al. 1994; Gardner et al. 2003). Univariate analysis of the random transect data revealed that coral cover at the East and West Banks remained stable in 2004 and 2005. Coral cover was also consistent with values from earlier studies (Dokken et al. 2001, Dokken et al. 1999, CSA 1996, Gittings et al. 1992), highlighting the stability over time of the coral assemblage at the Flower Garden Banks (Figure 4.1.2).

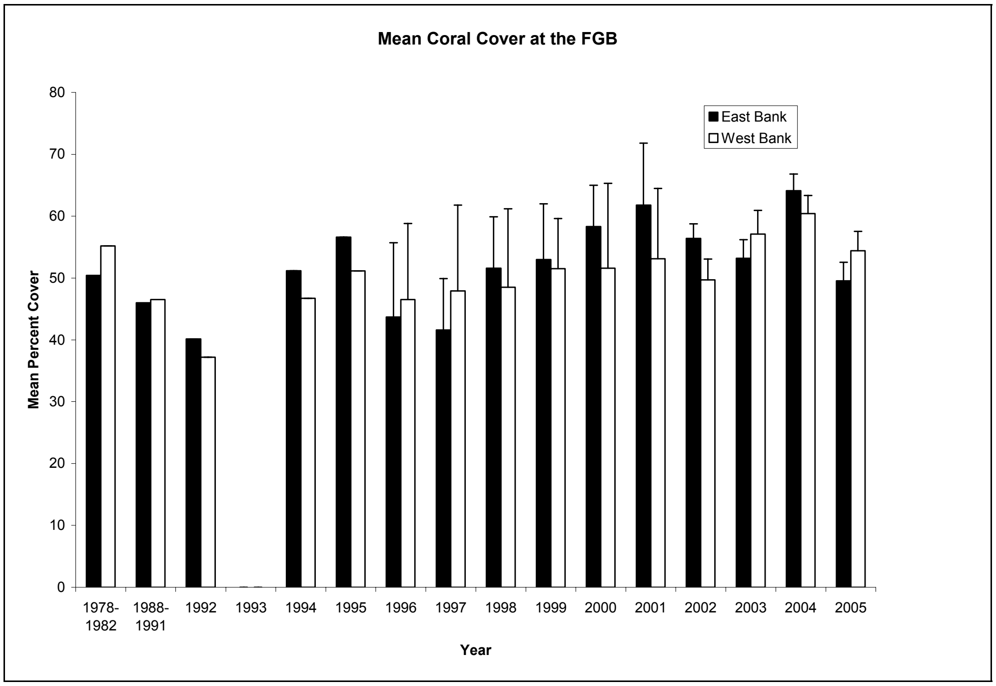


Figure 4.1.2. Mean percent coral cover at the Flower Garden Banks over time, showing the consistently high coral cover. No percent cover data were reported in 1993. 1978-1982 from Gittings et al. (1992), who reported data from Kraemer (1982). 1988-1991 from Gittings et al. (1992). 1992-1995 from USDOI, MMS (1996). 1996-2001 from Dokken et al. (2003). 2002-2003 from Precht et al. (2006).

East Bank Comparison 2004-2005. The random transect data for the East Bank in 2004 and 2005 showed similar values for all parameters measured, except for the macroalgae and CTB categories (Table 3.1.1). Macroalgae increased from 12.03% to 34.03% from 2004 to 2005. CTB decreased from 20.89% to 11.96% from 2004 to 2005. Although macroalgae and CTB fluctuated during the monitoring period, there was no change in coral cover during the sampling period, which remained stable from 2004 to 2005 (64.13% to 49.55%). The site x year interaction was not significant (P= 0.012).

All coral species, including the *Montastraea annularis* species complex, remained stable from 2004 to 2005 at the East Bank (Table 3.1.1). *Diploria strigosa* continued to be the second most abundant coral. This species showed a decline from 2004 to 2005, but this is most likely due to transect placement and probably does not reflect a decrease in *D. strigosa* cover at the Flower Garden Banks overall. Past studies have shown similar variations in relative abundance from year to year, attributable to sampling error (Dokken et al. 2003, 1999). Diversity (H') did not change significantly at the East Bank during the sampling period. H' was low at the East Bank due to the low species richness values and the dominance of a few species, namely the *Montastraea annularis* complex and *Diploria strigosa*.

West Bank comparison 2004-2005. Percent cover data for random transects at the West Bank in 2004 and 2005 showed similar values for all parameters overall. Macroalgae increased in transects from 14.75% to 18.35% from 2004 to 2005. The opposite trend was observed for CTB cover at the West Bank: 20.85% in 2004 to 18.27% in 2005. This inverse relationship at both banks is to be expected since these two components make up the majority of non-coral substratum at the Flower Garden Banks.

Coral cover decreased slightly at the West Bank, from 60.41% in 2004 to 54.41% in 2005. The dominance of the *Montastraea annularis* complex continued through this monitoring period. Diversity (H') at the Flower Garden Banks was lowest at the West Bank in 2005 and highest at East Bank in 2005.

Macroalgae and CTB were inversely related during the sampling period. Macroalgae increased from 2004 to 2005, and CTB declined. The site x year interactions were significant for both parameters ($P < 0.001$ for macroalgae and $P = 0.012$ for CTB), rendering the main effects difficult to interpret. The inverse relationship between CTB and macroalgae was evident in 2002-2003 as well. We believe the increase in macroalgae from 2004 to 2005 is a reflection of the different sampling periods in the two years. Data from 2004 were collected in the fall (September and November 2004), whereas the 2005 data were collected in June. Seasonal effects have been documented for coral reef macroalgal populations (Diaz-Pulido and Ferreira 2002). It is unlikely that CTB disappears during times of increased macroalgal coverage; rather, it is covered by macroalgae when conditions are favorable for macroalgal growth. The CTB category was the second highest cover category after coral in 2004 at the East Bank, and even with the increased cover of macroalgae at the West Bank, connoting high rates of herbivory and an overall healthy reef system. Increases in macroalgae have been documented in previous studies, when sampling was conducted in the fall, despite these increases, coral cover remained stable (CSA 1996, Dokken et al. 1999, Dokken et al. 2001).

Qualitative Comparison of Random Transect Results from 1992-2005 for Selected Parameters. A qualitative comparison of the dominant cover components from the random transects showed interesting results for several cover categories: *Montastraea annularis* species complex, algae, and "reef rock." The data analyzed in this section were collected by three different groups: Continental Shelf Associates, Inc. from 1992 to 1995, Dokken et al. from 1996 to 2001, and PBS&J from 2002 to 2005 (Table 4.1.2). The algae category from 1992 to 2001 was roughly equivalent to macroalgae, as analyzed in 2002-2005. The reef rock category from 1992 to 1995 and 1998-2001 included bare substrate and is equivalent to the 2002 to 2005 CTB category. In 1996 and 1997 no data were recorded for the reef rock category.

The *Montastraea annularis* complex showed an overall increase in cover during the period of 1992-2005 at the West Bank. It fluctuated at the East Bank but remained consistently at or above 20% cover (Figure 4.1.3). There were slight decreases in the *M. annularis* complex cover in 1996, 1999, 2003 at the East Bank and in 1996, 2000, and 2004 at the West Bank. These decreases coincide with increases in the algal component and decreases in the reef rock category. Despite slight depressions in the *Montastraea annularis* complex, the upward trend was reestablished after one year at both banks (Figures 4.1.3).

Diploria strigosa, important as the second most common species at the Flower Garden Banks, showed variation over time, but never decreased below 3.2% (measured in 2002) or exceeded 13.4% (measured in 2004) at the West Bank. In 2004 and 2005 *D. strigosa* cover was ~6-12% at the East Bank and ~7-13% at the West Bank (Table 4.1.2).

Porites astreoides, the third most common species at the Flower Garden Banks, was lowest at the West Bank and showed no change in relation to other coral species, algae, or reef rock at either bank. It has increased slightly since 2003 at the East Bank (Table 4.1.2). In 2004 and 2005, *P. astreoides* cover was ~8% at the East Bank and ~4-5% at the West Bank (Table 4.1.2).

Regional and local weather patterns affect benthic communities such as those at the Flower Garden Banks. Changes in the frequency and severity of the El Niño–Southern Oscillation (ENSO) have been partially responsible for transitions from coral-dominated communities to algae-dominated reef systems in the Caribbean (Goreau and Hayes 1994; Glynn 1993; Glynn 1984). In 1983, 1987, 1995, and 1998, severe ENSO events affected the western Atlantic causing coral bleaching, subsequent coral mortality, and then colonization of substrate by algae (Glynn 1984; McField 1999, Aronson et al. 2000). The Flower Garden Banks, being a system where these severe effects have not been documented, provides an opportunity to understand the dynamics of coral cover, macroalgae, and CTB.

Macroalgae tend to be ephemeral, with different species abundant under different seasonal conditions (Diaz-Pulido and Garzon-Ferreira 2002). Algal cover at the banks, here taken to mean macroalgae, remained relatively low from 1992 to 1998, never reaching more than 4.78% at either bank until it increased dramatically in 1996 at East Bank and at both banks in 1999 (Table 4.1.2, Figure 4.1.3). Concurrent with the increase in algae, the reef rock category declined from ~27% to ~11% at the East Bank in 1999 and from ~21% to ~8% in 2000 at the West Bank. In 2001 the reef rock category began an increasing trend at both the East and West Banks, while algae declined (Figure 4.1.3). At the same time that algae increased and reef rock decreased, the *Montastraea annularis* complex decreased slightly in 1999 (East Bank) and 2000 (West Bank), but continued to trend upward a year later (Figure 4.1.2).

Shifts in algae, *Montastraea annularis* complex, and reef rock occurred in the aftermath of the strong ENSO events of 1995 and 1998, which caused widespread coral bleaching throughout the Caribbean. Many areas affected by severe bleaching experienced coral mortality, and increased turf and macroalgae cover, in the weeks and months following ENSO-related heating events (McField 1999; Aronson et al. 2000; Ostrander et al. 2000). After the 1995 ENSO in Belize, McField (1999) documented 50% coral bleaching at fore-reef sites in Belize. Six months after the high-temperature event, ~10% of colonies experienced at least partial mortality. After the 1998 ENSO event, Kramer and Kramer (2000) reported remnant bleaching at fore-reef sites eight months after the onset of bleaching. Aronson et al. (2000, 2002; see also Peckol et al. 2003) reported nearly 100% mortality of the dominant coral *Agaricia tenuifolia* at southern lagoon reefs of the Pelican Keys, Belize. Mumby (1999) found that although ~80% of coral colonies bleached at Glover's Atoll (Belize), the colonies regained their pigment in subsequent months.

In contrast to these events, after the ENSO of 1995 and 1998, the Flower Garden Banks experienced a slight increase in macroalgae and a decline in bare rock (CTB). While *Montastraea annularis* complex, the dominant coral taxon at the Flower Garden Banks, declined slightly at the East Bank in 1996, there was no measurable effect at the West Bank. By 2000, *M. annularis* complex cover was near its highest level (Table 4.1.2, Figure 4.1.3). Such trends have not been documented at other reefs in the Caribbean/western Atlantic region. These slight shifts in community dynamics continue to be an interesting avenue of research and the coral reef system of the Flower Garden Banks continues to be one of the best places to study the subtleties of these patterns.

Table 4.1.2.

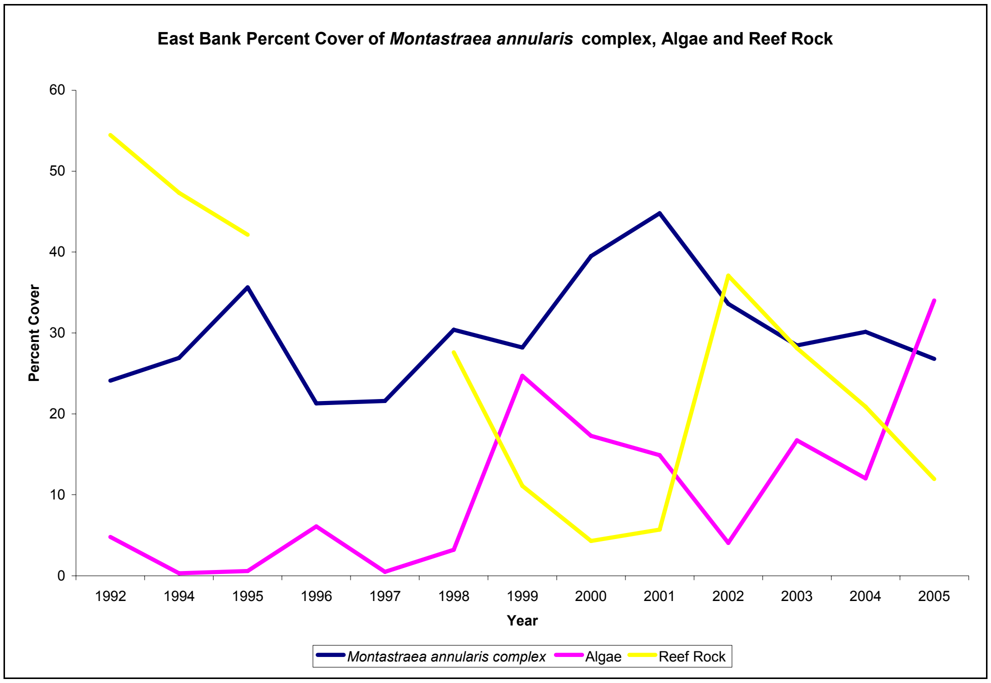
East and West Bank Random Transect Data for predominant cover categories as reported in CSA (1996) for data from 1992-1995 and Dokken et al. (2003) for data from 1996-2001.

East Bank Random Transect

	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
M. annularis spp. complex	24.12	26.93	35.65	21.3 (14.2)	21.6 (8.1)	30.4 (11.1)	28.2 (11.7)	39.5 (9.6)	44.8 (12.9)	33.59 (3.86)	28.47 (2.98)	30.14 (4.76)	26.8 (4.09)
Diploria strigosa	4.69	8.92	7.92	10.1 (7.1)	5.1 (4.4)	8.3 (3.7)	12.4 (6.0)	6.2 (2.8)	3.9 (4.1)	6.96 (1.69)	6.19 (1.55)	12.13 (2.82)	5.95 (1.26)
Montastraea cavernosa	1.49	4.80	3.20	3.7 (5.3)	4.7 (4.9)	3.5 (2.9)	2.4 (2.8)	4.8 (5.7)	3.6 (5.0)	3.9 (1.08)	4.24 (1.41)	7.73 (1.94)	3.4 (1.14)
Porites astreoides	4.57	3.89	2.71	3.6 (1.5)	5.3 (3.0)	4.2 (3.0)	3.4 (1.7)	2.6 (1.7)	4.6 (2.7)	6.79 (0.83)	5.69 (0.98)	8.19 (0.99)	7.55 (1.19)
Algae	4.78	0.29	0.57	6.1 (5.2)	0.5 (0.6)	3.2 (2.6)	24.7 (13.2)	17.3 (4.9)	14.9 (5.6)	4.06 (0.75)*	16.74 (2.05)*	12.03 (2.77)	34.03 (2.58)
Reef Rock	54.46	47.31	42.15	-	-	27.6 (5.9)	11.1 (8.2)	4.3 (1.7)	5.7 (3.6)	37.07 (2.69)*	28.12 (2.05)*	20.89 (3.08)	11.96 (1.49)

West Bank Random Transect

	1992	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
M. annularis spp. complex	23.02	24.95	31.00	27.2 (8.3)	27.7 (9.9)	28.4 (11.9)	31.7 (8.6)	30.9 (11.6)	35.1 (12.0)	31.73 (3.57)	33.8 (4.31)	31.70 (2.70)	36.2 (3.50)
Diploria strigosa	6.15	10.15	6.66	7.9 (3.5)	9.1 (5.9)	9.6 (4.8)	10.9 (7.8)	8.1 (6.7)	9.5 (5.8)	3.2 (0.91)	9.04 (2.68)	13.41 (1.74)	6.68 (1.29)
Montastraea cavernosa	0.87	3.15	2.33	1.5 (2.2)	4.3 (4.2)	2.6 (2.4)	2.4 (3.5)	5.8 (11.7)	2.1 (3.7)	2.74 (1.16)	2.67 (1.10)	3.70 (1.01)	2.43 (0.69)
Porites astreoides	1.49	2.55	2.44	2.5 (1.4)	2.7 (2.3)	2.4 (2.0)	2.7 (1.9)	2.5 (1.6)	2.0 (0.9)	3.44 (0.74)	3.77 (0.46)	5.19 (0.62)	4.04 (0.46)
Algae	4.45	0.42	2.7	4.5 (2.9)	0.1 (0.1)	2.3 (1.3)	18.8 (6.2)	22.6 (14.0)	25.4 (7.3)	19.14 (1.4)*	8.41 (1.41)*	14.75 (1.50)	18.35 (1.44)
Reef Rock	56.56	51.08	45.85	-	-	20.7 (11.2)	21.1 (9.8)	8.5 (3.7)	4.6 (2.9)	27.63 (3.14)*	31.63 (3.04)*	20.85 (2.11)	18.27 (1.67)



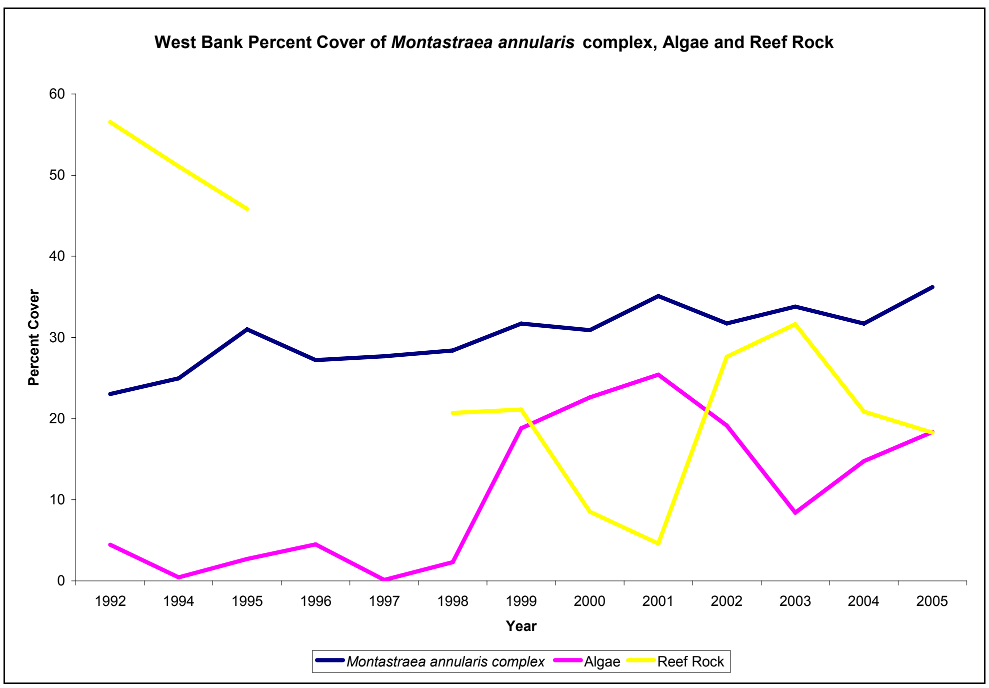


Figure 4.1.3. Percent cover of *Montastraea annularis* complex, algae, and reef rock from 1992-2005: East and West Banks.

4.1.3 Sclerochronology

Coral growth rates vary due to depth, salinity, temperature, light, as well as genetic factors and relative position on the colony (Knutson et al. 1972; Bak 1974; Weber and White 1977; Highsmith 1979; Hudson 1981a; Hudson et al. 1989; Smith et al. 1989). Accretionary growth rates of *Montastraea annularis* were documented over a wide geographic range of reefs throughout the Caribbean and varied from 3 to 12 mm/yr (Weber and White 1977). Growth rates were shown to vary with depth, with faster growth rates occurring in shallower water (Weber and White 1977). Hudson (1981a) reported growth rates of *M. annularis* in the Florida Keys to be 6.3 mm/yr on offshore reefs and 8.2 mm/yr on mid-shelf reefs from 1928-1978. The accretionary growth of *M. annularis* at the Flower Garden Banks was documented by Hudson and Robbin (1980), who obtained an average annual growth rate of 8.46 mm/yr and a range of 7.15-10.58 mm/yr from 1887 to 1979. Dokken et al. (2001) showed a lower growth rate for the period 1985-1999, with an average of 6.80 mm/yr at the East Bank and 5.13 mm/yr at the West Bank. The shorter sampling period was offered as an explanation for the observed differences. However, Dodge and Lang (1983) used data from Hudson and Robbin (1980) to correlate growth rates at the Flower Garden Banks to temperature and discharge from the Atchafalaya River. They found an overall decline in temperature and growth rates from 1950 to 1960 and variable growth values from the early 1960s to 1979, which were lower than pre-1957 rates (Dodge and Lang 1983).

For the 2005 sampling period, *Montastraea faveolata* growth ranged from 3.19-14.54 mm/yr at the East Bank and 2.75-8.78 mm/yr at the West Bank. These results differed slightly from the growth rates reported by Precht et al. (2006) but agreed with past work by Dokken et al. (2003), who reported a wider range of growth rates at the East and West Banks. Growth rates for *M. faveolata* at the East Bank, and less so at the West Bank, continued to be in the middle to upper range of Flower Garden Banks growth rates as recorded by Hudson and Robbin (1980). Three out of four cores do show discontinuities in accretion but they occur at different times in each core (Table 3.2.1). These discontinuities may be signs of stress or partial mortality, from which the colonies subsequently recovered. Stress or partial mortality may have been caused by bleaching, which has occurred throughout the Caribbean region and the Flower Garden Banks since long term monitoring began (Dokken et al. 2001, 2003).

The current sampling protocol, in which four cores are taken from each bank every other year, is useful for tracking the short-term growth rates (~10 years) of large *Montastraea faveolata* heads and monitoring physical changes within the cores. Long-term growth rates (10+ years) cannot be obtained using this method. Longer cores on which stable isotope analysis can be conducted, such as the ones taken by Amy Bratcher at Texas A&M University, Department of Oceanography, will show salinity and temperature data over time. This information will be a valuable addition and reveal regional influences, such as the Mississippi river output, on water quality affecting the coral reefs at the Flower Garden Banks.

Why *Montastraea faveolata*? Previous research on sclerochronology in the *Montastraea annularis* species complex has been extensive (Dustan 1975; Hudson et al. 1976; Emiliani et al. 1978; Foster 1980; Hudson 1981a; 1981b; Graus and Macintyre 1982; Dodge and Lang 1983; Dodge and Brass 1984; Leder et al. 1991). These studies have demonstrated that growth in massive colonies of *M. faveolata* is more or less evenly distributed over the entire surface except for the underside, and distinct annual growth bands are accreted along the axis of growth. An annual band is comprised of a high and low density portions, representing changes in both the rate of linear skeletal extension and calcification. It has also been shown that accelerated growth in *Montastraea* occurs during seasonally cooler periods (Leder et al. 1991). In addition, Highsmith (1979) noted that in *Montastraea* samples from Belize, the high-density bands appear to be deposited only for short periods of time, whereas the low-density bands are produced for a greater part of the year when compared with *Montastraea cavernosa* and *Porites astreoides* from the same locality.

Reef Disturbance, Coral Growth and Stress Bands. Growth rate of corals has been identified as one of the best quantitative measures of assessing stress due to disturbance because this parameter integrates a variety of physiological processes (Brown and Howard 1985). It is also widely accepted that coral growth rates may be inherently variable for a single species within reef zone and even within individual colonies (Buddemeier and Kinzie 1976). Gladfelter et al. (1978) described some species as conservative in their growth. Specifically, they argued that the *Montastraea annularis* species complex shows relatively little response in growth rate to varying environmental conditions. The use of X-radiography, however, has shown significant suppression of coral growth as a result of disturbance. This has been observed during short-term exposing *Montastraea faveolata* to high concentrations of drilling mud (Hudson and Robbin 1980), as well as by transferring *M. faveolata* from an offshore location to a more stressful inshore site (Hudson 1981b).

In long-term growth studies of *M. faveolata* from the East Bank (Hudson and Robbin 1980), and also sites within the Key Largo Coral Reef National Marine Sanctuary, Florida (Hudson 1981a; 1984), a decline in growth rates has been observed. In these studies, the authors could not directly attribute apparent growth suppression to any single environmental disturbance. They did note, however, that reduced growth rates in the Florida Keys coincided with a period of dredge-and-fill operations. Dodge and Lang (1983) and Dodge and Szmant-Froelich (1984) suggested that the decline in *M. faveolata* growth rates at the Flower Gardens may have been due to water temperature fluctuations and increasing river discharge.

Another feature revealed by X-radiography is the presence of high-density skeletal deposits or "stress" bands which have been observed in sections of *Montastraea annularis* during periods of rapid chilling and mixing of shallow inshore waters (Hudson et al. 1976; Hudson 1977; 1981a; Shinn et al. 1989) and during periods of increased sea surface temperatures and coral bleaching (Leder et al. 1991). We are currently evaluating the causality of skipped bands or lost years (visible as disconformity surfaces) in our core samples. These scars result from localized coral mortality followed by healing and re-sheeting of the colony.

4.1.4 Lateral Growth

Lateral growth measurements have been used for much of the monitoring history of the Flower Garden Banks and results have shown overall growth of monitored margins, with high variability among individual colonies (Dokken et al. 2001, 2003; Precht et al. 2006). Lateral growth measurements do not take into account the fact that individual corals may grow at different rates along different margins. While some margins may be advancing, others on the same colony may be retreating, potentially altering the overall picture of lateral change in a given colony and by extension a given bank and year. Additionally, lateral growth measurements do not take into account the height extension of *D. strigosa*.

Overall *Diploria strigosa* colonies showed a ~32% increase in colony area at both banks from 2003-2004. The 2004-2005 dataset was quite different at both banks. At the East Bank there was a decrease of 10% from the *Diploria strigosa* margins measured, while the West Bank continued to increase in cover by 38%. Aside from the decrease at the East Bank from 2004-2005, there was an overall gain in lateral growth of *D. strigosa* from 2003-2005, a continuation of stability of the second-most abundant scleractinian coral at the Flower Garden Banks.

4.1.5 Repetitive Quadrats

Study Site Quadrats. Repetitive 8 m^2 quadrats were analyzed for percent cover of benthic components, including coral species, algae, and the cover of coral health indicators (bleaching, paling, concentrated fish biting, isolated fish biting, and disease), and were compared between 2004 and 2005. Thirty eight images were analyzed for the East Bank in 2004 and 41 images were analyzed in 2005. Twenty images were analyzed for the West Bank in both 2004 and 2005. Higher coral cover estimates are obtained from the repetitive quadrats in comparison to the random transects at both the East and West Banks. The reasons for this difference are not clear; however, higher percent coral cover in repetitive quadrats relative to random transects was also documented in previous reports (Dokken et al. 2003, Precht et al. 2006). One likely reason for this difference is that repetitive quadrat stations were placed in areas of high coral cover to monitor community change over time.

Species distribution was similar to that in the random transects, with the predominant corals being *Montastraea annularis* species complex, *Diploria strigosa*, and *M. cavernosa*. The *M. annularis* complex had higher cover estimates in the repetitive quadrats (East Bank average from 2000-2005: 40.02%; West Bank average for the same period: 39.5%) than in the random transects. *Porites astreoides* and *M. cavernosa* were roughly equivalent, but *M. cavernosa* was consistently higher than *P. astreoides* in repetitive quadrat estimates, which was the opposite of trends in the random transect data (Dokken et al. 2003). These differences are small and probably caused by artifacts of the methodologies.

Coral disease was absent from analyzed quadrats at both banks in both years (Table 3.4.1). This appears to signify a decrease in disease from past monitoring, when low levels of disease were observed (West Bank 2000-2001: 0.3-0.4% cover; Dokken et al. 2003). It should be remembered that disease identification from photographs is problematic. Paling and bleaching were extremely rare at both banks, ranging from 0-0.57% cover. These values are similar to findings from previous investigators (Dokken et al. 2003). Bleaching occurred most frequently on colonies of *Millepora alcicornis* at the East Bank in 2005 (Table 3.4.2), while paling showed no pattern and occurred less frequently. Concentrated fish biting and isolated fish biting were similarly low at each bank, ranging from 0.30-4.73 % cover in both years (Table 3.4.1). Fish biting occurred primarily on the *M. annularis* complex and appeared to be more common at the East Bank in both years (Table 3.4.2).

To document the dynamics of particular coral colonies at the Flower Garden Banks, repetitive quadrats were analyzed quantitatively using planimetry. Four to six colonies of frame-building species, the margins of which were clearly defined, were chosen for analysis. *Montastraea annularis* species complex, the main contributor to coral cover at the Flower Garden Banks, appeared to decrease slightly from 2003 to 2004 at both banks, but the two banks did not differ significantly (t=0.25, df=127, P=0.8). *M. annularis* species complex increased from 2004 to 2005 at both banks, with no significant differences between banks (t=1.45, df =46, P=0.154). When considered together, the East and West Banks showed a net growth of the *M. annularis* complex similar to the *Diploria strigosa* colonies documented in the lateral growth stations.

Deep Station Quadrats. At the East Bank, nine deep stations (32-40 m) were established in April 2003 and all were photographed in September 2004 and June 2005. Coral cover is high (82.5%) in these deeper quadrats. This area is dominated by *M. annularis* complex and *M. cavernosa,* unlike the shallower study sites, and unlike the deeper *Stephanocoenia-Millepora* zone (36-48 m) described by Rezak et al. (1985). The difference between this area and the one described by Rezak et al. (1985) is probably due to natural spatial variability and/or the small sample area of 72 m^2.

Lateral growth of *Montastraea annularis* complex colonies at the deep stations remained stable from 2003-2005. A t-test assuming equal variances showed that the change in lateral growth between the two annual periods (2003-2004 and 2004-2005) was not significantly different (t=1.2, df=31, P=0.23).

4.1.6 Perimeter Videography

Videography of the perimeter lines and 360° panoramic views of the corner markers at the East and West Banks provided a general overview of coral condition and fish populations at the study sites in 2004 and 2005. Similar to the findings from the random transects, coral condition was very good at both banks for both years. There were no signs of disease and only a few isolated incidences of bleaching. The main impacts to coral colonies, observed at both banks during the sampling period, were concentrated and isolated fish biting. Concentrated fish biting is most likely caused by individuals from the genus *Sparisoma* (Bruckner and Bruckner 2000). Initial- and terminal-phase *Sparisoma viride* are known to remove coral polyps during their foraging activities, creating deep lesions on coral heads (Bruckner and Bruckner 2000). When *S. viride* were experimentally removed from affected reef areas in the Caribbean, lesions healed completely or ceased to increase in size (Bruckner and Bruckner 2000). Isolated fish biting at the Flower Garden Banks is attributed to damselfish territories.

From 2002 to 2005, *M. faveolata* and *M. franksi* were the most impacted coral species on the East Bank. In contrast, the two most affected coral species on the West Bank were *M. faveolata* and *Diploria strigosa* between 2002 and 2003 and *M. faveolata* and *M. franksi* between 2004 and 2005.

Fish populations were similar at both banks during both years (Table 3.5.2). However, fish were most abundant at the East Bank in 2004 and the West Bank in 2005. In 2005, the West

Bank had the most fish, with 346 individuals documented. Compared to 2002-2003, fish counts in 2004-2005 decreased markedly. A reported 901 individuals were observed at the East Bank in 2003 compared to 302 in 2004. The reason for this is not clear; however, looking at the fish data from cylinder surveys presented in this report, the highest abundance occurred at the East Bank in 2004. Thus, the video perimeter may not be indicative of fish populations.

Fish recorded in the 360° panoramic views were largely represented by water-column species, including Creole wrasse, Creole fish, Brown and Blue chromis. Due to the angle of the video camera, species recorded along the perimeter lines included these species as well as damselfish. For this reason, fish cylinders are more representative of actual fish populations at the Banks, although uncommon species such as grouper were documented in the video. It is not possible to ascertain fish sizes with this surveying technique because there is no scale reference. The perimeter surveys are intended to provide a general overview of ecosystem health.

It is important to note that a number of human errors could have influenced the data. First, while the perimeter lines at both banks were generally in the same locations, the transect lines did shift. This is due to the flexible nature of the transect line between the fixed corner markers, which are 100 meters apart. This was mostly apparent on the West Bank between 2004 and 2005: compared to the East Bank, fewer coral comparisons were made on the West Bank because of the shifting transect line and a lack of overlapping video footage. In addition, the 2 m height above the substratum was not always maintained, which changed the view and therefore the corals analyzed.

4.1.7 Disease and Bleaching at the Flower Garden Banks

Previous annual monitoring reports (Gittings et al. 1992; CSA 1996; Dokken et al. 1999, 2001, 2003; Precht et al. 2006) have documented the presence of coral diseases at the Flower Garden Banks, with a low prevalence in comparison to other reefs throughout the region. Studies focused on Caribbean reefs have documented alarming trends related to increases in the number and incidence of coral diseases (Richardson 1998; Green and Bruckner 2000; Porter et al. 2001; Richardson et al. 2001; Sutherland et al. 2004; Weil 2004) as well as the number of coral species susceptible to disease (Richardson et al. 1998; Porter et al. 2001).

In February 2005, managers of the Flower Garden Banks National Marine Sanctuary documented for the first time an outbreak of coral disease on the reefs. The affected corals exhibited disease signs very similar to those described for white plague. Observations made during field cruises in February and April 2005 indicated that at least seven coral species were affected: *Montastraea annularis*, *M. franksi*, *M. faveolata*, *Diploria strigosa*, *Stephanocoenia intersepta, Colpophyllia natans*, and *Porites astreoides* (Flower Garden Banks National Marine Sanctuary 2005a, b). Figure 4.1.7 below shows one of the affected coral colonies.

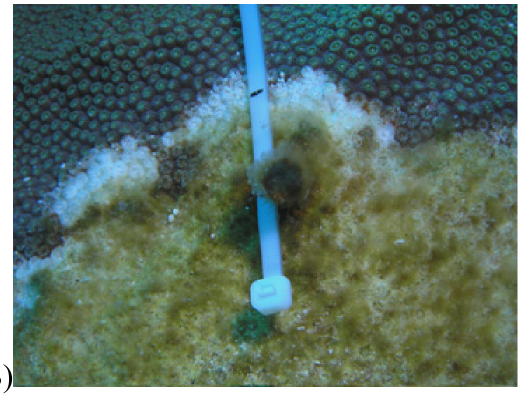
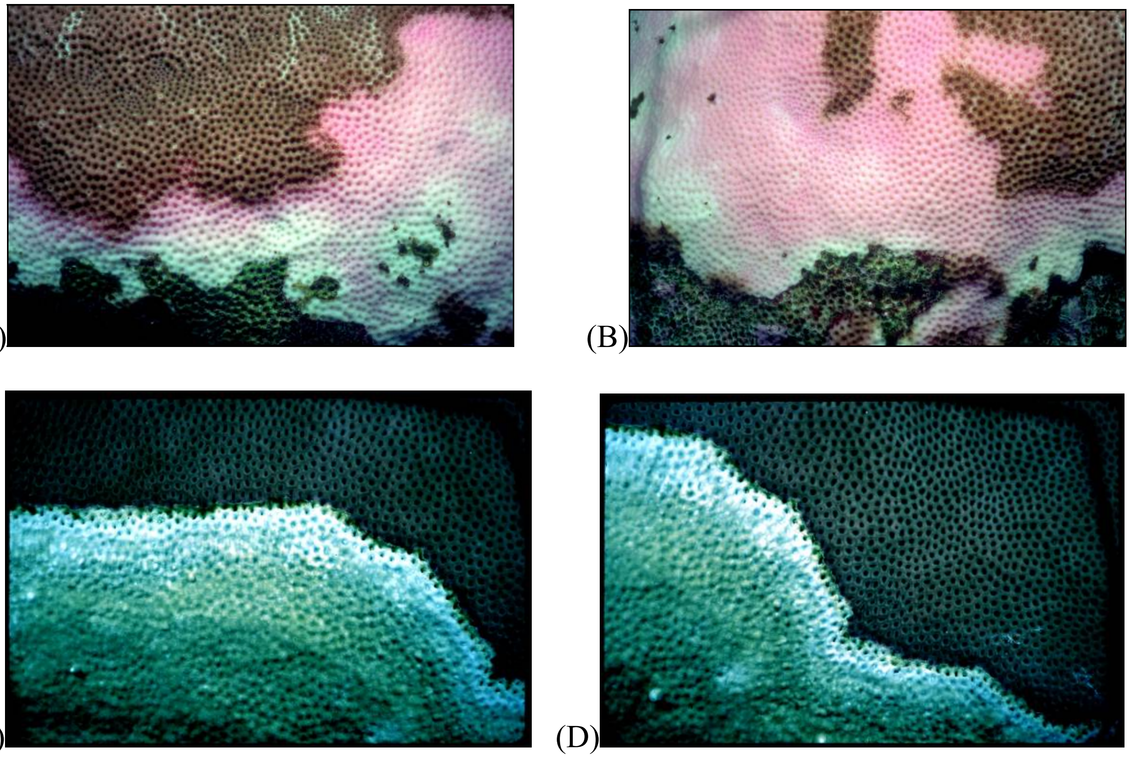
(A)  (B) 

Figure 4.1.7. (A) Photograph of a *Montastraea faveolata* colony exhibiting white plague-like disease signs at the East Bank in May 2005. (B) Close-up photograph of the disease lesion on this colony. Photographs from FGBNMS (2005a, b).

A potentially diseased colony of *Siderastrea siderea* was identified during the June 2005 cruise at the West Bank (Figure 4.1.8). The colony was photographed around its margin using a close-up kit. The coral was approximately 2 m in diameter and showed an apparent lesion separating healthy coral tissue from exposed coral skeleton. The pink coloration observed on the exposed skeleton was atypical of described diseases (Richardson et al. 1998). The lesion was not always a sharp line and there were patches of apparently healthy coral tissue in the affected area (Figure 4.1.8 A-B). A portion of the colony had *Millepora* sp. growing over the dead skeleton and had a black margin between healthy tissue and skeleton (Figures 4.1.8 C-D). Although this colony exhibits possible disease signs, its condition could also be the result of an unusual bleaching pattern.



(A) (B)

(C) (D)

Figure 4.1.8. *Siderastrea siderea* with disease-like signs. Photographs A and B were taken around the perimeter of the 2 m coral head, documenting potential disease lesion. Photographs C and D exhibit overgrowth by *Millepora* sp. Photographs by W. F. Precht.

White plague, first documented in Florida in the 1970s (Dustan 1977), is one of the most detrimental coral diseases affecting reefs of the wider Caribbean, causing considerable declines in coral populations (Nugues 2002; Kaczmarsky et al. 2005; Richardson and Voss 2005). Corals affected by white plague exhibit disease signs that consist of a sharp line of migrating tissue loss (the lesion) separating healthy tissue from exposed coral skeleton (Richardson et al. 1998). Only one previous study has been published that documented white plague on the reefs of the Flower Garden Banks, describing a low prevalence of 0.08% with only one coral colony affected (Borneman and Wellington 2005). Environmental stressors such as pollution, nutrient loading, African dust, and elevated temperature may be associated with disease outbreaks; however, causal connections have not been firmly established (Bruno et al. 2003; Richardson 1998).

Widespread coral bleaching in response to anomalously high summer-season temperatures has become more frequent since the 1980s throughout the western Atlantic-Caribbean region and the association of thermal stress with coral disease is of particular concern. At the Flower Garden Banks, the only major bleaching episode reported was in 1990, with minor bleaching having occurred in 1992, 1994, 1995 and 1998. These episodes were followed by recovery (Gittings et al. 1992; Hagman and Gittings 1992; CSA 1996; Dokken et al. 1999, 2001). Bleaching episodes on reefs in the western Atlantic-Caribbean region have also generally been followed by recovery, with partial or whole mortality events affecting populations locally (Aronson and Precht 2000). The post-hurricane bleaching of 2005 is discussed in a separate report.

4.1.8 Other Coral Mortality Factors at the Flower Garden Banks

Other causes of coral mortality in the Flower Garden Banks include predation by mobile fauna, inter- and intraspecific competition, toppling of colonies due to bioerosion, concentrated fish biting, and the impacts of damselfish territories. Concentrated fish biting, possibly a product of the high abundance of *Sparisoma* spp., has been observed in earlier monitoring photographs (Dokken et al. 2003) from the Flower Garden Banks but has not been specifically studied there. Concentrated fish biting should be investigated to better understand the phenomenon and its impact on the reefs. Although numerous sources of mortality are present, coral growth and recruitment appear to be in balance with coral loss, considering that coral cover continues to be consistently high.

4.2 Water Quality Parameters

Water quality data acquired from March 2004 to October 2005 included temperature, salinity, dissolved oxygen, pH, turbidity, photosynthetically active radiation (PAR), chlorophyll *a*, and nutrients. Water color and circulation were not part of the scope of work and are not discussed here. The accuracy of the water-quality data reported here depended largely on the performance of the YSI and HoboTemp instruments.

4.2.1 Physical Parameters

Temperature. Temperature data were acquired using YSI probes and HoboTemp thermistors. Combining temperature records by bank we could compare the seasonal heating (April through July), the summer temperature maximum (August), and seasonal cooling (September to November) between 2004 and 2005 at the East Bank (Figure 4.2.1). Using the combined YSI and HoboTemp records at the West Bank we could observe a complete temperature cycle on the reef cap from March 2004 to March 2005 and some of the seasonal warming and temperature maximum in 2005 (Figure 4.2.2). We observed predictable seasonal heat-budget patterns (Pickard and Emery 1982) of rapid warming and cooling of sea-surface temperature, coinciding with gradual warming and cooling at depth (i.e., on the reef cap).

In both 2004 and 2005 temperature on the reef cap overlapped that of the sea surface from March to late May (Figures 4.2.1 and 4.2.2). From late May to mid-August, sea-surface temperature predictably rose faster than on the reef cap to reach a summer maximum in mid-August. The summer peak was 1 °C higher in 2005 than in 2004 (a peak of ~31 °C in 2005). During the seasonal warming, temperature on the reef cap oscillated from late June to mid-July in both 2004 and 2005. These oscillations were very apparent in 2005 at the East Bank and in both years at the West Bank. The sea-surface temperature also oscillated during the same time but with less amplitude. The discrepancy between reef cap YSI data and sea surface temperature data may be due to the different technologies used to collect these data. Following the summer peak, the cooling phase was interrupted in 2005 by the passage of Hurricane Rita on September 23 and 24, which caused a temporary drop in temperature. Cooling of the surface and reef-cap water continued after the storm.

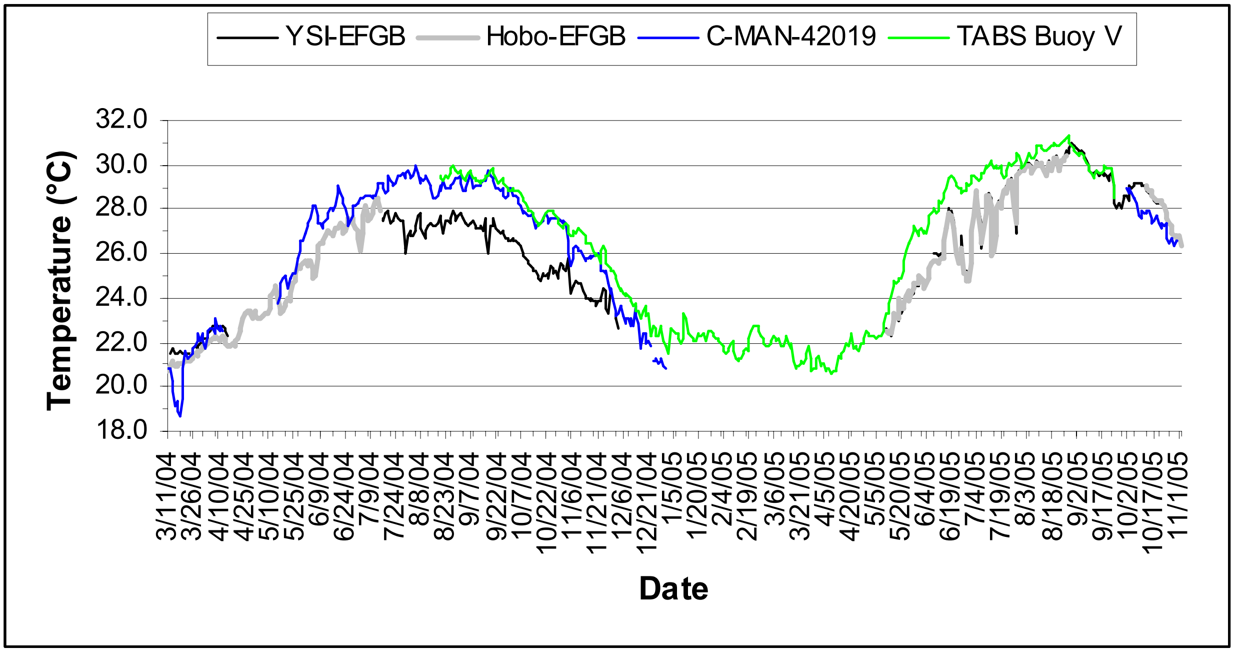


Figure 4.2.1. Seawater temperature on the East Bank reef cap in 2004 and 2005, using combined YSI temperature and HoboTemp records. Also depicted are the 2004 and 2005 sea-surface temperature records from Texas Automated Buoy System (TABS) buoy V (27°53.796' N, 93°35.838' W) located near the East Bank (Bender et al., personal communication 2005); and the sea-surface temperature recorded by Coastal-Marine Automated Network (C-MAN) buoy 42019 located 152 km west of the West Bank (27°54.783’ N, 95°21.600’ W; National Data Buoy Center 2005a).

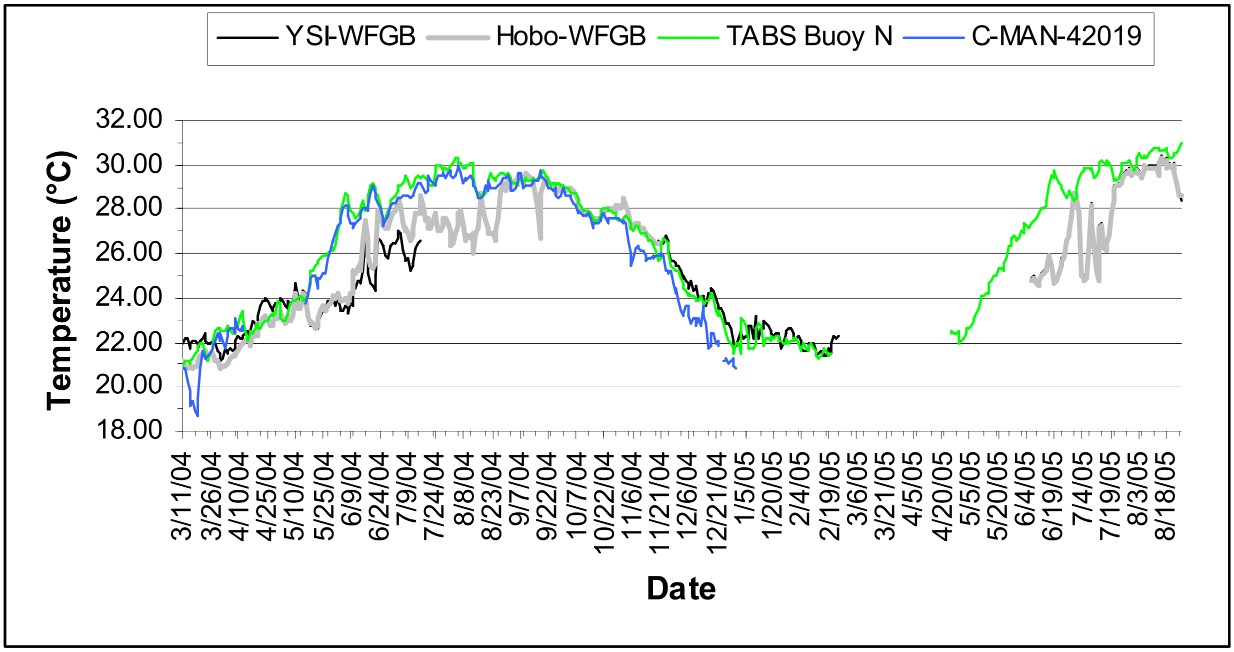


Figure 4.2.2. Seawater temperature on the West Bank reef cap in 2004 and 2005, using combined YSI temperature and HoboTemp records. Also depicted are the 2004 and 2005 sea-surface temperature records from Texas Automated Buoy System (TABS) buoy N (27°53.418'N, 94°02.202'W) located near the West Bank (Bender et al., personal communication 2005); and the sea-surface temperature recorded by Coastal-Marine Automated Network (C-MAN) buoy 42019 located 152 km west of the West Bank (27°54.783' N, 95°21.600' W; National Data Buoy Center 2005a).

The 2004 and 2005 YSI and HoboTemp temperature profiles at the East Bank were somewhat similar from March to late July (Figure 4.2.3). From late July through late November, the temperature was approximately 2 °C greater and crossed the 30 °C threshold for coral bleaching (Hagman and Gittings 1992) from early August to early September. Corals did in fact bleach on both banks in 2005 (Emma Hickerson, personal communication). Interestingly, the 2005 temperature profile resembled that of the mean temperature from 1990 to 1997 until late July, before the 2005 temperature curve crossed the bleaching threshold and exceeded 29.5 °C during 53 consecutive days (29 July to 19 September 2005; Appendix 5). Cooling took place after the summer maximum, beginning in early September, and temperatures dropped further (~2 °C) as Hurricane Rita passed through the Flower Garden Banks. Starting in early October, it appears that water temperature on the reef cap returned to where it was (29 °C) before the passage of Hurricane Rita until mid-October, before further cooling took place. Compared to the 1990-1997 mean temperature, the cooling occurred with a 2 ºC lag. The reef cap temperature record stops in early November, which does not allow a complete assessment of the fate of temperature on the reef cap.

During the summer of 1990, extensive coral bleaching coincided with excessive heating of the reef cap (Hagman and Gittings 1992). Seawater temperature then exceeded 30 °C for more than seven days. For as long as records have been available, seawater temperature on the East Bank had never been so elevated for so long as it was in 2005 (Figure 4.2.4). Furthermore, the reef cap seawater temperature was approximately 1 °C greater in 2005 than in 1990 for about 12 days in late August and early September (Figure 4.2.4). The prolonged warm temperature on the reef cap during the cooling phase following the summer maximum was unprecedented at the East Bank. In 2005, corals at the Flower Garden Banks were exposed to a prolonged thermal stress interrupted by the passage of a category 5 hurricane. In the end there were two episodes of thermal stress, the first one lasting over 50 days and the second lasting approximately 30 days. Thermal conditions on the reef cap were unquestionably more severe in 2005 than in 1990, which probably caused more stress to the reef sessile benthos.

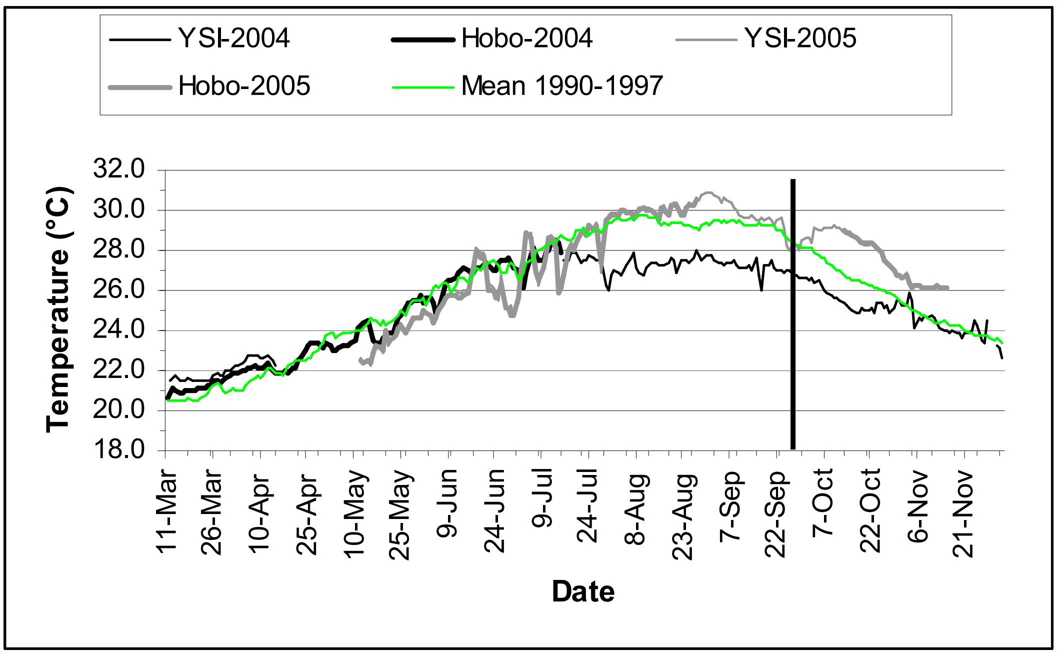


Figure 4.2.3. Comparison of the 2004 and 2005 seawater temperature records at the East Bank, using combined YSI and HoboTemp records. A vertical line drawn through the temperature profiles shows the timing of the passage of Hurricane Rita over the Flower Garden Banks (September 23 and 24, 2005)

.

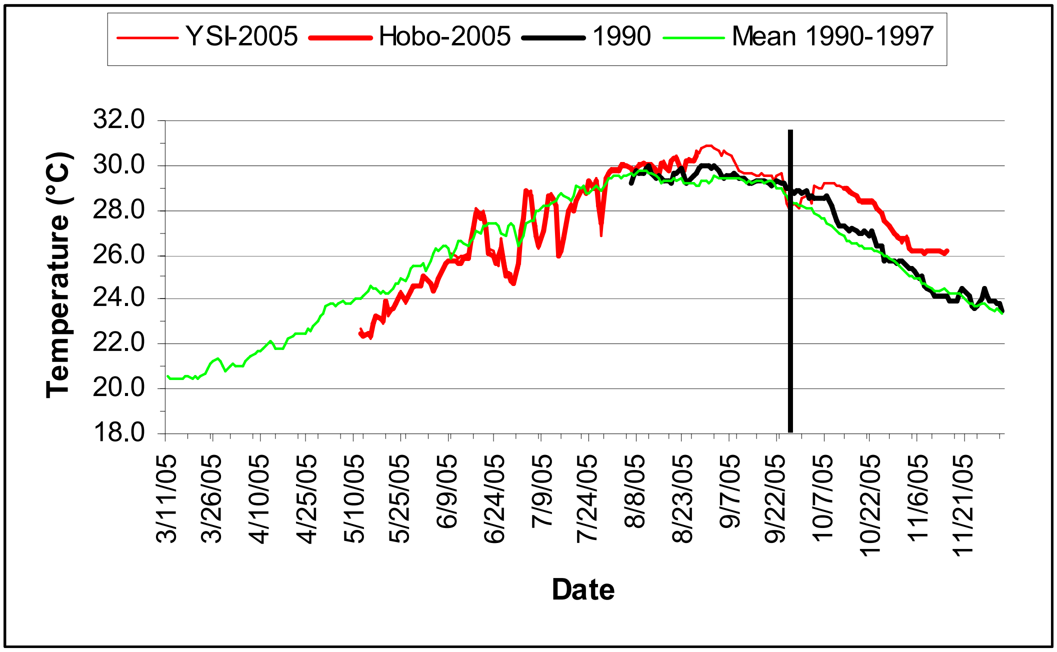


Figure 4.2.4. Comparison of water temperature at the East Bank in 1990 and 2005. The 1990 temperature data are from Gittings et al. (1992). A vertical line drawn through the temperature profiles shows the timing of the passage of Hurricane Rita over the Flower Garden Banks (September 23 and 24, 2005).

Turbidity. There were too few credible records to characterize turbidity in 2004 or 2005 at either bank. In 2005, water movement associated with Hurricane Rita removed substantial quantities of sediment from sand flats on the reef caps of the East and West Banks (Hickerson, personal communication 2005). Furthermore, we found that the YSI sondes had been heavily abraded following the passage of the hurricane. Severe resuspension of coarse sediments probably occurred during the passage of the hurricane which likely caused a temporary increase in turbidity.

PAR. The few PAR records acquired in 2004 and 2005 allow for a proper characterization of PAR on the reef cap. According to the literature, PAR and ultraviolet are highest on the reef cap when the sea surface is calm and the water column is clear (Falkowski et al. 1990; Gleason and Wellington 1993). Gleason and Wellington (1993) found that prolonged calm and clear seas (≥ three weeks) allow an elevated intensity of UV to reach the reef (even in water deeper than 20 m) and cause the bleaching of corals. The most severe thermal stress occurred from 29 July to 19 September 2005. This coincided with the lowest average significant wave height as measured at the Coastal-Marine Automated Network (C-MAN) buoy 42019, located 152 km west of the West Bank (27°54.783' N 95°21.600' W; National Data Buoy Center 2005b; Hagman et al. 1998). There were no significant wave height data collected at C-MAN buoy 42019 in 2005 to verify the sea state, yet it is quite possible that UV radiation exacerbated the effects of thermal stress, increasing the severity of coral bleaching.

Sea State. In 2004 and 2005, tropical storms and hurricanes entered the Gulf of Mexico and affected the sea state at the Flower Garden Banks. Two hurricanes and three tropical storms entered the Gulf of Mexico in 2004, the closest track being >300 km from the Flower Garden Banks (Table 4.2.1). The 2005 Atlantic hurricane season was the most active season on record, with six tropical storms and five hurricanes going through the Gulf of Mexico (National Climatic Data Center 2005). Hurricane Rita passed approximately ~97 km east of the Flower Garden Banks on September 23, 2005, while it was category 3 hurricane. The next closest tropical cyclone was tropical storm Cindy, which passed ~500 km from the Flower Garden Banks.

Hurricane Claudette, a category 1 hurricane that passed over the Flower Garden Banks in 2003, caused significant wave heights of 4 m at C-MAN buoy 42019 (Precht et al. 2006). In 2005, depth measured by the YSI instrument at the East Bank rose from 23 m to 25 m from 0300 hours on 09/23/2005 to 0400 hours on 09/24/2005, during the passage of Hurricane Rita. HoboTemp records at the West Bank showed that seawater temperature dropped on 09/23/2005 from 29.6 °C at 0033 hours to 27.4 °C at 1933 hours, and then went back up to 28.4 °C at 0733 hours on 09/24/2005. The highest point of the storm measured at C-MAN buoy 42019 took place on September 23 at 2000 hours, when significant wave height reached 5.9 m (National Data Buoy Center 2005b).

Table 4.2.1.

List of tropical cyclones that entered the Gulf of Mexico in 2004 and 2005.
The name and category of a given cyclone is listed according to its condition when it was closest to the Flower Garden Banks. Information on the cyclones was taken from The Weather Underground, Inc. (2005a, 2005b).

Name/Category	**Date**	**Wind Speed (mph) or Category**	**Trajectory**
Tropical Storm Bonnie	8/10/04	50	Central GOM, ~600 km east of the Flower Garden Banks
Hurricane Charley	8/13/04	Cat 4	Passed over the Florida Straits, southwest Florida
Tropical Storm Frances	9/4/04	65	Northeast GOM, >1000 km east of the Flower Garden Banks
Hurricane Ivan	9/15/04	Cat 4	Passed ~550 km east of the Flower Garden Banks
Tropical Storm Matthew	10/09/04	40	Passed ~320 km east of the Flower Garden Banks
Tropical Storm Arlene	6/11/05	70	Central GOM, ~600 km east of the Flower Garden Banks
Tropical Storm Bret	6/25/05	40	Southwest GOM, >800 km south of the Flower Garden Banks
Tropical Storm Cindy	7/5/05	70	Central GOM, ~500 km east of the Flower Garden Banks

Table 4.2.1. List of tropical cyclones that entered the Gulf of Mexico in 2004 and 2005 (continued).

Name/Category	Date	Wind Speed (mph) or Category	Trajectory
Hurricane Dennis	7/10/05	Cat 4	Central GOM, ~800 km east of the Flower Garden Banks
Hurricane Emily	7/19/05	Cat 1	Southwest GOM, ~600 km south of the Flower Garden Banks
Tropical Storm Gert	7/25/05	45	Southwest GOM, ~750 km south of the Flower Garden Banks
Tropical Storm Jose	8/23/05	50	Southwest GOM, ~800 km south of the Flower Garden Banks
Hurricane Katrina	8/28/05	Cat 5	Central GOM, ~500 km east of the Flower Garden Banks
Hurricane Rita	9/23/05	Cat 3	Central GOM, over the Flower Garden Banks
Tropical Storm Stan	10/3/05	40	Southwest GOM, ~850 km south of the Flower Garden Banks
Hurricane Wilma	10/24/05	Cat 3	Southeast GOM, ~900 km SE of the Flower Garden Banks

4.2.2 Biological Parameters

Chlorophyll *a*. Spot checks of water samples taken between March 2004 and October 2005 showed no detectable levels of chlorophyll *a* (the lower limit of detection is 1 mg/m^3). Known concentrations of chlorophyll *a* at the shelf edge in the northwestern Gulf of Mexico range from 0.1 to 0.3 mg/m^3 (Nowlin et al. 1998). Lower detection limits are needed to characterize the water column at the Flower Garden Banks. Ideally, water samples should be taken in order to assess seasonal variations of chlorophyll *a*. These concentrations could be correlated with local and regional nutrient supplies. The timing of the sampling could coincide with the winter temperature minimum (February), the onset of the seasonal warming and increased river runoff (April-May), the period of seasonal warming (June and July), the temperature maximum (August), and the period of seasonal cooling and winter overturning of surface waters (November-December).

4.2.3 Chemical Parameters

Salinity. During the reporting period, relatively few salinity data were collected. While most of the salinity recorded fell within the known range of salinity for the Flower Garden Banks region (~33-36.5 ppt; Nowlin et al. 1998), the YSI probe recorded brief episodes of low salinity on the reef cap on 21 June, 24 July, and 20 August 2005. Salinity on the reef cap temporarily dropped from approximately 36 ppt to 32.5 ppt. Furthermore, the timing of the salinity fluctuation coincided with the timing of salinity minima Nowlin et al. (1998) observed in 1992, 1993, and 1994 at 14 m water depth on a mooring located at 27º49.300’ N, 94º10.444’ W (mooring 8).

Furthermore, we recorded low salinity (32 ppt) in the upper 7 m of the water column on 8 June 2005 (section 3.6.4) and found this superficial layer to be distinct from the underlying oceanic water. The low salinity of the superficial layer is thought to originate from Louisiana and Texas river runoff (Deslarzes and Lugo-Fernández 2006). Low salinity events are recurrent along the shelf edge of the northwestern Gulf of Mexico (Nowlin et al. 1998).

There is need to acquire salinity data with more reliability so as to clearly identify salinity fluctuations on the reef cap. Since freshwater does get pulled down onto the reef cap, it is important to learn more about the intensity, frequency, and duration of these events. Having these data will provide a clearer picture of the recurrent exposure of the reef cap and associated biota to riverborne materials.

Dissolved Oxygen. Very few reliable DO data were collected on the reef cap in 2004 and 2005. More reliable DO probes are needed to monitor DO levels accurately at the Flower Garden Banks. The DO probe should be installed on the reef cap rather than on a sand flat considering that the productivity of microorganisms and algae in the sand flats is greater than that of the sessile benthos on the reef (Nelson et al. 1999; Boland, personal communication, 2007).

pH. During 2004 and 2005, mean daily pH was 8.18 (± 0.02 SE, n = 349) at the East Bank and 7.81 (± 0.01 SE, n = 349) at the West Bank (Table 3.6.1; Figures 3.6.4-C and 3.6.5-C). Since seawater pH typically ranges from 7.5 to 8.4 (Sverdrup et al. 1970), the values recorded are probably real. Precht et al. (2006) reported a pH of 8.24 from February to May 2003 at the West Bank. The data collected at the West Bank in 2004 and 2005 are probably more reliable than those collected at the East Bank during the same period. The West Bank pH data are more stable and consistent, whereas those from the East Bank seem faulty, particularly those collected in 2004 (Figures 3.6.4-D and 3.6.5-D).

Kleypas et al. (1999) and Anderson et al. (2003) showed that the pH in shallow ocean environments may decrease in the future as a result of increased atmospheric carbon dioxide. As pH decreases, so will the concentration of the carbonate ion required for the calcification of corals and algae (Kleypas et al. 1999). An accurate and continuous monitoring of pH at the Flower Garden Banks may contribute to detecting environmental changes associated with changing concentrations of atmospheric carbon dioxide. Hardware improvements are needed to allow more extensive monitoring of pH at the Flower Garden Banks.

Nutrients. Water samples were analyzed for the East and West Banks from the sea-surface, midwater, and reef-cap. All samples contained very low levels of ammonia (0.03-0.26 mg/l; Table 3.6.10). Nitrite and inorganic phosphorous (soluble reactive phosphorous) were not detectable in any of the samples; however, in June 2005, 0.20 mg/l of nitrate was recorded in the surface water of the West Bank. Such concentrations of dissolved inorganic nitrogen and inorganic phosphorous are characteristic of oligotrophic waters bathing western Atlantic reefs (D'Elia and Wiebe 1990). All water samples collected in 2004 and 2005 contained detectable dissolved organic nitrogen (total Kjeldahl nitrogen) in concentrations ranging from 0.19 to 2.24 mg/l (Table 3.6.10). These spot checks of nutrient concentrations are consistent with Nowlin et al. (1998) who found low levels of nutrients on the outer shelf.

Spot checks from nutrients need to be spread throughout the year, considering that potential local sources of nutrients are sediments (Entsch et al. 1983), benthic organisms, and planktonic organisms (D'Elia and Wiebe 1990; Sorokin 1995). Six water sampling efforts coincided with times of the year when recorded salinity dropped at the Flower Garden Banks (i.e., June-August). Such decreased salinity may indicate the presence of a mix of river runoff and seawater transported from the nearshore area to the shelf edge (Deslarzes and Lugo-Fernández 2006). Water samples taken in July 2004 and June and August 2005 did not contain unusual nutrient concentrations, either at the surface, in midwater, or over the reef cap (Table 3.6.10). This finding corroborates the low nutrient concentrations reported in Nowlin et al. (1998) and discussed in Deslarzes and Lugo-Fernández (2006). Nutrients are in low concentrations at the Flower Garden Banks even in waters that might have originated in the nearshore environment, due to nutrient depletion that takes place near the sea surface before that water reaches the shelf edge (Deslarzes and Lugo-Fernández 2006). Future water samples should be checked for salinity to characterize the water column better and investigate the correlation of salinity and nutrient content.

4.3 Fish Surveys

The fish surveys in 2004 and 2005 revealed a still-thriving reef-fish assemblage, as observed in the 2002-2003 surveys. It should be noted that the fish surveys in 2005 were conducted before the two powerful hurricanes, Katrina and Rita, passed through the area. Also of note were observations made by survey divers of a strong mixing layer persisting during surveys at both the East and West Banks in 2005.

The fish assemblages of the East and West Banks are unique in two respects: (1) their occurrence on a high-latitude coral reef system remote from other tropical reefs; and (2) their close proximity to offshore hydrocarbon production platforms. These are important factors shaping the fish assemblages. Fishing and recreational diving pressure, shipping traffic, water quality (including temperature and planktonic composition), and current patterns also affect the fish assemblages to varying degrees. The distance of the Flower Garden Banks from shore and their designation as a National Marine Sanctuary provide some protection to the fish populations. Importantly, the reef-fish assemblages are intimately related to the living aspect of the coral-reef benthos.

Divers recorded a total of 85 fish species during the 2004-2005 visual fish surveys. This is six more species than recorded during the previous two years of surveys. However, it is still less than the total species richness reported in other, earlier studies (Pattengill-Semmens and Gittings 2003; Wilson et al. 2003; Boland et al. 1983). Those studies used varied techniques, including remote video surveys and roving diver surveys, each with its advantages and disadvantages. Thus, roving diver surveys record more species, whereas stationary counts can estimate fish densities better (Bortone et al. 1989). Boland et al. (1983) recorded about 50 species using remote video, and Wilson et al. (2003), also with remote video, recorded about half that number. However, since these two video surveys used different techniques (i.e., different depths surveyed and target species recorded), the results are not necessarily comparable either. The species richness of the surveys collected in 2002-2003 and 2004-2005 are comparable to other stationary visual surveys conducted at the Flower Garden Banks using the Bohnsack-Bannerot approach

(Rooker et al. 1997). Poor weather during the 2004 survey efforts hampered the collection of fish data.

The high latitude and remote location of the Flower Garden Banks gives the fish assemblage a low diversity. Biomass, however, is relatively high (Pattengill-Semmens and Gittings 2003). It has been speculated that the large number of oil and gas production and exploration platforms and other structures in the Gulf of Mexico have facilitated colonization of the Flower Garden Banks by some fish species (Boland et al. 1983; Rooker et al. 1997; Gittings 1998). The fish assemblages of the Flower Garden Banks differ from assemblages in other reef/hard bottom systems in the Gulf of Mexico. Comparisons between artificial reefs in the Gulf of Mexico (both standing platforms and toppled platforms) and the Flower Garden Banks show that the natural reefs of the banks are distinct (Rooker et al. 1997; Wilson et al. 2003). For example, the Lutjanidae are underrepresented at the study sites at the East and West Banks. A review of the fish survey data of 2002-2003 and 2004-2005 show the fish assemblage undergoing a degree of fluctuation, although none of the changes appears to have been drastic.

Some components of the fish assemblages have experienced large fluctuations in the past. Herbivore populations appear to have responded to the mass mortality of *Diadema antillarum* at the Flower Garden Banks in 1983-1984 (Gittings et al. 1992). Also, red snapper, *Lutjanus campechanus*, were overexploited in the late 1950s, and their numbers have never recovered at the Flower Garden Banks (Boland et al. 1983; no observations were recorded at the study sites during the 2002-2003 or 2004-2005 survey periods). However, this is possibly a factor of habitat preference on the part of *L. campechanus*, considering that they were observed in low numbers on deeper, drowned reefs (Boland et al. 1983).

The fish assemblages observed in 2004 and 2005 were dominated by the Pomacentridae, Labridae, and Serranidae as in the 2002-2003 surveys. Sphyrenids were common at both banks in both years, but especially so at West Bank in 2004. Carangids were observed in large numbers at both banks in 2005 swimming through the water column in large schools. The "Scaridae" (i.e., Labridae: Scarinae) and Acanthuridae were the other abundant families.

The Pomacentridae was well represented, although by fewer species than exist in the Caribbean region as a whole. *Chromis multilineata, Chromis cyanea, Stegastes planifrons,* and *Stegastes partitus* were the dominant species of pomacentrids at the Flower Garden Banks. Although lower in abundance, *Microspathodon chrysurus* were commonly seen in the surveys. The Labridae were primarily represented by *Clepticus parrae,* which could be present in large schools, and by *Thalassoma bifasciatum,* which were nearly ubiquitous in crevices and low areas between coral formations. The Serranidae were among the dominant families on the reefs primarily due to the planktivorous species, *Paranthias furcifer*, which was widely distributed around the study sites. *Paranthias furcifer* was observed as a common species during the 2002-2003 surveys, as well as in other surveys (Boland et al. 1983; Wilson et al. 2003). *Mycteroperca tigris, Epinephelus adscensionis,* and *Cephalopholis cruentata* were the most common groupers observed.

The Flower Garden Banks reef cap has a distinctly low number of Lutjanidae species and a near-absence of Haemulidae (Rooker et al. 1997). Several large *Lutjanus jocu* were observed repeatedly (the same individuals presumably) at the East Bank in 2005 and several more at the West Bank in 2005. No Haemulidae were observed at either bank in either year.

The three Caribbean species of Acanthuridae occurred at the study sites in moderately high numbers. Abundances were generally greater than or equal to the abundances of "Scaridae" but less than the Pomacentridae and Labridae. Large schools of acanthurids, as seen on some coral reefs of the Caribbean, were not regularly present. *Acanthurus coeruleus* was the dominant species recorded. The "Scaridae," while less abundant than the Acanthuridae, were common, and individuals of large size were recorded (e.g., *Sparisoma viride* with a mean average fork length of 42 cm at the West Bank in 2004). The number of species of "Scaridae" recorded at the Flower Garden Banks is less than that in the wider Caribbean; a mean of six species were recorded at each bank per year. *Scarus vetula* and *S. viride* were the dominant species recorded.

Sphyraena barracuda were persistent at the study sites in both years. They were recorded in exceptionally large numbers and in large sizes at the West Bank in 2004. As in 2002-2003, they were regularly active throughout the study sites, patrolling the reef. Many exhibited a curiosity of diver activities and were often attracted to diver surveys. *S. barracuda* were often observed swimming in large and small groups as well as individually, near reef formations. They were rarely observed feeding. It has been previously suggested that the reef cap of the Flower Garden Banks may serve as a nursery for these fish.

Since the Flower Garden Banks are moderately deep reef systems, fishes of the water column are often observed over the study sites. As mentioned above, large schools of carangids were regularly recorded at both banks in both years. *Caranx hippos* was the dominant carangid species recorded in the water column over the reefs. *Caranx ruber* was commonly observed swimming around reef formations. Not recorded in diver surveys, but observed during dives, were the large filter-feeding fishes *Manta birostris* and, rarely, *Rhincodon typus*.

The Chaetodontidae and Pomacanthidae are not well-represented at the study sites, with a mean of four and three species per bank per year, respectively. *Chaetodon sedentarius* and *Chaetodon ocellatus* were the primary species of Chaetodontidae recorded. *Holocanthus tricolor, Holocanthus ciliaris,* and *Pomacanthus paru* were the primary species of Pomacanthidae recorded, but they did not occur in large numbers.

The survey technique is biased against cryptic species. The Gobidae, Blennidae, and Muraenidae were underrepresented in the surveys, although several were recorded at each study site. Also underrepresented were species associated with sandy habitats, such as *Malacanthus plumieri* (Malacanthidae) and *Opistognathus aurifrons* (Opistognathidae) since the surveys were restricted to habitats with coral cover. *Canthigaster rostra* (Tetraodontidae) was commonly recorded, seen actively exploring crevices and ledges in low areas of the reef formations.

Disturbance caused by multiple divers present in the study sites while fish surveys were being conducted was minimized by conducting censuses before other divers entered the water and by conducting surveys at distances away from other divers. However, some degree of disturbance to the natural density and distribution of the local fishes is likely to have occurred. The disturbance more likely affected midwater, pelagic predators such as the Carangidae, Serranidae, and Carcharhinidae. Recorded densities of Serranidae may be lower than actual undisturbed levels. Several large Serrandiae (such as *Mycteroperca tigris, Mycteroperca bonaci, Mycteroperca venenosa,* and *Mycteroperca interstitialis*) have been recorded variously between banks and years. Although no Carcharhinidae were recorded in the 2002-2003 or 2004-2005 surveys, some unidentified species were observed from a distance.

Herbivores are present in lower abundance and species richness at the Flower Garden Banks than Caribbean reefs (Rezak 1985; Dennis and Bright 1988). They were present in relatively high numbers during the 2004-2005 surveys compared to results from 2002-2003. As determined by the fish surveys of 2002-2003 at the Flower Garden Banks, the percentages of Acanthuridae and Scaridae are similar to deep/fore reefs of far western Cuba and Akumal, Yucatan, Mexico (Claro and Cantelar Ramos 2003; Steneck and Lang 2003).

The size-frequency distributions of herbivores were normally distributed, as they were in the 2002-2003 surveys. There was a greater mean abundance of fishes in the herbivore group recorded during the 2004-2005 surveys than in 2002-2003. The size-frequency distributions of the carnivore group showed a similar non-normal pattern as they did in the 2002-2003 surveys. The pattern likely reflects the differing sizes of the individual species in the carnivore group (Serranidae and Lutjanidae) rather than rare or missing size classes from the entire functional group. Abundances of individual species within the carnivore group were too low to generate size-frequency distributions by species. However a larger number of individuals were recorded in the carnivore group during the 2004-2005 surveys than in 2002-2003.

Interannual comparisons of fish statistics indicated generally stable assemblages, with some variation. The East Bank generally appears to support lower overall fish diversity but greater abundance. These generalizations are influenced by the presence or absence of large numbers of small schooling fish at different times. Shannon-Wiener diversity and evenness fluctuated among years, from 2002 through 2005 (Figure 4.3.1). Species and family richness fluctuated only slightly (more so at the East Bank), with the greatest number of species recorded in 2005 at both banks (Figure 4.3.2). The mean fish abundance recorded per diver survey increased at the East Bank until 2005, when it dropped back to its 2002 level, and it remained relatively constant at the West Bank (Figure 4.3.3).

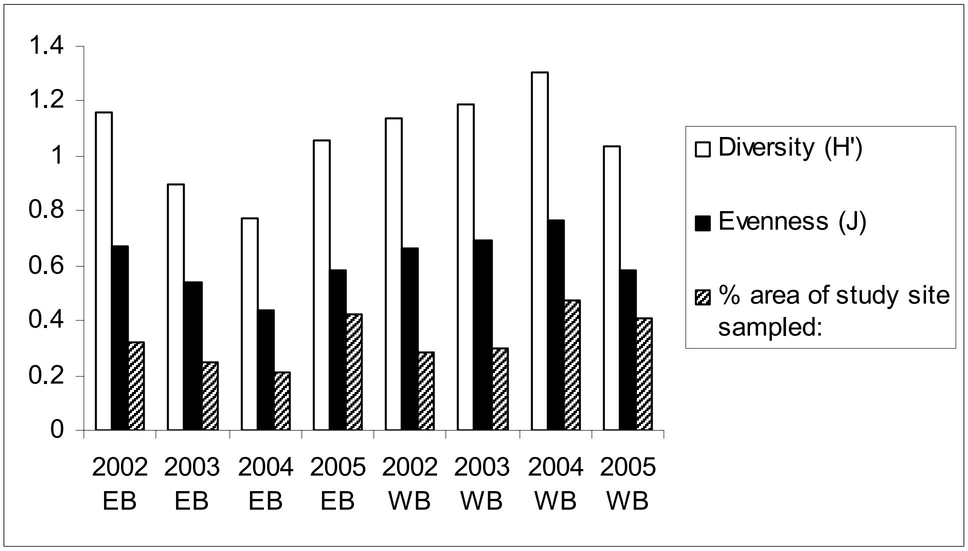


Figure 4.3.1. Fish diversity and evenness found at the East and West Banks from 2002 to 2005, with the percent of the study-site area covered by the surveys. Abbreviations: EB, East Bank; WB, West Bank.

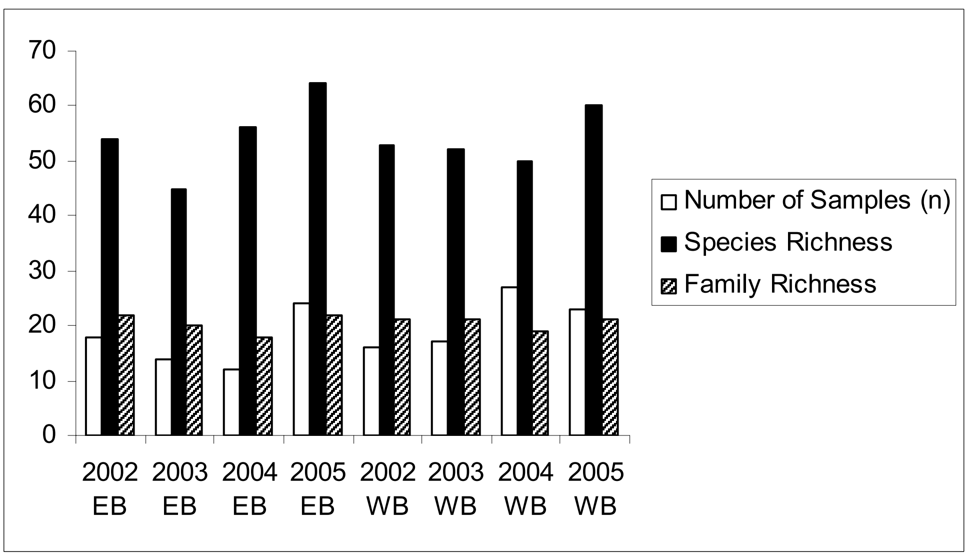


Figure 4.3.2. Species richness and family richness found at the East and West Banks from 2002 to 2005, with number of diver surveys/samples (n) shown.

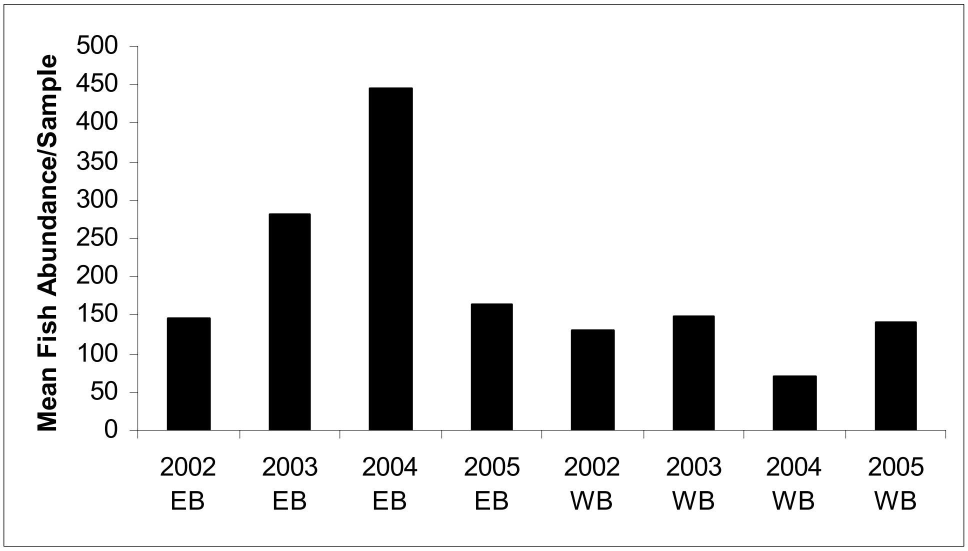


Figure 4.3.3. Fish abundance observed at the East and West Banks from 2002 to 2005.

4.4 Sea Urchin and Lobster Surveys

Regionally, *Diadema antillarum* populations are still low compared to their pre-1984 levels when a pathogen of unknown origin spread throughout the Caribbean decimating populations (Lessios et al. 1984). At the FGB densities of sea urchins were reported as 0.54-1.63 individuals/m^2 (Gittings and Bright 1987). Although there have been population recoveries in localized areas, population levels Atlantic-wide are still depressed compared to pre-1984 levels (Edmunds and Carpenter 2001).

Similar to the rest of the western Atlantic results at the FGB from sea urchin and lobster surveys continued to show low population densities at both banks in 2004 and 2005. The low densities reported here are similar to densities reported for the FGB in the past (Precht et al. 2006, Dokken et al. 2003). West Bank 2004 was an anomalous year with 44 individuals documented (0.11 individuals/m^2), however the trend did not continue in 2005, when surveyed populations were again depressed (0.013 individuals/m^2). Overall, these results do not differ from reports at coral reefs throughout the region.

5.0 LITERATURE CITED

Anderson, A.J., F.T. Mackenzie, and L.M. Ver. 2003. Solution of shallow-water carbonates: An insignificant buffer against rising atmospheric CO_2. Geology 31:513-516.

Aronson, R.B., P.J. Edmunds, W.F. Precht, D.W. Swanson, and D.R. Levitan. 1994. Large-scale, long-term monitoring of Caribbean coral reefs: simple, quick, inexpensive methods. Atoll Research Bulletin 421:1-19.

Aronson, R.B. and W.F. Precht. 2000. Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. Limnology and Oceanography 45:251-255.

Aronson, R.B., W.F. Precht, I.G. Macintyre, and T.J.T Murdoch. 2000. Coral bleach-out in Belize. Nature 405:36.

Aronson, R.B., W.F. Precht, T.J. 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 of Mexico Science 23:84-94.

Aronson, R.B., W.F. Precht, M.A. Toscano, and K.H. Koltes. 2002. The 1998 bleaching event and its aftermath on a coral reef in Belize. Marine Biology 141:435-447.

Aronson, R.B. and D.W. Swanson. 1997. Video surveys of coral reefs: uni- and multivariate applications, Proceedings of the 8th International Coral Reef Symposium, Panama 2. Pp.1441-1445.

Bak, R.P.M. 1974. Available light and other factors influencing growth of stony corals through the year in Curacao. Proceedings of the 2nd International Coral Reef Symposium, Brisbane, Australia. Pp. 229-233.

Bender, L., L. Lee, and N. Guinasso. 2005. Personal communication. Texas A&M University.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41:1-15.

Boland, G.S. 2007. Personal communication. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.

Boland, G.S., B.J. Gallaway, J.S. Baker, and G.S. Lewbel. 1983. Ecological effects of energy development on reef fish of the Flower Garden Banks. Final Report. Bryan, TX: National Marine Fisheries Service. 499 pp.

Borneman, E.H. and G.M. Wellington. 2005. Pathologies Affecting Reef Corals at the Flower Garden Banks, Northwestern Gulf of Mexico. Gulf of Mexico Science 23:95-106.

Bortone, S.A., J.J. Kimmel, and C.M. Bundrick. 1989. A comparison of three methods for visually assessing reef fish communities: Time and area compensated. Northeast Gulf Science 10:85-96.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and S.T. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: A comparison to other western Atlantic reefs. Bulletin of Marine Science 34:461-476.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippett. 1985. The Flower Gardens: A compendium of information. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 85-0024. 103 pp.

Bright, T.J. and L.H. Pequegnat. 1974. Biota of the West Flower Garden Bank. Houston, TX: Gulf Publishing Co. 435 pp.

Brown, B.E. and L.S. Howard. 1985. Assessing the effects of stress on reef corals. Advances in Marine Biology 22:1-63.

Bruckner, A.W. and R.J. Bruckner. 1998. Destruction of coral by *Sparisoma viride*. Coral Reefs 17:350.

Bruckner, A.W. and R.J. Bruckner. 2000. Coral predation by *Sparisoma viride* and lack of relationship with coral disease. Proceedings of the 9th International Coral Reef Symposium 2:1245-1249.

Bruckner, A.W., R.J. Bruckner, and P. Sollins. 2000. Parrotfish predation on live coral: "spot biting" and "focused biting". Coral Reefs 19:50.

Bruno, J.F., L.E. Petes, C.D. Harvell, and A. Hettinger. 2003. Nutrient enrichment can increase the severity of coral diseases. Ecology Letters 6:1056-1061.

Buddemeier, R.W. and R.A. Kinzie. 1976. Coral growth. Oceanography and Marine Biology: An Annual Review 14:183-225.

Buddemeier, R.W., J.E. Maragos, and D.W. Knutson. 1974. Radiographic studies of reef coral exoskeletons: rates and patterns of coral growth. Journal of Experimental Marine Biological Ecology 14:179-200.

Carleton, J.H. and T.J. Done. 1995. Quantitative video sampling of coral reef benthos: large-scale application. Coral Reefs 14:35-46.

Claro, R. and K. Cantelar Ramos. 2003. Rapid assessment of coral communities of Maria la Gorda, southeast Ensendada de Corrientes, Cuba (Part 2: Reef fishes). Atoll Research Bulletin 496:279-293.

Continental Shelf Associates (CSA). 1984. Impact assessment following an anchoring incident at the East Flower Garden Bank coral reef. Report to Mobil Producing Texas and New Mexico, Inc., Offshore Texas Division, The Woodlands, TX. 25 pp.

Continental Shelf Associates (CSA). 1996. Long-term monitoring at the East and West Flower Garden Banks. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 96-0046. 77 pp. + app.

D'Elia, C.F. and W.J. Wiebe. 1990. Biogeochemical nutrient cycles in coral-reef ecosystems. In: Dubinsky, Z., ed. Coral reefs. Amsterdam: Elsevier. Pp. 49-74.

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bulletin of Marine Science 43:280-307.

Deslarzes, K.J.P. and A. Lugo-Fernández. 2006. Influence of terrigenous runoff on offshore coral reefs: An example from the Flower Garden Banks, Gulf of Mexico. In: Aronson, R.B., ed. Geological approaches to coral reef ecology. New York: Springer. Pp. 125-129.

Diaz-Pulido, G. and J. Garzon-Ferreira. 2002. Seasonality in algal assemblages on upwelling-influenced coral reefs in the Colombian Caribbean. Botanica Marina 45:284-292.

Dodge, R. 1975. Hermatypic coral growth banding as environmental recorder. Nature 258:705-706.

Dodge, R. 1980. Skeletal Growth Chronologies of Recent and Fossil Corals. In: Rhoads, D.C. and R.A. Lutz, eds. Skeletal Growth of Aquatic Organisms. New York: Plenum Press. Pp. 493-517.

Dodge, R.E., R.C. Aller, and J. Thomson. 1974. Coral growth related to resuspension of bottom sediments. Nature 247:574-577.

Dodge, R.E. and G.W. Brass. 1984. Skeletal extension, density and calcification of the reef coral, *Montastraea annularis*, St. Croix, U.S.V.I. Bulletin of Marine Science 34:288-307.

Dodge, R.E. and K.E. Kohler. 1984. Image analysis of coral skeletons for extension rate and density. In: Glynn, P.W., A.M. Szmant-Froelich, and P.K. Swart, eds. Advances in Reef Science. Miami: Atlantic Reef Committee, University of Miami. Pp. 31-32.

Dodge, R.E., and J.C. Lang. 1983. Environmental correlates of hermatypic coral (*Montastraea annularis*) growth on the East Flower Garden Bank, northwest Gulf of Mexico. Limnology and Oceanography 28:228-240.

Dodge, R.E. and A. Szmant-Froelich. 1984. Effects of drilling fluids on reef corals: A review. In: Duedall, I.W., D.R. Kester, and P.K. Park, eds. Wastes in the Ocean: Volume 4. New York: Wiley Interscience. Pp. 341-364.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long-term monitoring of the East and West Flower Garden Banks 1996-1997. U.S. Dept. of the Interior, Mineral Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 99-0005. 101 pp.

Dokken, Q.R., I.R. MacDonald, J.W. Jr. Tunnell, T. Wade, C.R. Beaver, S.A. Childs, K. Withers, and T.W. Bates. 2001. Long-term monitoring of the East and West Flower Garden Banks, 1998-1999. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2001-101. 120 pp.

Dokken, Q. R., I.R. MacDonald, J.W. Jr. Tunnell, 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 National Marine Sanctuary, 1998-2001: Final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-031. 90 pp.

Dustan, P. 1975. Growth and form of the reef building coral, *Montastraea annularis*. Marine Biology 33:101-107.

Dustan P. 1977. Vitality of reef coral populations off Key Largo, Florida: recruitment and mortality. Environmental Geology 2:51-58.

Edmunds, P.J. and R.C. Carpenter. 2001. Recovery of *Diadema antillarum* reduces macroalgal cover and increases abundance of juvenile corals on a Caribbean reef. Proceedings of the National Academy of Sciences 98:5067-5071.

Emiliani, C., J.H. Hudson, E.A. Shinn, R.Y. George, and B. Lidz. 1978. Oxygen and carbon isotopic growth record in a reef coral from the Florida Keys and a deep-sea coral, Blake Plateau. Science 202:627-629.

Entsch, B., K.G. Boto, R.G. Sim, and J.T. Wellington. 1983. Phosphorous and nitrogen in coral reef sediments. Limnology and Oceanography 28:465-476.

Falkowski, P.G., P.L. Jokiel, and R.A. Kinzie III. 1990. Irradiance and corals. In: Dubinsky, Z., ed. Coral reefs. Amsterdam: Elsevier. Pp. 89-107.

Flower Garden Banks National Marine Sanctuary (FGBNMS). 2005a. Prepared by E. Hickerson. Coral Disease Response: Cruise Report - April 13-14, 2005. 10 pp.

Flower Garden Banks National Marine Sanctuary (FGBNMS). 2005b. Prepared by E. Hickerson and G.P. Schmahl. Cruise Summary: Flower Garden Banks National Marine Sanctuary Coral Disease Monitoring. 9 pp.

Foster, A.B. 1980. Environmental variation in skeletal morphology within the Caribbean reef corals *Montastraea annularis* and *Siderastrea siderea*. Bulletin of Marine Science 30:678-709.

Gardner, J.V., L.A. Mayer, J.E. Hughes Clarke, and A. Kleiner. 1998. High-resolution multibeam bathymetry of East and West Flower Gardens and Stetson Banks, Gulf of Mexico. Gulf of Mexico Science 16:131-143.

Gardner, T.A., I.M. Côté, 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. 1998. Reef community stability on the Flower Garden Banks, northwest Gulf of Mexico. Gulf of Mexico Science 1998:161-169.

Gittings S.R., G.S. Boland, K.J.P. Deslarzes, D.K. Hagman, and B.S. Holland. 1992. Long-term monitoring at the East and West Flower Garden Banks. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 92-0006. 206 pp.

Gittings, S.R. and T.J. Bright. 1986. Assessment of coral recovery following the incident of anchor damage at the East Flower Garden Bank, northwest Gulf of Mexico. Contract number NA85AA-H-CZ015. Draft final report to the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Sanctuary Division.

Gittings, S.R. and T.J. Bright. 1987. Mass mortality of *Diadema antillarum* at the Flower Garden Banks, northwest Gulf of Mexico: effect on algae and coral cover. Abstract. Benthic ecology meetings, Raleigh, NC.

Gladfelter, E.H., R.K. Monahan, and W.B. Gladfelter. 1978. Growth rates of five reef-building corals in the northeastern Caribbean. Bulletin of Marine Science 28:728-734.

Gleason, D.F. and G.M. Wellington. 1993. Ultraviolet radiation and coral bleaching. Nature 365:836-838.

Glynn, P.W. 1984. Widespread coral mortality and the 1982-83 El Niño warming event. Environmental Conservation 11:133-146.

Glynn, P.W. 1993. Coral reef bleaching: ecological perspectives. Coral Reefs 12:1-17.

Goreau, T.J. and R.L. Hayes 1994. Coral bleaching and ocean "hot spots". Ambio 23:176-180.

Goreau, T.F. and J.W. Wells. 1967. The shallow water Scleractinia of Jamaica: revised list of species and their vertical distribution range. Bulletin of Marine Science 17:442-454.

Graus, R.R. and I.G. Macintyre. 1982. Variation in growth forms of the reef coral *Montastraea annularis*: a quantitative evaluation of growth response to light distribution using computer simulation. Smithsonian Contributions to the Marine Sciences 12:441-464.

Green, E.P. and A.W. Bruckner. 2002. The significance of coral disease epizootiology for coral reef conservation. Biological Conservation 98:347-361.

Hagman, D.K. and S.R. Gittings. 1992. Coral bleaching on high latitude reefs at the Flower Garden Banks, NW Gulf of Mexico. Proceedings of the 7th International Coral Reef Symposium, Guam. 1:38-43.

Hagman, D.K., S.R. Gittings, and K.J.P. Deslarzes. 1998. Timing, species participation, and environmental factors influencing annual mass spawning at the Flower Garden Banks (Northwest Gulf of Mexico). Gulf of Mexico Science 16:170-179.

Heiss, G.A. and W.F. Dullo. 1995. Carbonate production recorded in coral growth rates. Facies 32:157-161.

Hickerson, E. 2005. Personal communication. Flower Garden Banks National Marine Sanctuary. Galveston, TX.

Highsmith R.C. 1979. Coral growth rates and environmental control of density banding. Journal of Experimental Marine Biology and Ecology 37:105-125.

Hudson, J. H. 1977. Long-term bioerosion rates on a Florida reef: a new method. Proceedings of the Third International Coral Reef Symposium, Miami. 2:491-497.

Hudson, J.H. 1981a. Growth rates in *Montastraea annularis*: A recording of environmental change, Key Largo Coral Reef National Marine Sanctuary, Florida. Bulletin of Marine Science 31:444-459.

Hudson, J.H. 1981b. Response of *Montastraea annularis* to environmental change in the Florida Keys. Proceedings of the 4th International Coral Reef Symposium, Manila. 2:233-240.

Hudson, J.H. 1984. A century of *Montastraea annularis* at Looe Key National Marine Sanctuary, Florida. In: Glynn, P.W., A.M. Szmant-Froelich, and P.K. Swart, eds. Advances in Reef Science. Miami: Atlantic Reef Committee, University of Miami. P. 55.

Hudson, J.H., G.V.N. Powell, M.B. Robblee, and T.J. Smith, III. 1989. A 107 year old coral from Florida Bay: Barometer of natural and man-induced catastrophes? Bulletin of Marine Science 44:283-291.

Hudson, J.H. and D.M. Robbin. 1980. Effects of drilling mud on the growth rate of the reef-building coral *Montastraea annularis*. In: Geyer, R.A., ed. Marine environmental pollution. Amsterdam: Elsevier Oceanography. Pp. 455-470.

Hudson, J.H., E.A. Shinn, R.B. Halley, and B.H. Lidz. 1976. Sclerochronology: a tool for interpreting past environments. Geology 4:361-364.

Humann, P. 1994. Reef fish identification: Florida, Caribbean, Bahamas. Verona, Italy: New World Publications. 400 pp.

Humann, P. and N. DeLoach. 2002. Reef fish identification: Florida, Caribbean, Bahamas: 3rd edition. Verona, Italy: New World Publications. 512 pp.

Insalaco, E. 1996. The use of Late Jurassic coral growth bands as palaeoenvironmental indicators. Paleontology 39:413-431.

Jones, R.S. and M. Clark. 1981. Fishes. In: Jameson, S.C., ed. Key Largo Coral Reef National Marine Sanctuary deep water resources survey. U.S. Department of Commerce NOAA Technical Report CZ/SP-1. Pp. 25-29.

Kaczmarsky, L.T., M. Draud, and E.H. Williams. 2005. Is there a relationship between proximity to sewage effluent and the prevalence of coral disease? Caribbean Journal of Science 41:124-137.

Kaufman, L. 1977. The three spot damselfish: effects on benthic biota of Caribbean coral reefs. Proceedings of the 3rd International Coral Reef Symposium, Miami. 1:559-564.

Kleypas, J.A., R.W. Buddemeier, D. Archer, J.P. Gattuso, C. Langdon, and B.N. Opdike. 1999. Geochemical consequences of increased atmospheric carbon dioxide on coral reefs. Science 284:118-120.

Knutson, D.W., R.W. Buddemeier, and S.V. Smith. 1972. Coral chronometers: seasonal growth bands in reef corals. Science 177:270-272.

Kraemer, G.P. 1982. Population levels and growth rates of the scleractinian corals within the *Diploria-Montastraea-Porites* zones of the East and West Flower Garden Banks. M.S. Thesis, Texas A&M University, College Station, TX. 138 pp.

Kramer, P. and P.R. Kramer. 2000. Ecological status of the Mesoamerican Barrier Reef System: Impacts of Hurricane Mitch and 1998 coral bleaching. Final report to the World Bank. Miami: Rosenstiel School of Marine and Atmospheric Science, University of Miami.

Leder, J., A.M. Szmant, and P.K. Swart. 1991. The effect of prolonged ‘bleaching’ on skeletal banding and stable isotopic composition in Montastraea annularis. Coral Reefs 10:19-27.

Lessios, H. A.., D.R. Robertson, and J.D. Cubit. 1984. Spread of *Diadema* Mass Mortality Through the Caribbean. Science 19:335-337.

Lugo-Fernández, A. 1998. Ecological implications of hydrography and circulation to the Flower Banks, Northwest Gulf of Mexico. Gulf of Mexico Science 16:144-160.

Lukens, R.R. 1981. Observations of deep-reef ichthyofauna from the Bahamas and Cayman Islands, with notes on relative abundance and depth distribution. Gulf Research Reports 7:79-81.

Macintyre, I. G. and S.V. Smith. 1974. X-radiographic studies of skeletal development in coral colonies. Proceedings of the 2nd International Coral Reef Symposium, Brisbane. 2:277-287.

McField, M. 1999. Coral response during and after mass bleaching in Belize. Atoll Research Bulletin 466:1-11.

McField, M. 2000. Influence of disturbance on coral reef community structure in Belize. Proceedings of the 9th International Coral Reef Symposium, Bali. 1:63-68.

Morse, D.E., N. Hooker, A.N.C. Morse, and R.A. Jensen. 1988. Control of larval metamorphosis and recruitment in sympatric agaricid corals. Journal of Experimental Marine Biology and Ecology 116:193-217.

Mumby, P.J. 1999. Bleaching and hurricane disturbances to populations of coral recruits in Belize. Marine Ecology Progress Series 190:27-35.

Murdoch, T.J.T. and R.B. Aronson. 1999. Scale-dependent spatial variability of coral assemblages along the Florida Reef Tract. Coral Reefs 18:341-351.

National Climatic Data Center. 2005. Climate of 2005: Atlantic hurricane season. Internet website: http://www.ncdc.noaa.gov/oa/climate/research/2005/hurricanes05.html.

National Data Buoy Center. 2005a. 42019 significant wave height (meters) 5/1990 – 2/2001. Internet website: http://www.ndbc.noaa.gov/images/climplot/42019_wh.jpg.

National Data Buoy Center. 2005b. Station 42019 - Freeport, TX. 60 NM South of Freeport, TX: Historical data. Internet website: http://www.ndbc.noaa.gov/station_history.php?station=42019.

Nelson, J.R., J.E. Eckman, C.Y. Robertson, R.L. Marinelli, and R.A. Jahnke. 1999. Benthic microalgal biomass and irradiance at the sea floor on the continental shelf of the South Atlantic Bight: Spatial and temporal variability and storm effects. Continental Shelf Research 19(4): 477-505.

Nowlin, W.D., A.E. Jochens, R.O. Reid, and S.F. DiMarco. 1998. Texas-Louisiana shelf circulation and transport processes study: synthesis report. Volume II: Appendices. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 98-0036. 288 pp.

Nugues, M.M. 2002. Impact of a coral disease outbreak on coral communities in St. Lucia: what and how much has been lost? Marine Ecology Progress Series 229:61-71.

Ostrander, G.K., K.M. Armstrong, E.T. Knobbe, D. Gerace, and E.P. Scully. 2000. Rapid transition in the structure of a coral reef community: The effects of coral bleaching and physical disturbance. Proceedings of the National Academy of Sciences 97:5297-5302.

Pattengill, C.V. 1998. The structure and persistence of reef fish assemblages of the Flower Garden Banks National Marine Sanctuary. Doctoral dissertation, Texas A&M University, College Station, Texas. 176 pp.

Pattengill-Semmens, C.V. and S.R. Gittings. 2003. A rapid assessment of the Flower Garden Banks National Marine Sanctuary (stony corals, algae, and fishes). Atoll Research Bulletin 496:501-511.

Peckol, P., H.A. Curran, E. Floyd, M. Robbart, B.J. Greenstein, and K. Buckman. 2003. Assessment of the condition of forereef and backreef sites of northern and south-central Belize, including recovery from bleaching and hurricane disturbances (stony corals, algae and fish). Atoll Research Bulletin 496:146-171.

Pickard, G.L. and W.J. Emery. 1982. Descriptive physical oceanography: An introduction. Oxford: Pergamon Press. 320 pp.

Porter J.W., P. Dustan, W.C. Jaap, K.L. Patterson, V. Kosmynin, O.W. Meier, M.E. Patterson, and M. Parsons. 2001. Patterns of spread of coral disease in the Florida Keys. Hydrobiologia 460:1-24.

Precht, W.F., R.B. Aronson, K.J.P. Deslarzes, M.L. Robbart, A. Gelber, D. Evans, B. Gearheart, and B. Zimmer. 2006. Long-term monitoring at the East and West Flower Garden Banks, 2002-2003: Final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-031. 182 pp.

Rezak, R. 1981. Geology. In: Rezak, R. and T.J. Bright, eds. Northern Gulf of Mexico topographic features study. Final report to the U.S. Dept. of the Interior, Bureau of Land Management. Contract #AA551-CT8-35. Vol. 1. NTIS Order No. PB81-248650. Pp. 23-59.

Rezak, R. 1985. Geology of the Flower Garden Banks area. In: Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A. Trippett, compilers. The Flower Gardens: A compendium of information. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 85-0024. Pp. 31-50.

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. New York: John Wiley and Sons. 259 pp.

Richardson, L. 1998. Coral diseases: What is really known? Trends in Ecology and Evolution 13:438-443.

Richardson L.L., W.M. Goldberg, R.G. Carlton, and J.C. Halas. 1998. Coral disease outbreak in the Florida Keys: Plague Type II. Revista de Biología Tropical 46:187-198.

Richardson L.L., G.W. Smith, K.B. Ritchie, and R.G. Carlton. 2001. Integrating microbiological, microsensor, molecular, and physiologic techniques in the study of coral disease pathogenesis. Hydrobiologia 460:71-89.

Richardson, L.L. and J.D. Voss. 2005. Changes in a coral population on reefs of the northern Florida Keys following a coral disease epizootic. Marine Ecology Progress Series 297:147-156.

Rooker, J.R., Q.R. Dokken, C.V. Pattengill, and G.J. Holt. 1997. Fish assemblages on artificial and natural reefs in the Flower Garden Banks National Marine Sanctuary, USA. Coral Reefs 16:83-92.

Shinn, E.A., B.H. Lidz, R.B. Halley, J.H. Hudson, and J.L. Kindinger. 1989. Reefs of Florida and the Dry Tortugas, Field Trip Guidebook T176. Washington, DC: 28th International Geological Congress. 53 pp.

Smith, T.J., J.H. Hudson, M.B. Robblee, G.V.N. Powell, and P.J. Isdale. 1989. Freshwater flow into Florida Bay: A historical reconstruction based on fluorescent banding in the coral *Solenastrea bournoni*. Bulletin of Marine Science 44:274-282.

Sorokin, Y.I. 1995. Coral reef ecology. New York: Springer. 465 pp.

Sutherland, K.P., J.W. Porter, and C. Torres. 2004. Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. Marine Ecology Progress Series 266:273-302.

Steneck, R.S. 1988. Herbivory on coral reefs: A synthesis, Proceedings of the 6th International Coral Reef Symposium, Townsville. 1:37-49.

Steneck, R.S. and J.C. Lang. 2003. Rapid assessment of Mexico's Yucatan reef in 1997 and 1999: Pre- and post-1988 mass bleaching and Hurricane Mitch. Atoll Research Bulletin 496: 294-317.

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1970. The oceans: Their physics, chemistry, and general biology. Englewood Cliffs, New Jersey: Prentice Hall, Inc. 1088 pp.

Targett, N.M., L.D. Coen, A.A. Boettcher, C.E. Tanner. 1992. Biogeographic comparisons of marine algal polyphenolics: Evidence against a latitudinal trend. Oecologia 89:464-470.

U.S. Dept. of the Interior, Geological Survey (USGS). 2001. Flower Garden Banks National Marine Sanctuary: shaded relief of East and West Flower Garden Banks. Internet website: http://walrus.wr.usgs.gov/pacmaps/. Accessed 3 August 2006.

U.S. Dept. of the Interior, Minerals Management Service. 1998. Gulf of Mexico OCS oil and gas lease sales 171, 174, 177, and 180: Western planning area. Final environmental impact statement. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS EIS/EA MMS 98-0008.

U.S. Dept. of the Interior, Minerals Management Service. 2002. Gulf of Mexico OCS oil and gas lease sales: 2003-2007. Central planning area sales 185, 190, 194, 198 and 201. Western planning area sales 187, 192, 196 and 200. Final environmental impact statement. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS EIS/EA MMS 2002-052.

Valiela, I. 1984. Marine ecological processes. New York: Springer. 346 pp.

The Weather Underground, Inc. 2005a. Hurricane archive: 2004. Internet website: http://www.wunderground.com/hurricane/at2004.asp. Accessed 21 December 2005.

The Weather Underground, Inc. 2005b. Hurricane archive: 2005. Internet website: http://www.wunderground.com/hurricane/at2005.asp. Accessed 21 December 2005.

Weber, J.N. and E.W. White. 1977. Caribbean reef corals *Montastraea annularis* and *Montastraea cavernosa* – long term growth data as determined by skeletal x-radiography. American Association of Petroleum Geologists Studies 4:172-179.

Weil, E. 2004. Coral Diseases in the Wider Caribbean. In: Rosenberg, E. and Y. Loya, eds. Coral health and disease. Berlin: Springer. Pp. 35-68.

Wellington, G.M. and P.W. Glynn. 1983. Environmental influences on skeletal banding in Eastern Pacific (Panama) corals. Coral Reefs 1:215-222.

Wells, J.W. 1963. Coral growth and geochronometry. Nature 197:948-950.

Wilson, C.A., A. Pierce, and M.W. Miller. 2003. Rigs and Reefs: A comparison of the fish communities at two artificial reefs, a production platform, and a natural reef in the northern Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2003-009. 95 pp.

Zar, J.H. 1984. Biostatistical analysis, second edition. Englewood Cliffs, NJ: Prentice Hall. 718 pp.

Zimmer, B. 2005. Personal communication. PBS&J. Miami, FL.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.