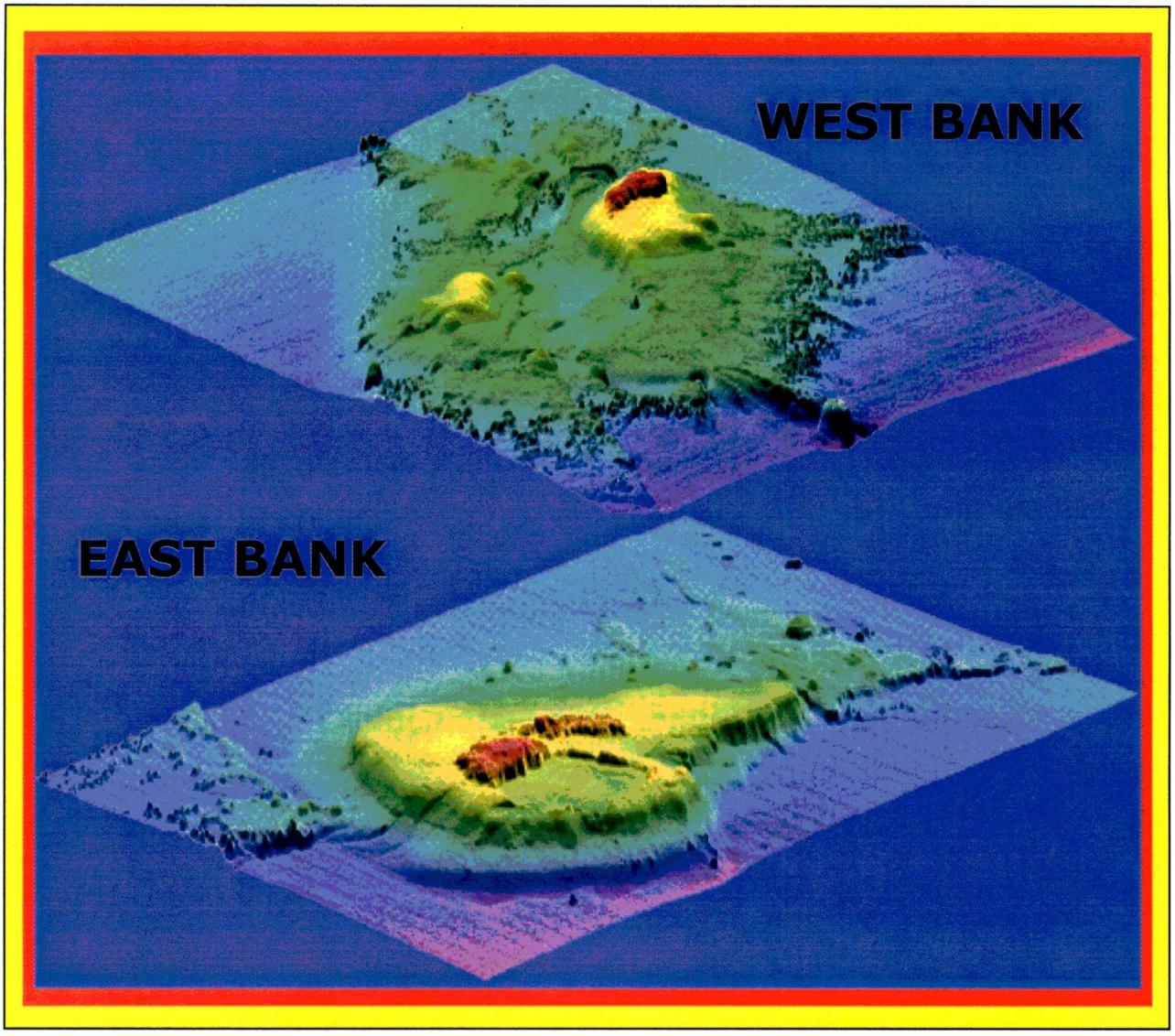
OCS Study
MMS 2001-101

Long-Term Monitoring at the East and West Flower Garden Banks National Marine Sanctuary, 1998-1999



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

OCS Study
MMS 2001-101

Long-Term Monitoring at the East and West Flower Garden Banks National Marine Sanctuary, 1998-1999

Authors

Quenton R. Dokken
Ian R. MacDonald
John W. Tunnell, Jr.
Terry Wade
Carl R. Beaver
Susan A. Childs
Kim Withers
Thomas W. Bates

Prepared under MMS Contract
1435-01-98-CT-30905
by
Texas A&M University
6300 Ocean Drive
Corpus Christi, Texas 78412

Published by

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

New Orleans
March 2002

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS), the National Oceanic and Atmospheric Administration (NOAA) and the Center for Coastal Studies (CCS), Texas A&M University-Corpus Christi, and the Geological and Environmental Research Group (GERG), Texas A&M University-College Station. This report has been technically reviewed by MMS and NOAA, and 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:

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell, Jr., 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. OCS Study MMS 2001-101. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 120 pp.

ACKNOWLEDGMENTS

Project personnel and their major responsibilities:

1. Quenton R. Dokken	Project Manager, Co-Principal Investigator
2. Ian R. MacDonald	Scientist, Co-Principal Investigator
3. John W. Tunnell, Jr.	Scientist, Co-Principal Investigator
4. Norman Guinasso	Scientist/Data Analysis
5. Terry Wade	Scientist/Data Analysis
6. Carl R. Beaver	Scientist/Logistics/Data Analysis /Field Management
7. Susan A. Childs	Scientist/Data Management/Field Management

Project Divers

Susan Childs	Suzanne Dilworth	Kathy Viola
Terry Riggs	Mike Fredricks	Ed Andrews
Jeff Childs	Mark Miltello	James Giesen
Tony Sebastian	Noe Barrera	Thomas Bates
Joe Westphal	Matt Campbell	David Gray
Ian MacDonald	Debbie Witcher	Rick Maxey
Albert Oswalt	Franklin Viola	Roy Lehman
Steve Van Buren	Amy Koltermann	Erin Albert
Carl Beaver	Quenton Dokken	Lee Lehman

Individual authors/contributors and the tasks they performed are listed below.

REPORT	Task/Analysis	Author/Contributor
LONG-TERM MONITORING AT THE FLOWER GARDEN BANKS, 1998-1999 (MMS/NOAA FUNDED PROJECT)	Project Management, Conclusions, Recommendations, Editorial Management	Quenton R. Dokken Ian R. MacDonald John W. Tunnell, Jr.
	Random Photographic Transects	Carl Beaver, Amy Koltermann, and Susan Childs
	Encrusting Growth Stations	Carl Beaver
	Repetitive Quadrats	Carl Beaver and Thomas Bates
	Sclerochronology	Carl Beaver, Susan Childs, and Kim Withers
	Water Chemistry	Terry Wade
	Insolation	Ian R. MacDonald and Norman Guinasso
	Temperature	Carl Beaver
	Urchin Surveys	Carl Beaver
	Document Layout & Preparation	Susan Childs, Kim Withers, Thomas Bates, and Suzanne Dilworth

ATTACHMENTS	AUTHOR/CONTRIBUTOR	INSTITUTION
1 LIST OF THE MACROALGAE COLLECTED DURING THE ANNUAL MONITORING CRUISE AT THE TEXAS FLOWER GARDEN BANKS, SEPTEMBER 15-20, 1999 ON BOARD OF THE M/V SPREE (Ancillary Project)	Suzanne Fredericq, Naomi Phillips, Showe-Mei Lin, Brigitte Gavio, and Fred Gurgel	Department of Biology, University of Louisiana at Lafayette
2 ALGAL COMMUNITY STRUCTURE OF THE EAST AND WEST FLOWER GARDENS, NORTHWESTERN GULF OF MEXICO (Ancillary Project)	Roy L. Lehman and Erin M. Albert	Center for Coastal Studies Texas A&M University-Corpus Christi
3 FOOD WEB STRUCTURE AND MACROALGAL PRIMARY PRODUCTION IN THE FLOWER GARDEN BANKS (Ancillary Project)	Ken Dunton and Harlin Miller	The University of Texas Marine Science Institute, Port Aransas
4 MICROMOLLUSCAN FAUNAL SURVEY OF THE EAST AND WEST FLOWER GARDEN BANKS (Ancillary Project)	John W. Tunnell, Jr. and Noe Barrera	Center for Coastal Studies, Texas A&M University-Corpus Christi
5 TOXICITY TESTING OF SEDIMENT PORE WATER FROM THE FLOWER GARDEN BANKS, GULF OF MEXICO (Ancillary Project)	Marion Nipper[1] and R. Scott Carr[2]	[1]Center for Coastal Studies and [2]U.S. Geological Survey-Biological Resources Division Marine Ecotoxicology Research Station, Texas A&M University – Corpus Christi

EXECUTIVE SUMMARY

With joint funding from the Minerals Management Service and the National Oceanic and Atmospheric Administration, Texas A&M University-Corpus Christi Center for Coastal Studies and Texas A&M University Geochemical Environmental Research Group continued the long-term monitoring of the Flower Garden Banks (FGB) coral reef habitats in 1998 and 1999. The FGB lies within the Flower Garden Banks National Marine Sanctuary and comprises the East and West Flower Garden Banks (EFGB and WFGB). Each topographic high is within 25 m of the surface. A 100 x 100 m study site has been delineated at each bank and several methods were used to monitor changes in coral reef communities.

Random photographic transects were used to provide an overall evaluation of community composition at the FGB. Fourteen 10 m transects were taken providing 238 photographs at each bank. The dominant coral species at both banks were *Montastraea annularis* and *Diploria strigosa*. The occurrence of algae increased from 3% in 1998 to over 20% in 1999. This increase was due to the presence of large amounts of red turf algae in the Order Ceramiales and was mainly at the expense of bare reef rock.

Annual growth rates of *Montastraea faveolata* were measured using sclerochronolgy, a measurement of accretionary growth bandwidths. One core was removed from both the EFGB and WFGB, longitudinally sectioned, and x-rayed to reveal growth bandwidths. Mean accretionary growth from 1998-1999 averaged 7.3 mm/year at the EFGB and 5.0 mm/year at the WFGB.

Sixty permanent encrusting growth stations of *Diploria strigosa* were photographed at each bank and used to calculate growth and/or retreat rates in cm/year. The EFGB exhibited a net retreat in 1998 and net advance in 1999. Net retreat was reported for both years at the WFGB.

Repetitive quadrats were used to monitor changes in structure of particular coral communities at the FGB. Yearly repeated photographs of forty stations at each bank were compared to previous years. Percent cover, number of individual coral colonies, incidents of coral bleaching and disease, and tissue loss were recorded from the photographs. Mean coral cover at the EFGB was greater than 55% in 1998 and 1999, and 52% both years at the WFGB. Several incidents of bleaching occurred, with the highest occurrence recorded at the WFGB in 1999. Only three incidents of coral disease were reported. The majority of tissue loss was due to coral retreat/algal replacement and sediment deposition on living coral colonies.

Water quality, insolation, and temperature parameters were monitored at both sites. Semi-Permeable Membrane Devices (SPMD) were used to monitor the presence of hydrocarbons and other analytes in the water column. No significant amount of toxins were accumulated in the SPMD's. Photosynthetically active radiation (PAR) and temperature were monitored in an attempt to relate community changes with major fluctuations of irradiance and temperature; however correlations were difficult to make due to instrument complications/failure.

Sea urchin surveys were conducted at the EFGB to monitor changes in abundance of *Diadema*. Three transects covering 600 m^2 revealed seven individuals. Population levels of *Diadema* at the FGB have been low since the major "die-off" in the mid-1980s.

Ancillary studies (Attachments 1-5) supplement this report, describing algae and micromolluscan populations, primary production of macroalgae, and porewater toxicity tests at the Flower Garden Banks. Fredericq *et al.* (Attachment 1) and Lehman and Albert (Attachment 2) recorded a combined taxonomic list of 72 species of algae collected at the FGB. Fredricq *et al.* noted an abundance of blue-green algae and speculate it was caused from nutrient loading. Dunton and Miller (Attachment 3) reported blue-green algae as the primary source of nitrogen in the water column and described the FGB as being "autogenous" in meeting nutrient supplies. Barrera and Tunnell (Attachment 4) reported an increase of 100 species of the known micromolluscan faunal assemblage at the FGB. Porewater toxicity testing conducted in sediments of the FGB by Nipper and Carr (Attachment 5) revealed no toxicity due to organic or inorganic pollutants.

The FGB coral reef habitats remain healthy and productive especially when compared to other reefs of the Gulf of Mexico and Caribbean. The causes of negative shifts during 1998-1999 are unknown. The impact of these shifts will be monitored in 2000-2001 to determine if these were short-term anomalies or the beginning of long-term trends. The monitoring database at the FGB is perhaps the most complete long-term database for a coral reef ecosystem in the Gulf of Mexico. The effectiveness of these long-term monitoring efforts will improve substantially with the implementation of the following:

- advanced instrumentation for in situ observations of the associated physiochemical water parameters,
- expanded ancillary studies, and
- increased sampling events from annual to quarterly investigations.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

1.0 INTRODUCTION

1.1 OVERVIEW

The current long-term monitoring efforts at the Flower Garden Banks coral reefs began in 1989 (Gittings *et al.*, 1992) and continue (Dokken *et al.*, 1999) for the purposes of:

1) providing relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and production in the vicinity of sensitive ecosystems associated with the Flower Gardens coral reefs,
2) documenting long-term changes in reef-building coral and associated communities at the Flower Garden Banks caused by either impacts of petroleum exploration and production or other human impacts,
3) documenting long-term natural variation in reef growth and associated communities on the Flower Garden Banks and,
4) stimulating ancillary research efforts and coordinating monitoring activities with agencies and institutions conducting water quality assessments and other studies in the vicinity of the Flower Garden Banks in order to better evaluate causes of environmental change.

1.1.1 Habitat Description

The Flower Garden Banks (FGB) are deep-water coral habitats in the northwestern Gulf of Mexico and were given "National Marine Sanctuary" status in 1992. The FGB are located on the edge of the outer continental shelf of the Gulf of Mexico. The East Flower Garden Bank (EFGB) is located at 27° 54.5' N latitude and 93° 36.0' W longitude, approximately 193 km southeast of Galveston, Texas. The West Flower Garden Bank (WFGB) is located approximately 172 km southeast of Galveston at 27° 52.4' North latitude and 93° 48.8' West longitude (Figure 1.1.1.1). Both banks are topographic features created by the uplift of underlying salt domes of Jurassic, Louann origin (Rezak, 1981). These bedrock domes overlying uplifted salt domes are capped by an overgrowth of calcareous marine organisms and represent the largest charted calcareous banks in the northwestern Gulf of Mexico (Bright *et al.*, 1985) and the northernmost coral reefs on the continental shelf of North America (Bright *et al.*, 1984).

The coral cap ranges in depth from approximately 18 to 36 m (Rezak *et al.*, 1985). The pear shaped EFGB, encompassing an area of approximately 67 km^2 (Rezak *et al.*, 1985) slopes from the crest at roughly 20 m to a seabed plane of terrigenous muds surrounding the banks at a depth of 100-120 m. The eastern and southern edges of the bank slope steeply while the area to the north and west of the coral cap exhibits a more gentle slope (Figure 1.1.1.2).

The major features of the 137 km^2 WFGB are three crests aligned along an east-west axis (Figure 1.1.1.3). The middle crest rises from a depth of 100–150 m to within 18 m of the surface and supports a coral reef habitat (Rezak *et al.*, 1985).

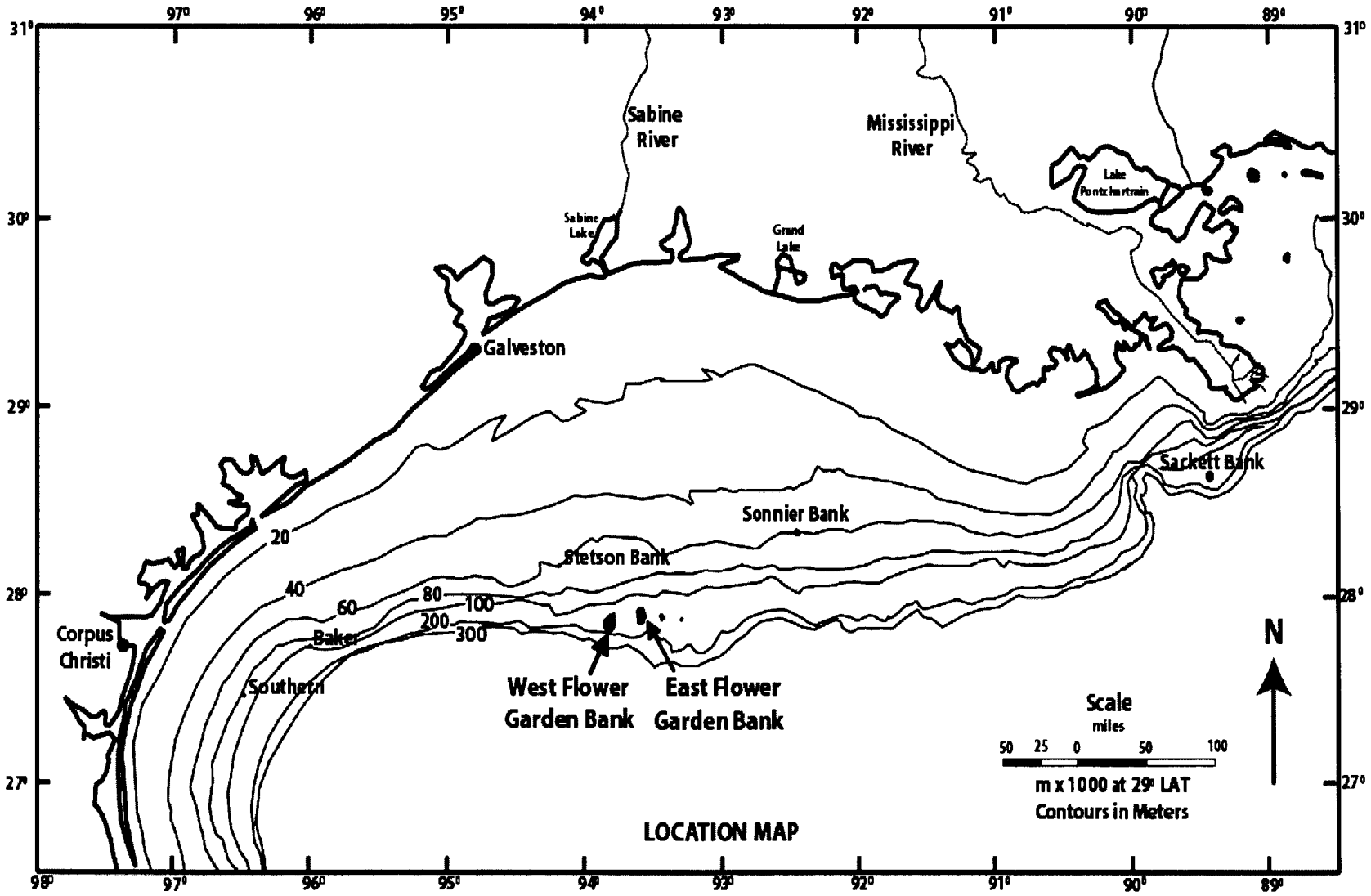


Figure 1.1.1.1. Location map of the East and West Flower Garden Banks in relation to the continental shelf and other topographic features of the northwestern Gulf of Mexico (from Gittings *et al.* 1992).

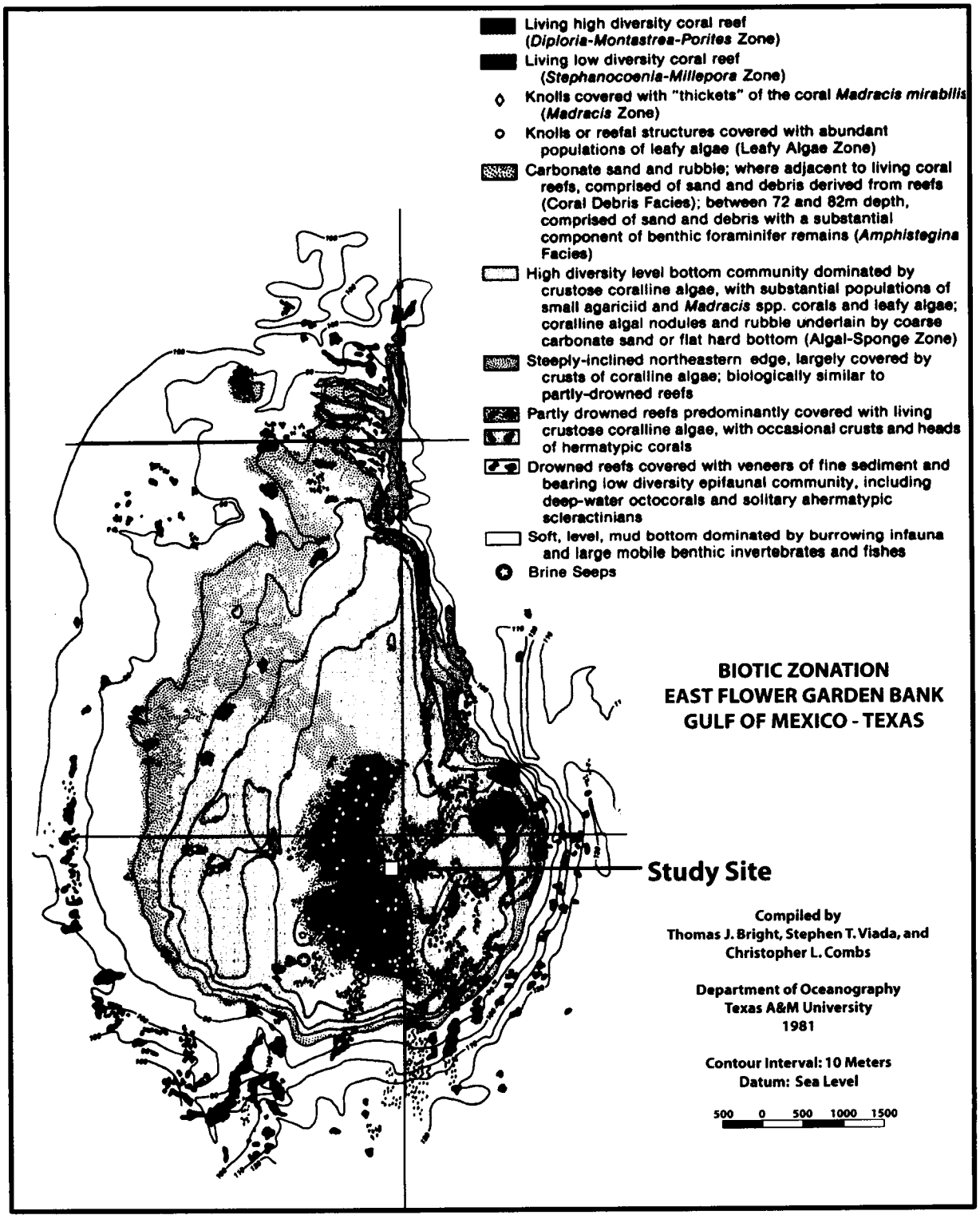


Figure 1.1.1.2. Biotic zonation and topography of East Flower Garden Bank. The darkest area depicts the high diversity coral reef zone. (from Rezak *et al.* 1985)

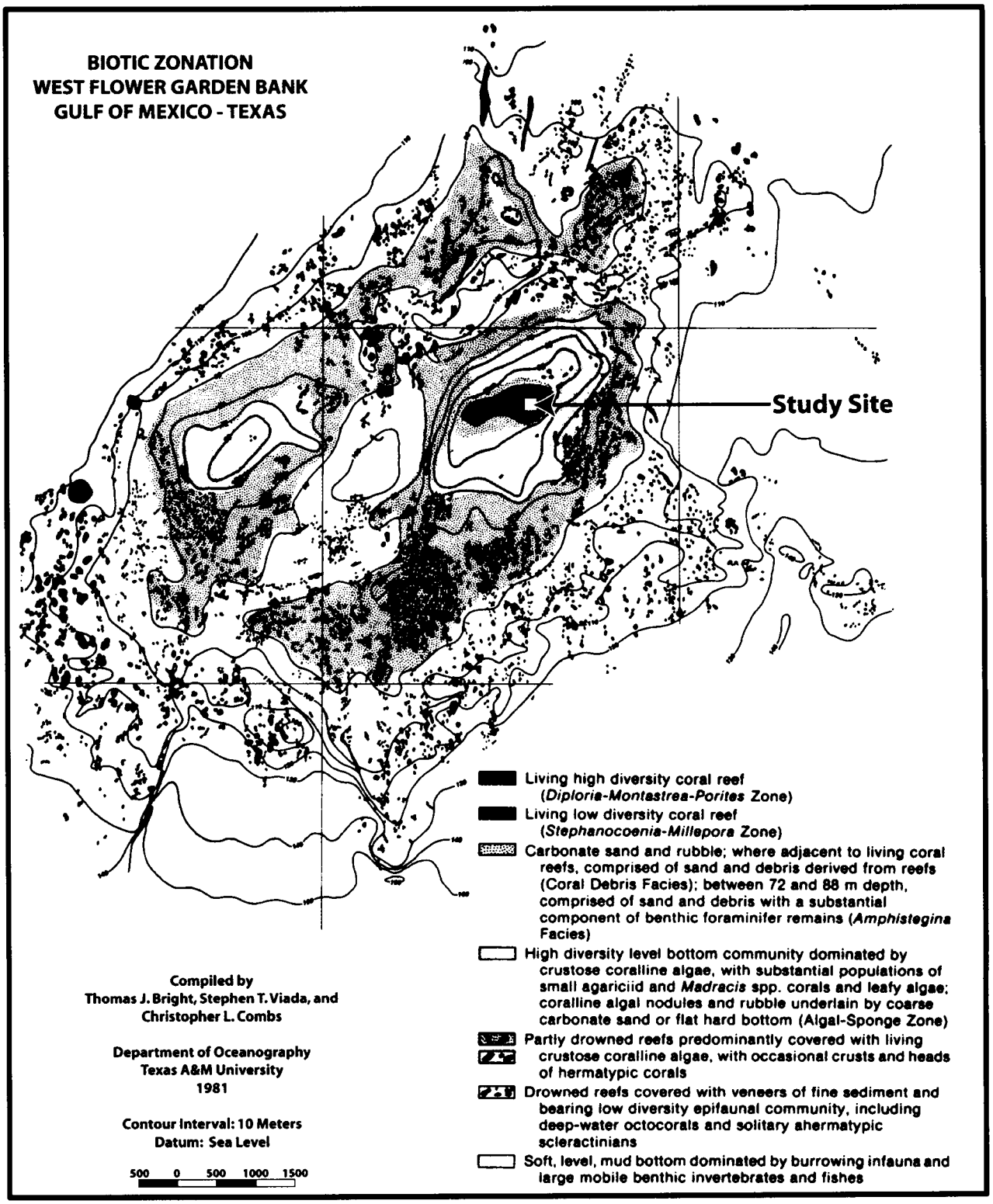


Figure 1.1.1.3. Biotic zonation and topography of the West Flower Garden Bank. The darkest area depicts the high diversity coral reef zone (from Rezak *et al.* 1983).

The FGB are elements of a widely dispersed and discontinuous arc of reefal material along the outer continental shelf of the Gulf of Mexico (Rezak *et al.*, 1985). Although low diversity communities exist on neighboring banks, the reefs at Cabo Rojo, approximately 100 km south of Tampico, Mexico, are the closest extensively developed coral reef in the Gulf of Mexico.

Environmental conditions on the northern Gulf's outer continental shelf are generally favorable for development of hermatypic scleractinian coral species. Salinities range between 34 and 36 ppt at the surface of the reef while water temperatures range from a low of ~ 20°C (mid-February) to a high of ~ 30°C (August). Water clarity permits an average 75% per meter transmission of white light with 40% to 50% of surface light reaching 37 m (McGrail *et al.*, 1982).

The diversity of the coral community can be described as depauperate as it supports only 20 species of hermatypic corals (Bright *et al.*, 1984), whereas upwards of 67 species may be found inhabiting some Caribbean reefs. Acroporid branching scleractinians and gorgonians are absent from the Flower Garden reefs.

The biological zonation of the coral reefs is dominated with high scleractinian diversity in the *Montastraea-Diploria-Porites* Zone, which is limited to a depth of less than 36 m (Figure 1.1.1.4). The lower diversity *Stephanocoenia-Millepora* Zone extends from 36–52 m. (Rezak *et al.*, 1985). A lower diversity reef environment is found in the Algal-Sponge Zone from ~ 46 – 88 m. Lower portions of this depth range are characterized by antipatharians which grade into a soft bottom environment composed of coarse carbonate sands below ~ 88 m.

In the *Montastraea-Diploria-Porites* Zone, the *Montastraea annularis* species complex (*Montastraea annularis, M. faveolata,* and *M. franksi*; Weil and Knowlton, 1994) represents the dominant scleractinian taxa, followed by *Diploria strigosa, M. cavernosa, Porites astreoides,* and *Colpophyllia natans*. Total live coral cover in this zone is ~ 45–52% and crustose coralline and calcareous green algae are also common (Dokken *et al.*, 1999). The high coral cover is interrupted by areas of bare reef rock and patches of biogenic sands. The calcium carbonate substrate in this zone was formed and is primarily maintained by 16 species of scleractinian corals and approximately 9 genera of crustose coralline algae. In addition to the aforementioned taxa, over 250 species of invertebrates (Bright and Pequenat, 1974) and 120 species of fishes (Pattengill *et al.*, 1997) inhabit this community.

Along the narrow depth gradient between 36 and 46 m, the scleractinian *Stephanocoenia intersepta* and the hydrozoan *Millepora alcicornis* dominate the substrate in the *Stephanocoenia-Millepora* Zone. In addition to *Stephanocoenia* and *Millepora*, 11 species of scleractinians are present including *Diploria strigosa*, *M. cavernosa*, *Colpophyllia natans* and *Agaricia* spp.

The FGB are unique because they exist in the most active offshore oil/gas exploration and production area in the world. Approximately 4,000 production platforms are located in the northern Gulf of Mexico primarily in the northwestern quadrant where the FGB are located. Two kilometers to the east of the EFGB, a production platform was installed in 1982 and has been producing natural gas since installation. In 1998, an additional well was drilled at this production site (dry well). To date, the production of oil and gas in the near vicinity has not been demonstrated to be detrimental to the health and productivity of the FGB.

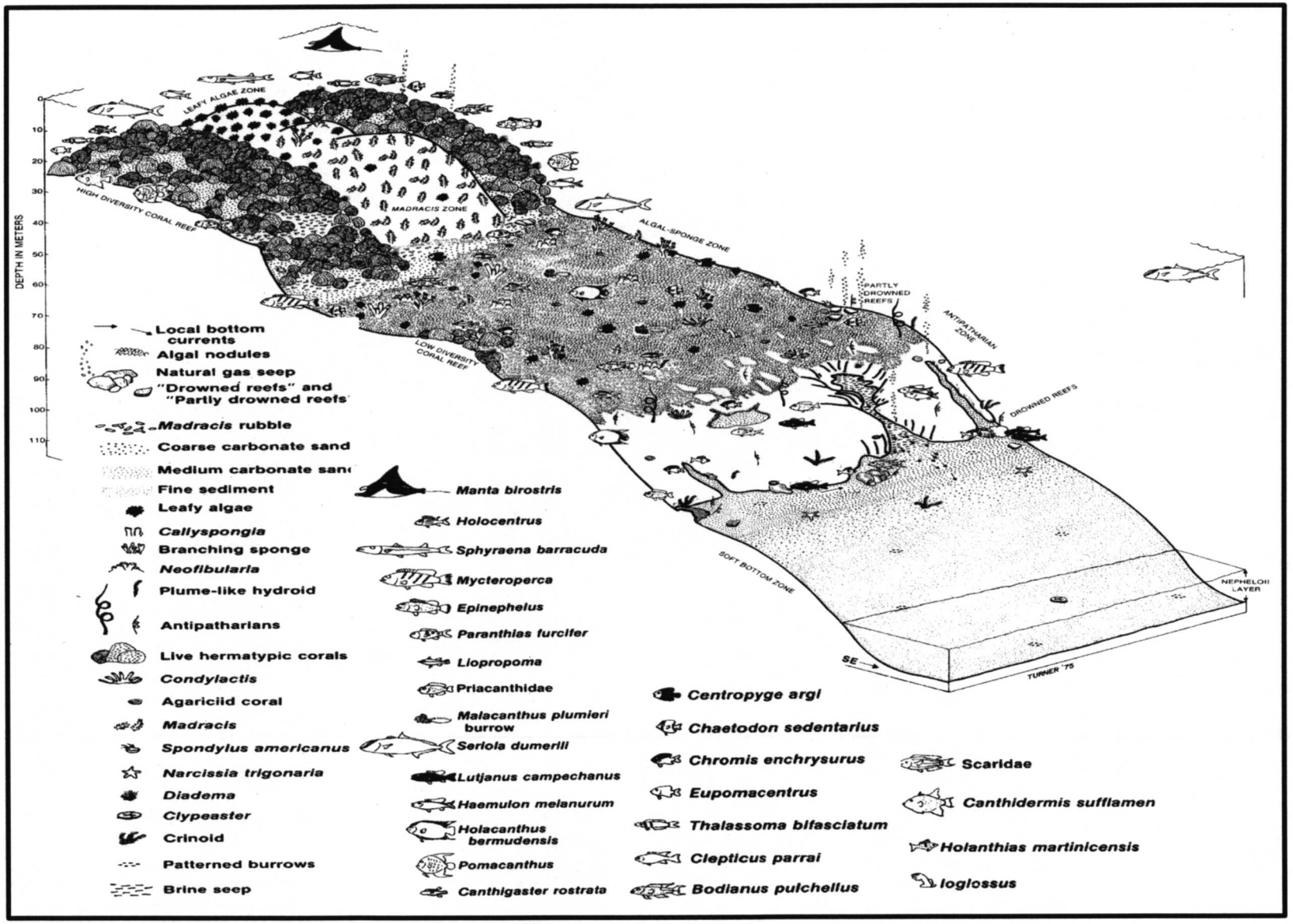


Figure 1.1.1.4. Cross-section of East Flower Garden Bank showing zonation and distribution of common species (from Rezak *et al.* 1985)

2.0 METHODS

2.1 FIELD LOGISTICS

Sampling cruises were conducted aboard the M/V Fling during 27 September - 1 October 1998 and 12-16 September 1999. Weather conditions were excellent during the 1998 cruise; however, conditions during the September 1999 cruise were marginal, forcing postponement of one contracted task (core extraction) and ancillary deepwater studies. The core extraction was eventually collected in February 2000.

2.2 STUDY SITES

During 1998 and 1999, sampling was conducted within previously established 100 x 100 m study sites on both the EFGB and WFGB. The EFGB study site was initially established in 1989 by Texas A&M University during early MMS-funded monitoring efforts (Gittings *et al.*, 1992). The WFGB was originally established by Continental Shelf Associates (CSA) in 1988 and incorporated into the MMS monitoring efforts by Texas A&M University (Gittings *et al.*, 1992). Subsurface buoys attached to stainless steel eyebolts cemented into the reef rock mark the four corners of each study site. During each sampling effort, graduated, color-coded polypropylene lines were extended between each corner eyebolt to mark the boundaries of the study sites and aid in diver navigation and location of individual monitoring stations. Lines were allowed to float approximately 1 m above the reef substrate to increase visibility for the divers and to reduce contact with the living reef. Boundary lines were installed prior to and removed at the end of sampling. Each dive team was supplied with detailed underwater maps depicting the relative position of each repetitive station in relation to boundary lines and major topographical features (Figures 2.2.0.1 and 2.2.0.2). A master map on the surface was updated after each dive with the relative positions of new or re-numbered stations added during each cruise. During spring, summer, and fall a large surface buoy is secured to a mooring line that is attached to a stainless steel u-bolt permanently cemented into the reef rock within each site. The buoys are owned by the Flower Garden Banks National Marine Sanctuary (FGBNMS) and maintained by contract with Buoy Services, Inc. of Freeport, Texas. The buoys served as mooring sites for the research vessel during monitoring missions.

2.3 RANDOM TRANSECTS

Random photographic transects were conducted within the boundaries of each study site to provide data on coral community population diversity and cover. Fourteen 10 m transects, each containing seventeen non-overlapping photographs, were taken on each site during 1998 and 1999 (Gittings *et al.*, 1992; Hagman and Gittings, 1992). Divers were equipped with Nikonos III or V cameras loaded with Kodak Ektachrome 100, 36 exposure color slide film, 28 mm lens and dual Nikonos strobes mounted on a rectangular aluminum or stainless steel camera frame (Figure 2.3.0.1). The bottom of each frame was wrapped in closed cell foam to protect the corals from damage. This system produced color positive images of reef substrate approximately 44 x 63 cm in size.

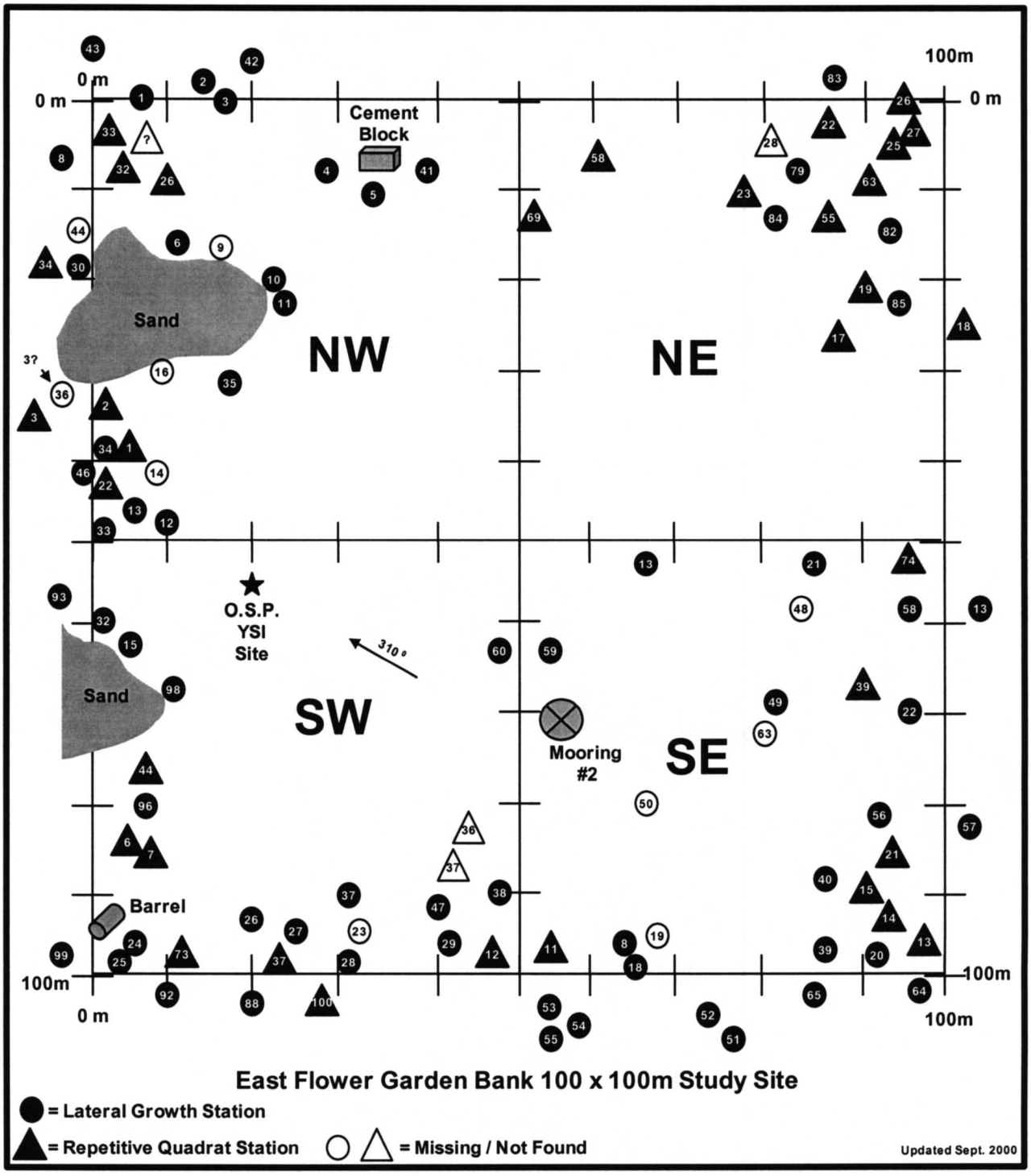


Figure 2.2.0.1. Map of East Flower Garden Bank 100 m x 100 m study site showing relative positions of permanent stations, mooring bolt and other conspicuous features.

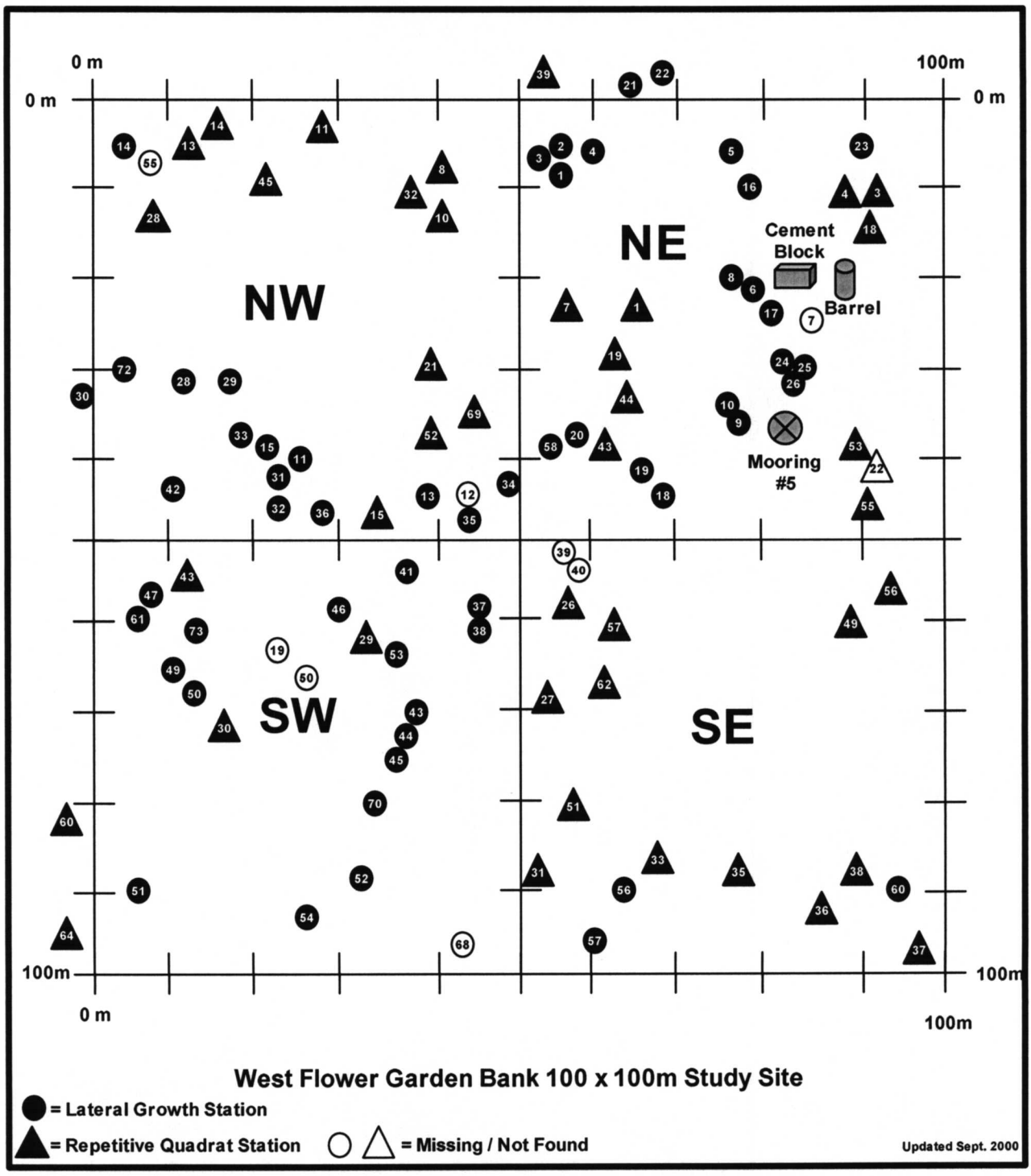


Figure 2.2.0.2. Map of West Flower Garden Bank 100 m x 100 m study site showing relative positions of permanent stations, mooring bolt and other conspicuous features.

Figure 2.3.0.1. Diver with random transect camera framer.

Each diver was assigned two sets of random numbers. The first (1) number of each set represented a compass heading, and the second (2) set represented a number of fin kicks. The diver would descend to the seafloor and proceed in the specified direction (1) for the specified number of fin kicks (2) to the point at which the transect would begin. Transects would continue along the same direction until seventeen non-overlapping photographs were taken. The diver would then proceed in the direction (1) and distance (2) specified in a second set of random numbers to begin the second transect.

All slides were developed and digitally recorded on CD-ROM media. The two dimensional projection of the digitized images on the computer screen was considered the areal coverage of the transect in square centimeters. Data were acquired using a Wacom serial graphics tablet and Jandel Scientific Sigma Scan Pro 4.0 software. Photographic measurements were standardized by entering the known area of the photograph into Sigma Scan 4.0. Colonies were outlined using the serial graphics pen and areal coverage was automatically calculated. Percent cover data were calculated for corals, sponges, turf algae and exposed reef rock. Species diversity, evenness, and relative dominance were calculated as described in Brower *et al.* (1998).

Percent cover data was determined by compiling all coverage data from all photographs for each bank, and then determining each species coverage in comparison to all others. Analysis of Variance (ANOVA) was applied to determine statistically significant differences in diversity, evenness, or relative dominance between time periods and sites within this contract period and

between this study and previous studies. A Tukey's HSD multiple range test was used to define differences.

2.4 OUTSIDE RANDOM TRANSECTS

Three transects outside of the study site boundary line consisting of 14 images each were taken at the EFGB and WFGB. Location of these transects was dependent upon positioning of the boat to the u-bolt and the direction the diver randomly chose. These transects were analyzed to determine if the study sites established by previous studies are truly representative of the coral fauna found on the remainder of the coral cap. All images were processed and analyzed in the same manner as those taken within the boundaries of the study sites. Outside random transect data were compared to pooled mean percent cover and relative abundance data from previous years.

2.5 SCLEROCHRONOLOGY

Sclerochronology, the determination of annual coral growth rates through measuring accretionary growth bandwidths, is the accepted form of determining growth rates within the FGBNMS. In order to minimize impact to coral colonies, cores are extracted only during the second year of the monitoring contract. During the September 1999 cruise, it was decided to postpone core extraction until sea conditions were calm enough to minimize risk of equipment and environmental damage. An onboard hydraulic pump connected by hoses to an underwater drill is normally used to extract the cores from the selected *Montastraea faveolata* colony. Rough water conditions increased the possibility of equipment damage creating a risk of water contamination by hydraulic fluid.

In accordance with NOAA permit FGBNMS-11-99, one core sample was obtained from both the EFGB and WFGB during February 2000. To reduce potential risks to the environment, coral cores were obtained using a pneumatic drill attached to a compressed air scuba cylinder instead of the hydraulic previously described equipment. Resulting cores were 60 mm in diameter and were drilled to a depth of at least 100 mm representing more than ten years of growth. To obtain the most accurate and continuous growth information, it was also essential to drill the core sample perpendicular to the surface of the coral head.

Cores were longitudinally sectioned in the TAMUCC laboratory using a dual-blade diamond impregnated rock saw to produce 3-4 mm thick slabs. Coral slabs were arranged on Kodak brand Industrix 400 x-ray film and exposed to x-rays (100 mA, 20 KV for 1.25 seconds) to reveal annual density bands. A machined metal scale included in each x-ray image was used as a length standard to insure precise measurement of growth bands. Measurement standards were included in each x-ray, therefore, film negatives were scanned into a computer and enlarged for growth band analysis to avoid compromising the image's scale.

One annual growth increment was defined as the combination of one low-density band and its adjacent high-density band (Knutson *et al.*, 1972). The area between the upper boundaries of two sequential high-density growth bands was considered an annual growth increment. Scanned images were expanded by a factor of ten for measurement of growth bandwidths. An object-oriented drawing program was used to place measurement lines parallel to the growth axis, which

automatically displayed the information (line length). Pseudo-replicate measurements were taken at three separate locations for each annual growth band from a single core of *M. faveolata*. Measurement data was corrected using the x-rayed precision metal scale included in each x-ray. A student t-test was used to determine if significant differences existed among years. Differences between banks were determined using an Analysis of Variance (ANOVA). A Duncan's Multiple Range Test was applied to determine which years were significantly different. Linear regression analysis was performed on the core data to determine if significant relationships exist between accretionary growth and year.

2.6 ENCRUSTING GROWTH

During previous studies (Continental Shelf Associates, 1996; Gittings *et al.*, 1992), 60 colonies of *Diploria strigosa* were established as permanent encrusting growth stations on each bank. Growth stations were set up along the margin of live coral growth adjacent to bare reef rock. These stations were created by permanently embedding two pins in the reef rock in such a manner that the growth margin of the coral would bisect a repeatable close-up photograph of the station. A uniquely numbered plastic tag secured to one of the pins identified each station.

A Nikonos V camera equipped with a 28 mm lens, Nikonos close-up kit, strobe, and Kodak Ektachrome 100, 36-exposure slide film was used to produce 13.3 x 19.7 cm photographic images of each station. By placing the inside lower edge of the camera framer against the two pins, a repeated image of the station was produced (Figure 2.6.0.1). Each station was photographed and the station and frame number recorded on an underwater slate. The information was transferred to the permanent data log. All resulting images were digitized and stored on CD-ROM digital media. Identical images taken on previous cruises were matched by ridge position of the corals. Consecutive images were traced on a Wacom serial graphics tablet using Jandel Scientific Sigma-Scan Pro 4.0 software. The area coverage (cm^2) was calculated relative to growth and retreat of live coral for each photograph as outlined in Gittings *et al.* (1992). Growth and/or retreat rates for each station were determined by dividing area coverage by the border length of *D. strigosa* shown in the photograph. Net growth was determined by pooling growth and retreat measurements from all stations.

2.7 REPETITIVE QUADRATS

Repetitive quadrats were used to monitor changes in the structure of particular coral communities at the FGBNMS. Forty permanent, repetitive photographic stations on each bank were sampled during the 1998 and 1999 cruises. Individual stations were identified by securing a numbered plastic tag to a stainless steel post inserted into the reef rock (Figure 2.7.0.1). During the 1998 and 1999 cruises, each station was photographed using a T-shaped camera frame bearing a Nikonos V camera with a 15 mm lens. Two Ikelite 225 watt-second strobes were mounted on the ends of the horizontal bar (Gittings *et al.*, 1992). Distance was set at 2 m and *f*-stop at 8, which produces the highest quality image. Yearly repeated photographs were accomplished by consistent orientation of the camera frame using a compass and bubble level. After placing the vertical bar against the steel post, each station was photographed with the compass needle oriented to magnetic north and bubble leveled.

Analysis of the individual station photographs was conducted by projecting images onto a flat surface, generating a 25.2 cm X 37.9 cm image. For each station, the margins of individual coral colonies were traced from 1997 photographs. The 1998 and 1999 photographs were then super-imposed upon the 1997 templates for temporal comparisons.

Figure 2.6.0.1. Diver photographing a permanent encrusting growth station.

Differences between current and pre-existing margins at the FGBNMS were identified and characterized in one of the following categories: (1) growth, marginal or in-filling; (2) loss of tissue caused from growth of algae, deposition of sediment, disease, competition, and predation by fish; (3) and incidence of bleaching. For each station, percent cover by species was determined by overlaying the image with 100 randomly positioned markers. Three overlays were used and averaged to determine a final percent cover. Cover estimates were based upon the total number of markers that intersected live coral tissue. This same procedure was used to estimate bleached cover or tissue loss resulting from suspected disease at stations in which these observations were made.

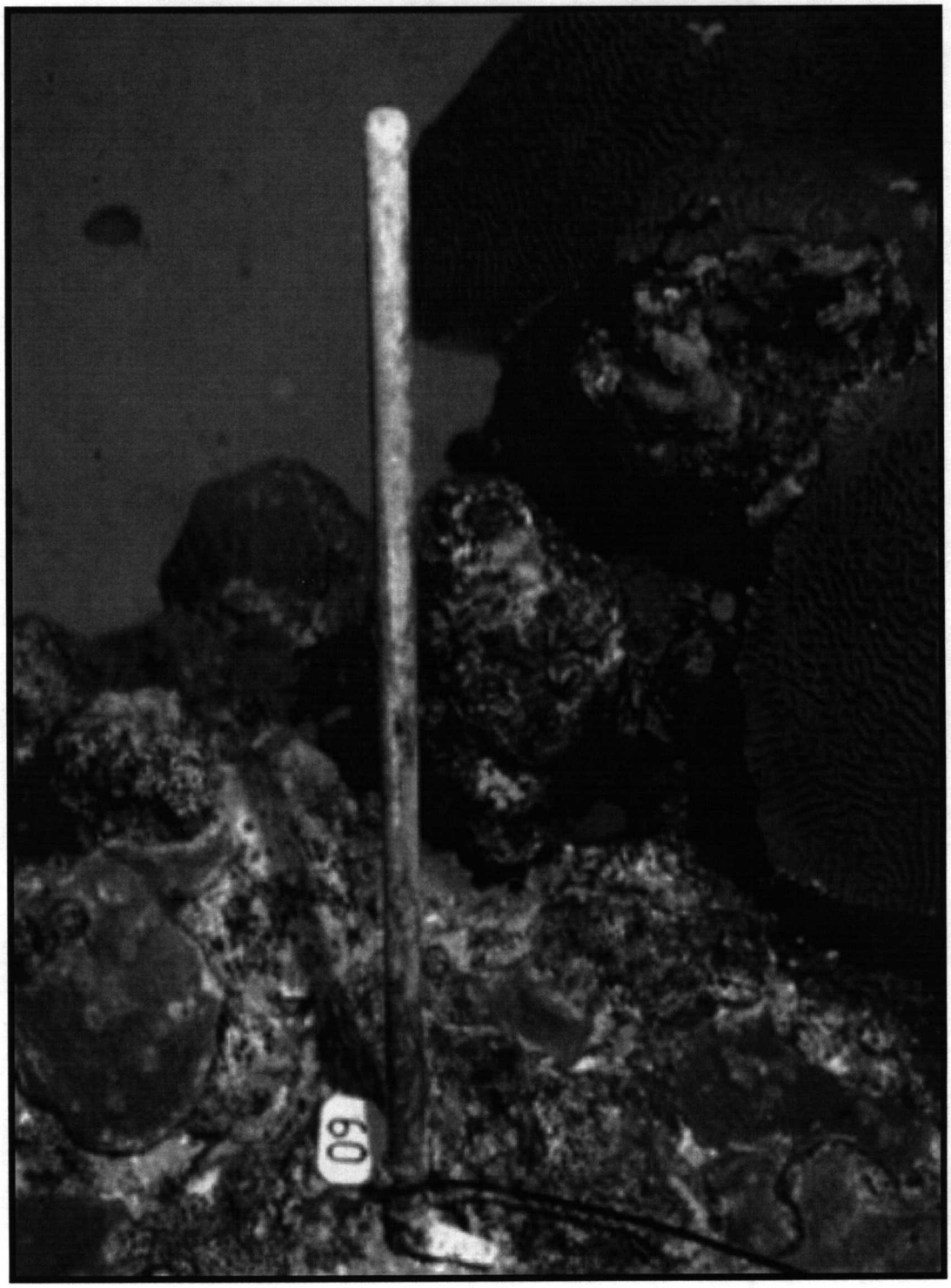


Figure 2.7.0.1. Permanent repetitive photographic station.

2.8 VIDEO TRANSECTS

Similar to the three previous studies (Gittings *et al.*, 1992; Continental Shelf Associates, 1996; Dokken *et al.*, 1999), diver-held video transects were recorded to establish a permanent record of visual observations at the study sites. Two transects were performed on each bank using identical techniques as in previous studies. A Hi-8 video camcorder in an underwater housing was "flown" across the bottom by a diver at an angle of approximately 45°. A target height above bottom was maintained by using a weighted, 2 m plumb-line attached to the camera housing. This resulted in a transect width of 3.5 m on the videotape when viewed at the center of the television monitor. Each 100 m transect represented a total area of 350 m^2. The transect areas videoed at the EFGB site were the northern boundary line (from west to east) and the eastern boundary line (from north to south). At the WFGB site the transect areas were the southern boundary line (from east to west) and the western boundary line (from south to north).

In addition to the two 100 m boundary line transects at each bank, a 360° circular-view video was performed at each of six corner markers (three on each bank marking the ends of two adjacent boundary lines). Using the corner markers as a center point, the video camera was held nearly horizontal and low to the reef and panned slowly in a full circle. This technique was useful for observing detail and minor changes to the areas of the reef around each corner marker. Prior to performing the video transects, the transect lines were pulled tight between anchor points, to insure the best chance of obtaining transect data matched previous efforts.

2.9 WATER QUALITY / INSOLATION / TEMPERATURE

2.9.1 Water Quality

Semi-Permeable Membrane Devices (SPMD) were deployed quarterly on both banks to monitor the presence of hydrocarbons and other analytes in the water column. The SPMDs were installed in special housings and anchored to the sea floor near the surface and u-bolt. The SPMDs were sent to Environmental Sampling Technologies in St. Joseph, Missouri for dialyses. The Geochemical and Environmental Research Group (GERG) at Texas A&M University, College Station, performed the purification and analyses. Three sample sets were analyzed.

All SPMDs were dialyzed and diasylates for a site were combined and evaporated to two ml or less, sealed in an ampoule, and shipped to GERG. At GERG, the samples and field blanks were purified using gel permeation chromatography (HPLC with Phenogel) to remove triolein. The sample extracts and field blanks, as well as laboratory quality control samples (procedural blank, spike blank and spike blank duplicate), were analyzed for pesticides/PCB or PAH by standard GERG procedures.

2.9.2 Insolation

At each bank, an underwater Li-Cor spherical light sensor and Li-1000 data logger was used to monitor photosynthetically active radiation (PAR) in order to relate biological changes with changes in irradiance. Both sensors were deployed at a depth of 23.8 m. The data loggers were set to record values during daylight hours by setting a minimum threshold value in the data logger configuration. All instruments were configured to record hourly averages in units of μM /

$s \cdot m^2$, where M=moles. Values were converted to M / $h \cdot m^2$. Data were recovered from the data loggers during the monitoring cruises in 1998 and 1999. Beginning in 1998, sensor units were fitted with TBT-impregnated collars to inhibit algae growth on sensor surfaces. Sensor units were re-calibrated annually.

A reference sensor was deployed on the HI-A389 platform to monitor atmospheric PAR intensity. The attenuation coefficient for light transmission through water, k, is a parameter in the equation (1):

$$I_d = I_0 e^{-kd} \quad \textbf{(1)}$$

where I_0 and I_d are light intensities at the surface and some depth (d), in meters (Parsons et al., 1984). By rearranging this equation (2),

$$ln(I_d/I_0)/-d = -k \quad \textbf{(2)}$$

it is possible to calculate the measured light attenuation ($-k$) in the water column. Synoptic values were compared to in-air light levels recorded at the reference sensor on the HI-A389 platform. These estimates of $-k$ were calculated from the accumulated daily PAR at each sensor where full-day values were available for the reference and the underwater sensors.

2.9.3 Temperature

Temperature readings were collected at each bank to detect relationships between temperature and biological changes at the FGBNMS during the monitoring period. One Hobo-Temp recording thermograph (Onset Instruments, Pocasset, Massachusetts), sealed in a watertight container, was attached to a bottom structure near the light meters at each study site. Thermographs were set to record water temperature at 20-minute intervals. Temperature data was supplemented with Sea Surface Temperature (SST) data retrieved from data buoys (National Data Bouy Center No. 42019 located at 27.92 N, 95.35 W).

2.10 SEA URCHIN SURVEYS

Transects were conducted to monitor changes in the abundance of sea urchins at the FGB. Evening transects were conducted approximately 1.5 hrs after sunset to establish density levels of *Diadema antillarium* to serve as a basis for comparison with future observations. Site boundary lines were used as transect lines. Divers swam the length of the 100 m transect line recording the number of *Diadema* observed within one meter of the line. Each transect encompassed a total 200 m^2.

3.0 RESULTS

3.1 RANDOM TRANSECTS

3.1.1 Cover and Relative Dominance

The *Montastraea annularis* complex was the dominant coral taxon in both percent cover (Table 3.1.1.1) and relative dominance (Table 3.1.1.2). During the 1998 cruise to the EFGB, the *M. annularis* complex had a mean percent cover and relative dominance of 34.35% and 55.43%, respectively. On the WFGB the *M. annularis* complex displayed a mean 39.64% cover and relative dominance of 59.25%. *Diploria strigosa* was second in percent cover at both study sites comprising 8.65% and 13.38% mean cover on the EFGB and WFGB, respectively. Mean relative dominance for *D. strigosa* was 13.97% for the EFGB site and 20.01% for the WFGB site.

The *Montastraea annularis* complex continued to be dominant during the 1999 cruise with percent cover of 31.43% and 33.29% for the EFGB and WFGB, respectively. Relative dominance was 53.26% for the EFGB and 60.96% for the WFGB. On the EFGB, *Diploria strigosa* displayed an increase in both percent cover and relative dominance between 1998 and 1999. Percent cover increased from 8.65% in 1998 to 13.84% in 1999 and relative dominance increased from 13.97% in 1998 to 23.46% in 1999. At the WFGB, *Diploria strigosa* did not vary compared to the previous year in either percent cover (11.55%) or relative dominance (21.14%).

A decrease in coral cover from 67.13% in 1998 to 54.57% in 1999 was recorded at the WFGB using the random photo technique. An ANOVA revealed that the percent of turf algae observed at both banks was significantly ($p < 0.05$) greater during 1999 than 1998. This increase came at the expense of bare reef rock, which showed a significant decrease at both banks for the same period. The percent cover of turf algae at the EFGB increased from 3.30% in 1998 to 27.57% in 1999. Concurrently, the percent of bare reef rock on the EFGB decreased from 31.44% in 1998 to 10.60% in 1999. The WFGB showed an increase in turf algae from 3.2% in 1998 to 20.72% in 1999 and a decrease in bare reef rock, 28.99% in 1998 to 22.50% in 1999.

Percent cover for each species was compared between study sites by year, among years with sites pooled and among pooled data from all previous cruises (Table 3.1.1.3). Total coral cover was significantly higher ($p < 0.05$) at the WFGB during 1998. This was true for comparisons between banks, among years, and among pooled data from all previous years. However, it should be noted that due to random transect methodology, variation in coral cover may be a direct result of sampling versus an actual increase or growth of coral.

3.1.2 Species Diversity and Evenness

Random transect data were used to estimate diversity and evenness (Table 3.1.2.1) based on percent cover. Comparisons of diversity and evenness were made between study sites by year, among years with sites pooled and between the 1998 and 1999 cruises and pooled data from all previous cruises. Comparisons using Analysis of Variance (ANOVA) and Tukey's HSD tests showed no significant differences in diversity or evenness between banks, between studies or between data from the 1998 and 1999 study compared to pooled data from all previous studies.

Table 3.1.1.1

Mean percent cover (%) on random transects at Flower Garden Banks, 1998-1999

Analyzed Component	MEAN PERCENT COVER			
	EFGB		WFGB	
	1998	1999	1998	1999
*Montastraea "annularis"**	34.4	31.4	39.6	33.3
Diploria strigosa	8.70	13.8	13.4	11.6
Porites astreoides	4.50	3.80	3.30	3.00
Montastraea cavernosa	3.70	2.70	3.60	2.50
Colpophyllia natans	1.70	4.00	2.40	1.00
Millepora alcicornis	1.50	1.80	1.10	0.90
Agaricia agaricites	0.40	0.20	0.20	0.20
Stephanocoenia intersepta	0.60	<0.10	0.80	<0.10
Madracis decactis	<0.10	0.40	0.30	0.50
Siderastrea siderea	0.30	0.70	2.30	1.50
Mussa angulosa	0.10	0.10	0.10	0.20
Scolymia cubensis	<0.10	<0.10	<0.10	<0.10
Madracis mirabilis	0.30	<0.10	<0.10	<0.10
TOTAL CORAL	**56.1**	**59.0**	**67.1**	**54.6**
Reef Rock	31.4	10.6	29.0	22.5
Turf Algae	3.30	27.6	3.20	20.7
Sponge	0.60	2.80	0.90	0.80
Sand	0.00	0.00	0.00	1.30

Table 3.1.1.2

Relative dominance (%) on random transects at the Flower Garden Banks, 1998-1999

Analyzed Component	RELATIVE DOMINANCE			
	EFGB		WFGB	
	1998	1999	1998	1999
*Montastraea "annularis"**	55.4	53.3	59.3	61.0
Diploria strigosa	14.0	23.5	20.0	21.1
Porites astreoides	7.20	6.50	4.90	5.60
Montastraea cavernosa	6.10	4.60	5.40	4.50
Colpophyllia natans	2.70	6.80	3.60	1.80
Millepora alcicornis	2.50	3.00	1.60	1.60
Agaricia agaricites	0.67	0.30	0.40	0.40
Stephanocoenia intersepta	1.60	<0.10	1.20	<0.10
Madracis decactis	0.70	0.60	<0.10	0.90
Siderastrea siderea	0.50	1.20	<0.10	2.70
Mussa angulosa	0.20	0.20	1.20	0.40
Scolymia cubensis	0.00	<0.10	<0.10	<0.10
Madracis mirabilis	0.50	0.50	0.00	0.10

**Montastraea annularis* complex includes *M. annularis*, *M. faveolata*, and *M. franksii*

Table 3.1.1.3

Summary of analyses of percent cover for all corals, reef rock, turf algae, sponge, and sand from random transects at the East and West Flower Garden Banks (ns=no significant difference)

Analyzed Component	Bank	Year (Banks Pooled)	Previous studies (since 1989; pooled)	Tukey* Groups
*Montastraea "annularis"***	ns	ns	ns	ns
Diploria strigosa	ns	ns	ns	ns
Porites astreoides	EFGB>WFGB98 EFGB>WFGB99	ns	ns	1 2 3 4 5 6
Montasraea cavernosa	ns	ns	ns	ns
Colpophyllia natans	EFGB<WFGB98 EFGB>WFGB99	ns	WFGB 98< previous WFGB	2 4 6 1 3 5
Millepora alcicornis	ns	ns	ns	ns
Agaricia agaricites	ns	ns	ns	ns
Stephanocoenia intersepta	ns	ns	ns	ns
Madracis decactis	ns	ns	ns	ns
Siderastrea siderea	ns	ns	ns	ns
Mussa angulosa	ns	ns	ns	ns
Scolymia cubensis	ns	ns	ns	ns
Madracis mirabilis	ns	ns	ns	ns
TOTAL COVER	**WFGB >EFGB98**	**ns**	**WFGB 98 > previous WFGB**	**1 2 4 6 5 3**
Reef Rock	ns	98>99	W&EFGB< previous studies	1 2 3 4 5 6
Turf Algae	ns	98<99	W&EFGB99 > previous studies	1 2 3 4 5 6
Sponge	ns	ns	ns	ns
Sand	ns	ns	ns	ns

* **1= West Bank previous studies pooled** **2= East Bank previous studies pooled**
3= West Bank 97-98 study **4= East Bank 97-98 study**
5= West Bank 98-99 study **6= East Bank 98-99 study**

** *Montastraea annularis* complex includes *M. annularis*, *M. faveolata*, and *M. franksii*

3.1.3 Incidence of Coral Bleaching

No species had greater than 5% bleached colonies at either bank during the 1998-1999 investigations. Additionally, limited numbers of bleached colonies of the *Montastraea annularis* complex, as well as the hydrozoan *Millepora alcicornis,* were observed in the analysis of random transects.

Table 3.1.2.1

Comparison of species diversity and evenness (based on the natural log, ln) by percent cover for all monitoring cruises to the East and West Flower Garden Banks

Year	Diversity (H')		Evenness (J')	
	EFGB	WFGB	EFGB	WFGB
1992	1.21	1.11	0.56	0.50
1994	1.34	1.20	0.60	0.55
1995	1.11	1.13	0.53	0.54
1996	1.56	1.38	0.43	0.44
1997	1.54	1.60	0.46	0.52
1998	1.37	1.37	0.36	0.33
1999	1.79	1.77	0.40	0.39
All Years	1.35	1.28	0.52	0.51

3.2 SCLEROCHRONOLOGY

X-ray images of *Montastraea faveolata* shown in Figure 3.2.0.1 represent longitudinal cross sections of cores taken from the EFGB and WFGB. Dark bands represent low density or faster growth areas, and the light bands are high density, slow growth areas. A pair of high density and low-density bands constitute one year of coral accretionary growth. Band measurements are reported in Tables 3.2.0.1 and 3.2.0.2. Yearly means and overall mean growth for the EFGB and WFGB are presented in Figure 3.2.0.2. Overall growth appears to be stable, however, there is some variability, particularly at the EFGB site. Mean growth for the entire 15 years was higher at the EFGB.

Analysis of variance (ANOVA) indicates there were statistically significant differences among years at both the EFGB ($df = 14,44$; $F = 6.93$; $p < 0.001$) and the WFGB ($df = 19,59$; $F = 2.78$; $p = 0.016$). Duncan's Multiple Range Test (DMRT) delineated seven homogeneous subsets (Figure 3.2.0.3). Of the seven subsets at the EFGB, 1999 and 1990 reflect the highest and lowest values, respectively. A DMRT delineated four homogeneous subsets at the WFGB revealing 1991 and 1997 with the highest values and 1986, 1990, and 1999 showed the lowest values. A two-tailed student t-test determined a statistical difference between banks ($p = 0.001$). Years that were significantly different ($\alpha = 0.05$) from each other between banks were: 1986 through 1989, 1991, 1993 through 1995, and 1998 through 1999. Regression analysis performed on sclerochronological growth data did not reveal a significant relationship between years and growth (Figure 3.2.0.4).

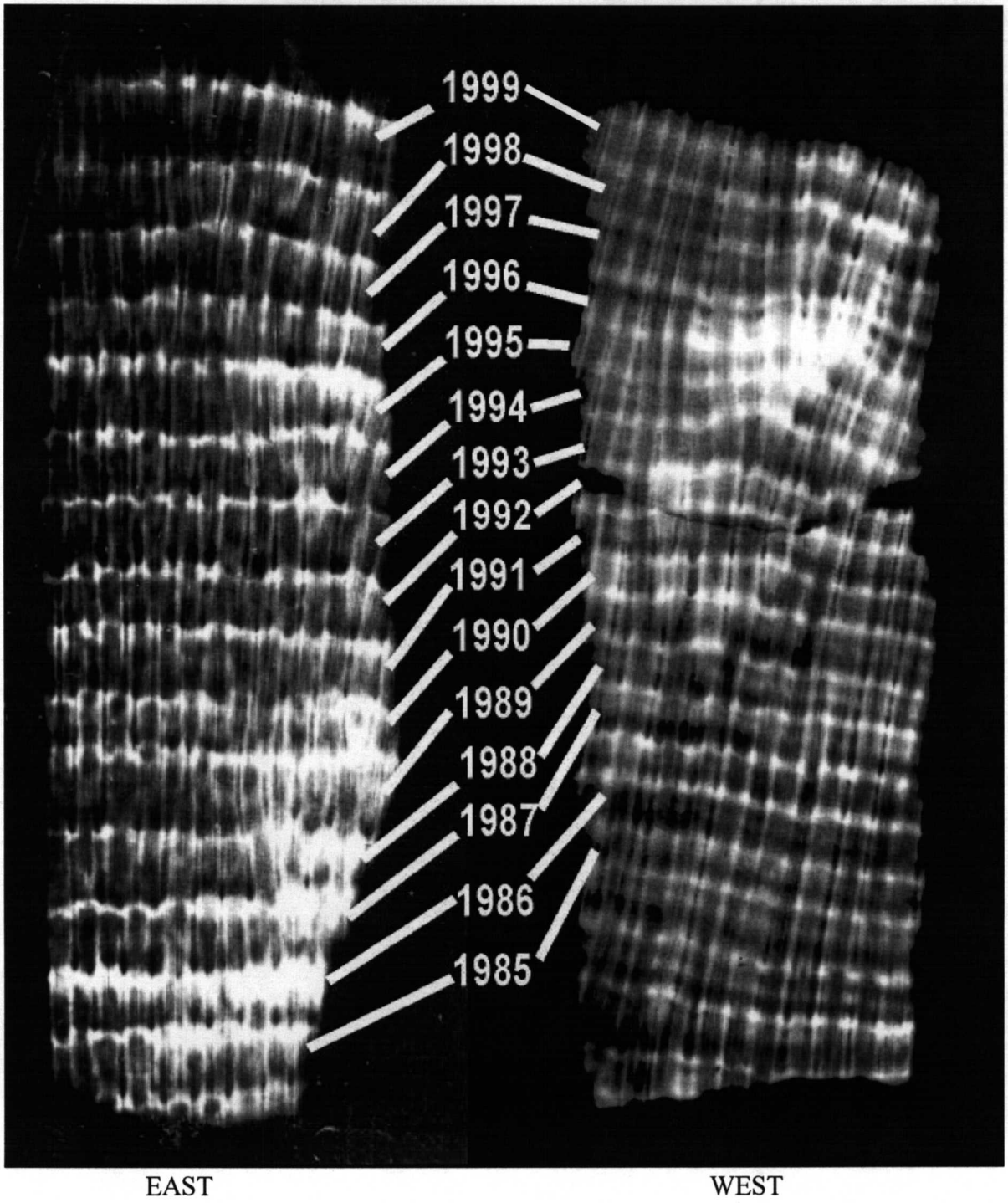


Figure 3.2.0.1. X-ray images of *Montastraea faveolata* cores collected from the East and West Flower Garden Banks, 15 February 2000.

Table 3.2.0.1

East and West Flower Garden Bank sclerochronology measurements; *Montastraea faveolata* sampled 15 February 2000. Measurements of annual growth taken at three different areas from a single core

	East Flower Garden Bank			
YEAR	**1**	**2**	**3**	**MEAN (mm)**
1985	6.52	6.65	5.58	**6.25**
1986	6.25	5.45	6.65	**6.12**
1987	7.45	7.58	7.18	**7.41**
1988	7.98	6.65	7.45	**7.36**
1989	7.98	7.84	7.71	**7.84**
1990	5.05	5.45	5.45	**5.32**
1991	7.18	7.18	6.65	**7.00**
1992	5.45	5.98	5.85	**5.76**
1993	7.18	7.45	8.11	**7.56**
1994	6.78	6.38	5.98	**6.38**
1995	7.58	8.51	6.53	**7.54**
1996	5.72	6.91	5.75	**6.13**
1997	7.06	6.83	6.03	**6.64**
1998	6.65	5.98	6.73	**6.46**
1999	8.78	8.64	7.18	**8.20**
	West Flower Garden Bank			
YEAR	**1**	**2**	**3**	**MEAN (mm)**
1985	4.94	5.57	5.78	**5.43**
1986	4.28	4.82	4.70	**4.60**
1987	5.33	5.35	5.42	**5.37**
1988	4.81	4.95	5.21	**4.99**
1989	5.21	4.79	4.41	**4.81**
1990	5.33	3.88	4.25	**4.49**
1991	6.10	6.31	5.41	**5.94**
1992	4.82	4.93	5.28	**5.02**
1993	5.33	5.41	5.93	**5.56**
1994	4.70	3.99	5.5	**4.73**
1995	5.18	5.48	4.00	**4.89**
1996	5.78	5.03	4.73	**5.18**
1997	6.06	6.65	5.22	**5.98**
1998	5.06	5.84	5.18	**5.36**
1999	4.53	4.68	4.68	**4.63**

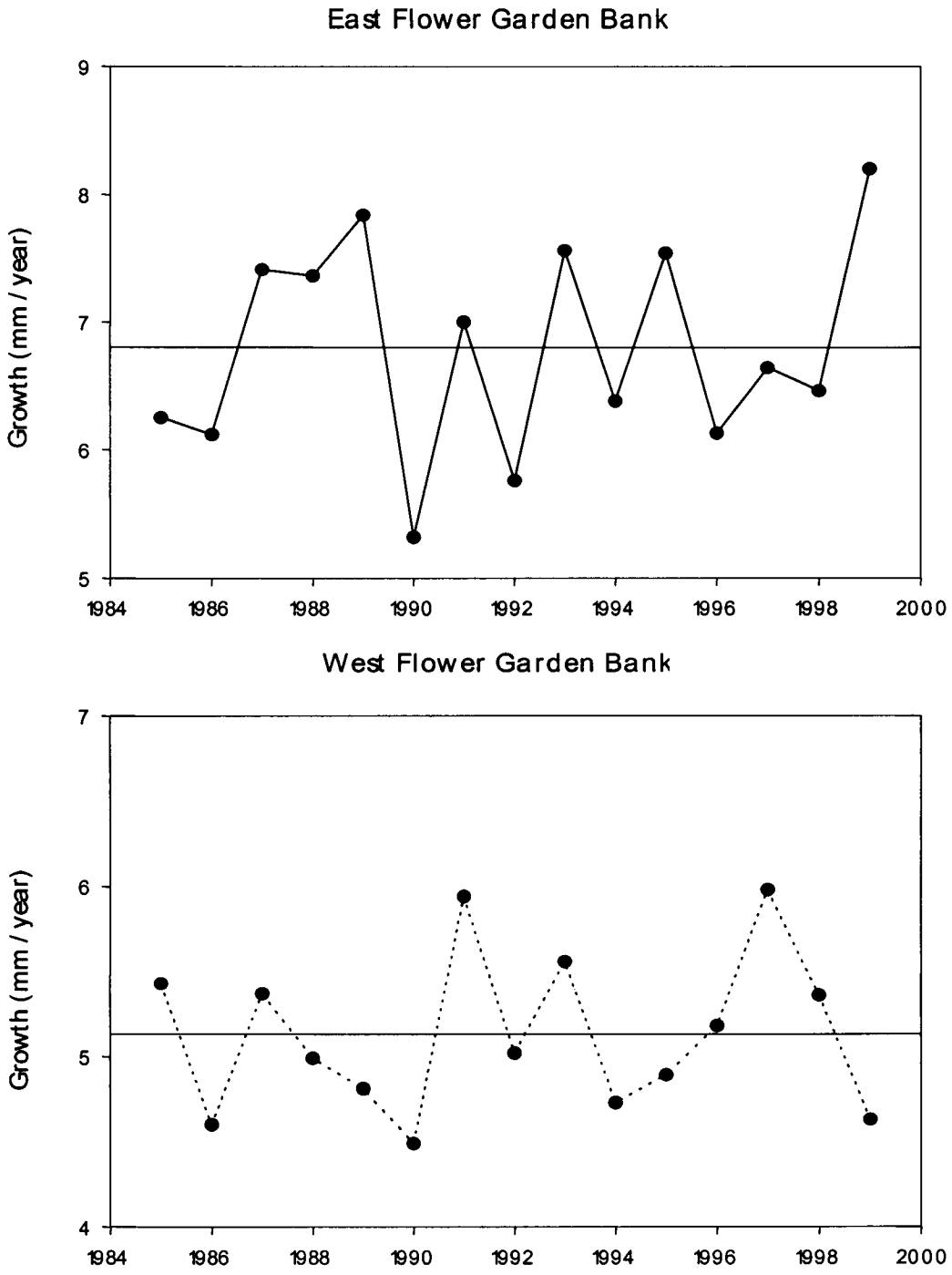


Figure 3.2.0.2. Accretionary growth values from sclerochronological analysis of the East and West Flower Garden Banks. Mean growth values, 6.8 mm/yr (EFGB) and 5.1 mm/yr (WFGB), are represented in each figure.

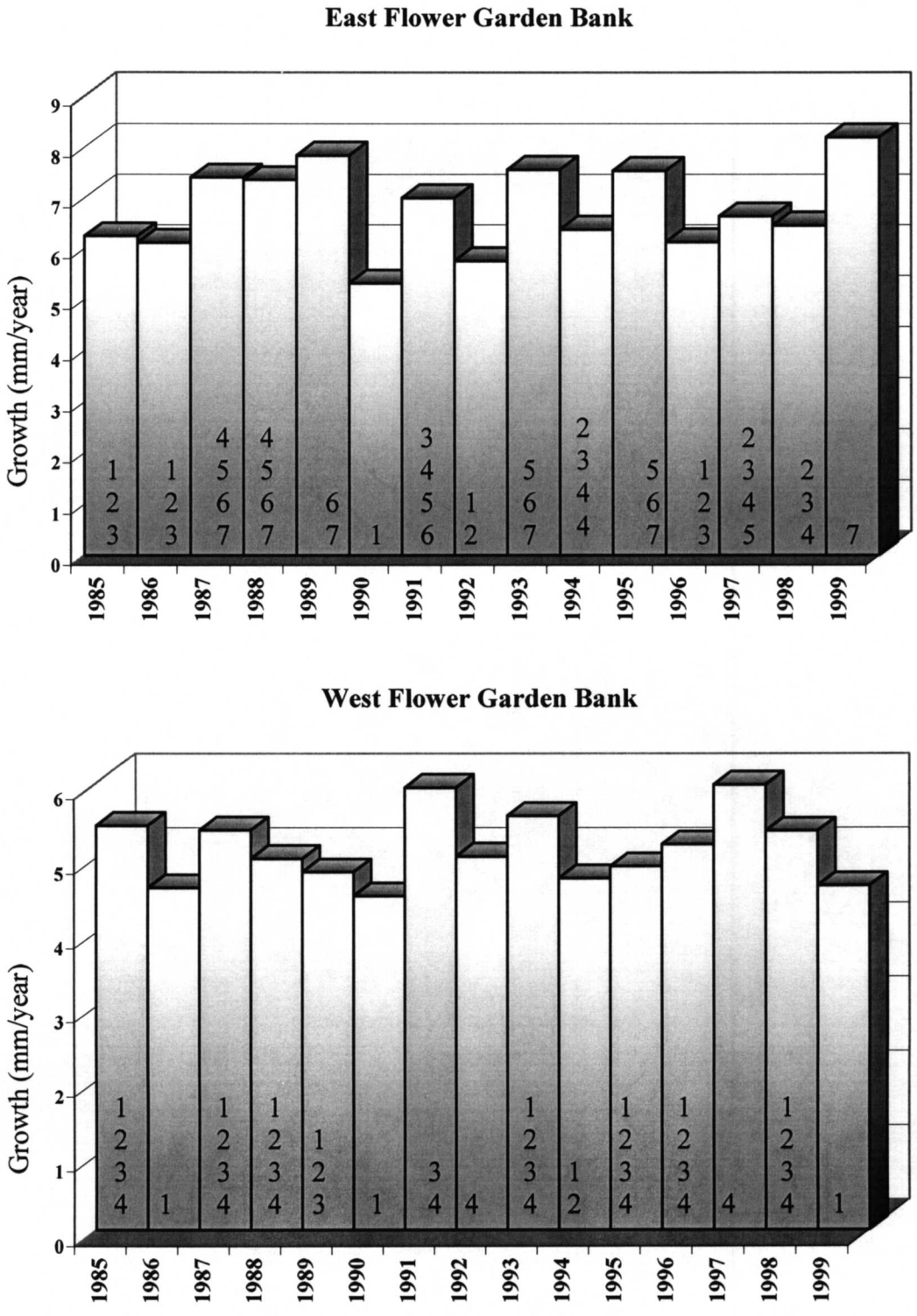


Figure 3.2.0.3. Accretionary growth comparison from 1985 through 1999 between the East and West Flower Garden Banks. Numbers indicate homogenous subsets delineated by Duncan's Multiple Range test at $\alpha = 0.05$.

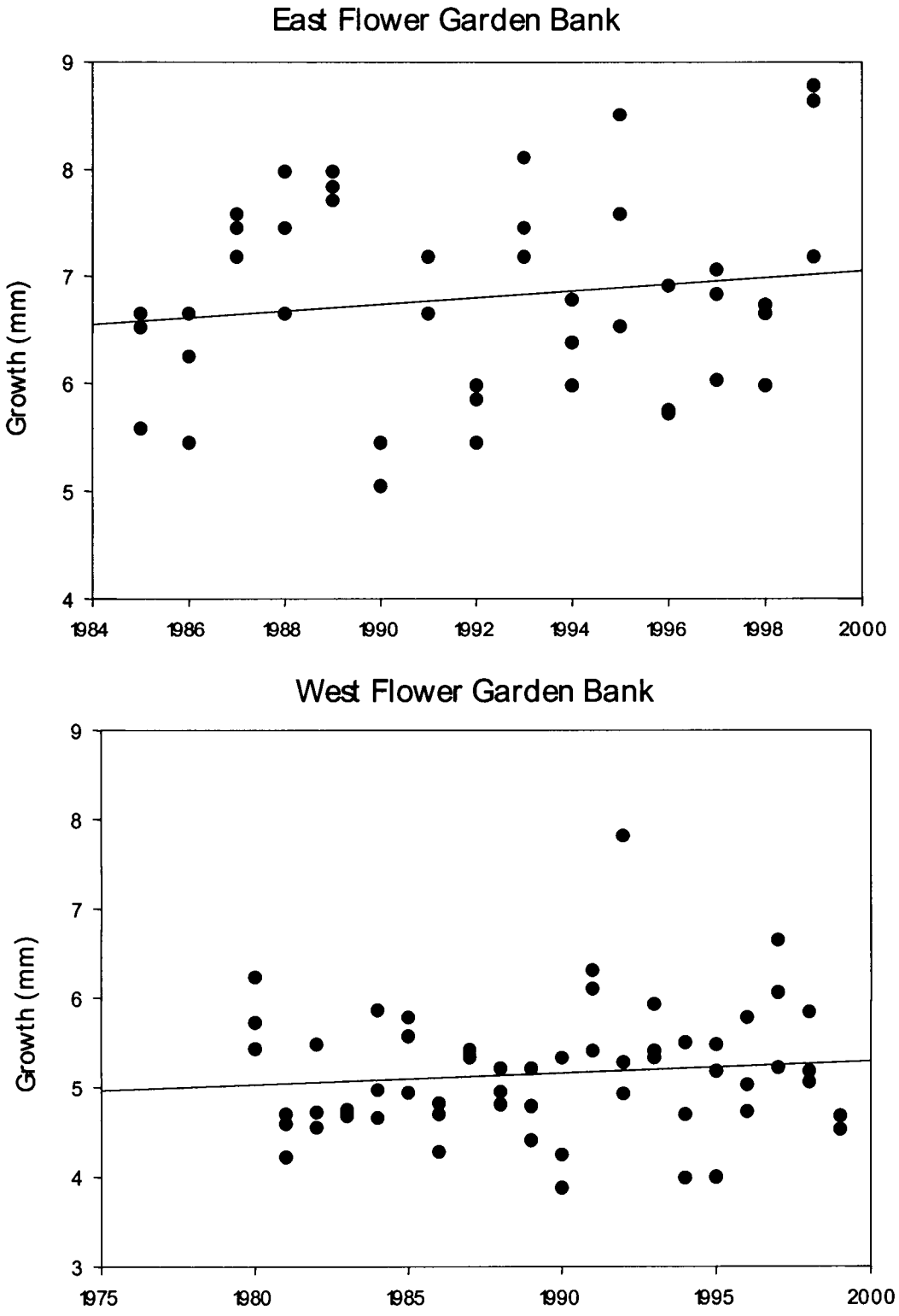


Figure 3.2.0.4 Regression values from sclerochronological analysis at the East and West Flower Garden Banks, February 2000, showed no significant relationship.

3.3 ENCRUSTING GROWTH

A substantial number of stations were unsuitable for analysis in 1998. Some stations were lost due to loss of pins, or the coral margins had advanced or retreated to the point that the colony's growth margin was no longer visible in the photograph. Forty-six out of sixty stations on the EFGB were in suitable condition for comparison. Coral tissue change revealed by encrusting growth data is shown in Table 3.3.0.1. The first three rows of data in the table show tissue gain, tissue loss, and no change. Total net change by year for both banks is shown in the last row.

Mean advance rate for 1998 at the EFGB was 0.14 cm/yr whereas the retreat rate was 1.0 cm/yr. WFGB colonies displayed an advance rate of 0.23 cm/yr and a retreat rate of 0.42 cm/yr. Fourteen new stations on the EFGB and 14 new stations on the WFGB replaced those lost during 1998.

In 1999, 50 EFGB and 47 WFGB encrusting growth stations were found to be suitable for comparison. East Flower Garden Bank stations included 27 displaying tissue advance, 12 stations with tissue retreat and 11 stations with no difference in the amount of tissue present. Forty-seven WFGB stations included 17 displaying tissue gain, 22 stations with a loss of tissue, and 8 stations with no change. East Flower Garden Bank stations displayed a 0.27 cm/yr advance rate and a 0.63 cm/yr retreat rate while WFGB stations reflected a 0.36 cm/yr advance rate and a 0.42 cm/yr retreat rate (Table 3.3.0.1).

Table 3.3.0.1

Number of encrusting growth permanent transect stations of *Diploria strigosa* exhibiting net gain, loss, or no change of coral tissue

EFGB				**WFGB**			
1998		**1999**		**1998**		**1999**	
No. of Changes	**cm/yr**	**No. of Changes**	**cm/yr**	**No. of Changes**	**cm/yr**	**No. of Changes**	**cm/yr**
21	(+) 0.14	27	(+) 0.27	19	(+) 0.23	17	(+) 0.36
14	(–) 1.00	12	(–) 0.63	14	(–) 0.42	22	(–) 0.42
11	(=) 0.00	11	(=) 0.00	6	(=) 0.00	8	(=) 0.00

(+) tissue gain; (-) tissue loss; (=) no tissue change

3.4 REPETITIVE QUADRATS

Data obtained from 33 EFGB stations photographed during the 1998 and 1999 surveys showed mean coral coverage of 56.5 ± 1.9% (standard deviation) and 54.0 ± 2.0%, respectively. Total observations of growth (253) exceeded the combined incidence of tissue loss (215) attributable to algae, sediment, disease, and other factors (Table 3.4.0.1). At the EFGB, bleaching was observed in the 1998 and 1999 repetitive quadrats. In 1998 it was estimated that 0.9% of the total coral cover was bleached. Seven incidents of bleaching observed at the EFGB during 1998

resulted in four incidents of mortality during 1999. During the 1998-1999 study, 125 instances of what appeared to be coral retreat/algal replacement were recorded from approximately 2,000 colonies observed. Considering 73 of the 125 instances, algal mediated retreat accounted for an estimated total tissue loss of 2.8%.

A total of 35 stations were photographed at the WFGB during the 1998 and 1999 surveys. Mean coral cover was estimated at 52.4 ± 2.8% (standard deviation) and 52.9 ± 2.6% for 1998 and 1999, respectively. Sixty-one instances of coral retreat/algal replacement and 66 instances of sediment replacement were observed at the WFGB during the 1999 surveys. These factors combined accounted for 51% of all tissue loss.

Coral cover estimates at the quadrat stations ranged from 27.5% - 88.0% in 1998, and from 25.4% - 80.5% in 1999. Total observations of growth (579) exceeded the combined incidences of tissue loss (464) (Table 3.4.0.1). Only 3 incidents of disease were observed in approximately 2,000 colonies resulting in an estimated total tissue loss of 0.43%.

Table 3.4.0.1

Incidents of bleaching, disease, tissue loss, and growth from analysis of 8 m^2 repetitive photographic quadrats at the East and West Flower Garden Banks (coral cover estimates, and number of coral colonies)

OBSERVATION	**EFGB**		**WFGB**	
	1998	**1999**	**1998**	**1999**
Bleaching followed by mortality	0	4	8	26
Bleaching not followed by mortality	7	2	9	0
Disease followed by mortality	0	0	1	1
Disease not followed by mortality	0	1	0	0
Coral retreat/algal replacement	77	48	42	19
Sediment replacement	28	9	58	8
Algae/sediment replacement	2	5	2	20
Tissue loss due to competition	1	0	2	3
Fish biting resulting in tissue loss	0	0	0	0
Unexplained tissue loss	9	23	14	15
Growth: infilling	11	17	5	22
Growth: marginal (encrusting or lateral)	150	75	185	114
Estimated Coral Cover (%)	56%	54%	52%	52%
Approximate number of colonies	**2000**		**1800**	

3.5 WATER QUALITY / INSOLATION / TEMPERATURE

3.5.1 Water Quality

Upon retrieval at both banks, the integrity of SPMD membranes was questionable. Postlarval crustaceans, primarily lobster and crab, took up residence in the metal housings in which the SPMDs were suspended. Presumably while feeding, these clawed animals caused pinholes in the SPMD membrane. We do not know what effect this had, if any, on the final results. Deployment, retrieval, and dialyzation dates are reported in Table 3.5.1.1.

The first set of SPMDs consisted of four samples, two per bank. Two membranes at the EFGB had a hole and five at the WFGB. The second set consisted of samples placed at the bottom of both the EFGB and WFGB. Two holes were reported in membranes deployed at the EFGB and three in samples from the WFGB. The third set was also placed on the bottom (approx. 20m). One hole was found in the membrane from the EFGB and several small holes were reported in the SPMD from the WFGB. Each set of SPMDs were accompanied by a field blank per study site. Field blanks were used to collect airborne analytes introduced to the sample SPMDs during deployment and retrieval.

Table 3.5.1.1

Semi-Permeable Membrane Device (SPMD) sampling periods for the East and West Flower Garden Banks

EFGB			**Both Banks**	**WFGB**		
Deployed	**Recovered**	**No. Days**	**Date Dialyzed**	**Deployed**	**Recovered**	**No. Days**
7/27/98	9/28/98	64	11/10/98	7/29/98	9/30/98	64
9/28/98	3/8/99	161	4/8/98	9/30/98	3/4/99	161
3/8/99	6/14/99	98	9/14/99	3/9/99	6/15/99	98
6/14/99	9/14/99	90		6/15/99	9/15/99	90

The SPMD analyses were problematic due to high concentrations of triolein from the dialyses. The purification step was not sufficient to remove all of the interference from the lipids used in the SPMD. The procedural blanks were acceptable indicating no contamination of samples at GERG laboratories. The field blanks contained many of the analytes at concentrations similar to those in the samples, making interpretation of these concentrations problematic. The recovery in spike blanks and spike blank duplicates was acceptable, so the analytical methods were operating in a controlled state. The high field blank concentrations reflect contamination that was introduced in the field and during the dialyses.

In spite of accumulation of analytes in field blanks some analytes were still detected in SPMD samples (Table 3.5.1.2). These concentrations are listed in units of nanograms/SPMD. Analytes that were at least 2 times blank concentrations are noted. All of the analytes detected

were at extremely low concentrations if the sampling rate of the SPMD is considered. For example, the SPMDs for the second sampling were exposed for 160 days. The 4,4-DDE concentration was 5 ng/SPMD. There were 5 SPMDs so a total of 25 ng of 4,4-DDE was collected in 160 days. In that period 5 SPMDs would theoretically have sampled 3,200 liters (4 liters/day x 5 SPMDs). Assuming the sampling rate is correct, the average concentration of 4,4-DDE was less than 10 picograms/liter (10×10^{-15}). This indicates that the concentration of all the analytes detected in Table 3.5.1.2 have concentrations in the water less than 25 pg/liter (25×10^{-15}). The PAH analyses is complicated by the presence of analytes in the field/dialyses blank. The concentrations in the samples are only slightly higher than the blanks making it difficult to determine with confidence that these compounds were actually present. If they were present and the sampling rate is assumed to be 4 liters/day, the concentration for total PAH for the second sampling would be less than 5 ng/liters (5×10^{-12}).

Table 3.5.1.2

Concentrations (ng/SPMD) for selected analytes from SPMD deployed at the East and West Flower Garden Banks (ET = EFGB top, EB = EFGB bottom, WT = WFGB top, WB = WFGB bottom; reported sample concentrations less than 2 times the blank are shown in bold)

Sampling Period	**1**				**2**		**3**	
Analyte	**ET**	**EB**	**WT**	**WB**	**EB**	**WB**	**EB**	**WB**
HCB	1.3	1.4	2.1	1.7	2.45	2.51	11.1	3.2
A. Chlordane	10.8	7.6	5.5	11.3	13.5	13.2	6.5	11.1
G. Chlordane	**9.5**	**9.4**	**6.8**	**4.3**	14.3	14.6	**1.9**	**3.6**
Cis-Nonachlor	3.1	4.3	1.5	5.6	18.9	22.6	ND	ND
Trans-Nonachlor	3.5	2.0	3.6	1.9	0.36	0.38	2.2	3.3
Aldrin	ND	ND	ND	ND	0.83	0.86	ND	ND
Dieldrin	1.3	ND	3.2	1.7	2.66	2.62	0.63	1.71
Chlorpyrifos	5.2	2.5	1.7	**0.5**	1.77	1.42	**3.0**	**3.2**
Mirex	ND	ND	ND	ND	4.64	4.45	9.7	7.2
4,4-DDE	2.3	8.2	2.3	5.8	5.04	5.14	4.8	8.8
4,4-DDD	1.8	1.3	2.9	0.73	5.34	4.32	6.9	20.8
2.4-DDT	4.4	4.1	8.7	2.8	3.13	3.24	2.9	3.4
4,4-DDT	6.1	3.2	8.7	4.1	3.46	3.20	**4.7**	**7.2**

3.5.2 Insolation

This report presents all available data collected since February 1997 (Table 3.5.2.1). Portions of the 1997 data sets were previously described in an earlier report (Dokken, *et al.*, 1999) and are re-plotted here for completeness (Figures 3.5.2.1, 3.5.2.2, and 3.5.2.3). Mean values and variances for the three instruments are reported in Table 3.5.2.2. Mean PAR irradiance and corresponding values for light attenuation ($-k$) were lower at the WFGB instrument than at the EFGB station, however, it does not appear that these differences are significant. Several sensors were broken on recovery which resulted in data loss and required replacement with new sensors.

Seasonal variation in light levels is clearly evident in the plot of PAR values recorded at the HI-A389 platform (Figure 3.5.2.1). Higher frequency variability is caused by weather patterns that periodically increase cloud cover. During 1999, a transient problem with the instrument resulted in three data gaps (E, F, and G in Figure 3.5.2.1). PAR levels were recorded during these gaps, but the levels were unacceptably low and were rejected. The cause of these events is under investigation, but may have been due to mechanical shading of the sensor during platform operations.

Seasonal variation in PAR dosage is present, but less coherent for values recorded by the instruments at both banks (Figures 3.5.2.2 and 3.5.2.3). For example, PAR doses recorded at the EFGB instrument, during summer months in 1997 and 1999, show distinct decreases during month-long episodes that are not reflected in values recorded at the HI-A389 platform. The cause for these deviations is presumably change in the transmission characteristics of the water at the site. Decreased transmissivity could result from presence of more turbid coastal water masses, increases in phytoplankton production over the site, or both. Direct comparison of PAR dosage and water column attenuation was made for the 405 days when synoptic values were available for both underwater sensors and the reference sensor (Figure 3.5.2.4).

Table 3.5.2.1

Dates of monitoring and other servicing cruises with summary of data collection intervals and quality description for East and West Flower Garden Banks and HI-389 platform reference sensor. Letters describing data gaps refer to notation in Figures 3.5.2.1, 3.5.2.2, and 3.5.2.3.

Cruise	**EFG data interval**	**WFG data interval**	**HI-A389 data interval**
		9-Sep-97 to 8-Nov-97 (**D.** data logger overflow)	
8 Sep 97	10-Sep-97 to 3-Mar-98 (good data)	9-Nov-97 to 2 Mar 98 (good data)	9-Sep-97 to 3-Mar-98 (good data)
2 Mar 98	3-Mar-98 to 26-Aug-98 (**A.** sensor broken on deployment)	3-Mar-98 to 24-Aug-98 (good data)	4-Mar-98 to 26-Aug-98 (good data)
24 Aug 98	24-Aug-98 to 11-Oct-98 (good data)	24-Aug-98 to 14-Oct-98 (good data)	26-Aug-98 to 13-Oct-98 (good data)
14 Oct 98	14-Oct-98 to 23-Mar-99 (**B.** sensor broken on deployment)	14-Oct-98 to 23-Mar-99 (good data)	13-Oct-98 to 22-Mar-99 (acceptable data, **E.** transient error 25-Nov to 30 Dec-99)
23 Mar 99	22-Mar-99 to 5-Apr-99 (data logger overflow) 5-Apr-99 to 27-July-99 (good data)	23-Mar-99 to 26-Jul-99 (good data)	23-Mar-99 to 26-Jul-99 (acceptable data, **F.** transient error 12-Mar to 26-Apr-99)
26 Jul 99	27-Jul-99 to 13-Sep-99 (good data)	27-Jul-99 to 13-Sep-99 (good data)	26-Jul-99 to 13-Sep-99 (good data)
2 Sep 99	14-Sep-99 to 26-Oct-99 (**C.** data logger overflow)	14-Sep-99 to 26-Oct-99 (data logger overflow)	14-Sep-99 to 26-Oct-99 (**G.** data logger overflow)
25 Oct 99	26-Oct-99 to 16-Feb-00 (good data)	26-Oct-99 to 16-Feb-00 (good data)	26-Oct-99 to 16-Feb-00 (good data)
15 Feb 00	current	current	current

Table 3.5.2.2

Mean values for PAR dosage and the light attenuation parameter, *-k,* for underwater and reference instruments

Instrument location	PAR (M/m^2day)	*-k*
HI-A389 Platform (air)	2.37 (1.858)	NA
EFGB (23.8 m depth)	0.50 (0.527)	0.081 (0.0471)
WFGB (23.8 m depth)	0.38 (0.333)	0.083 (0.0341)

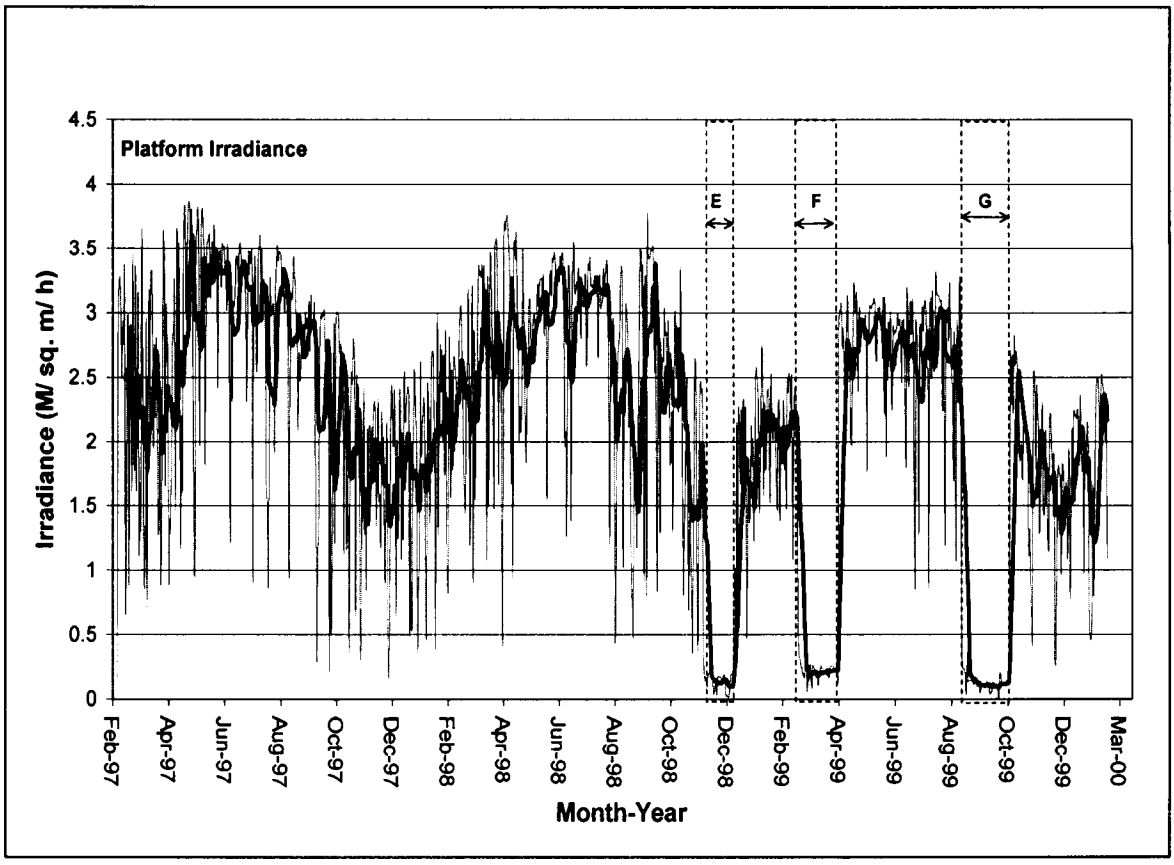


Figure 3.5.2.1. PAR dosage recorded at the HI-A389 platform between February 1997 and February 2000. Sensor was located on the platform helicopter deck approximately 30 m above sea level (E, F, and G are data gaps).

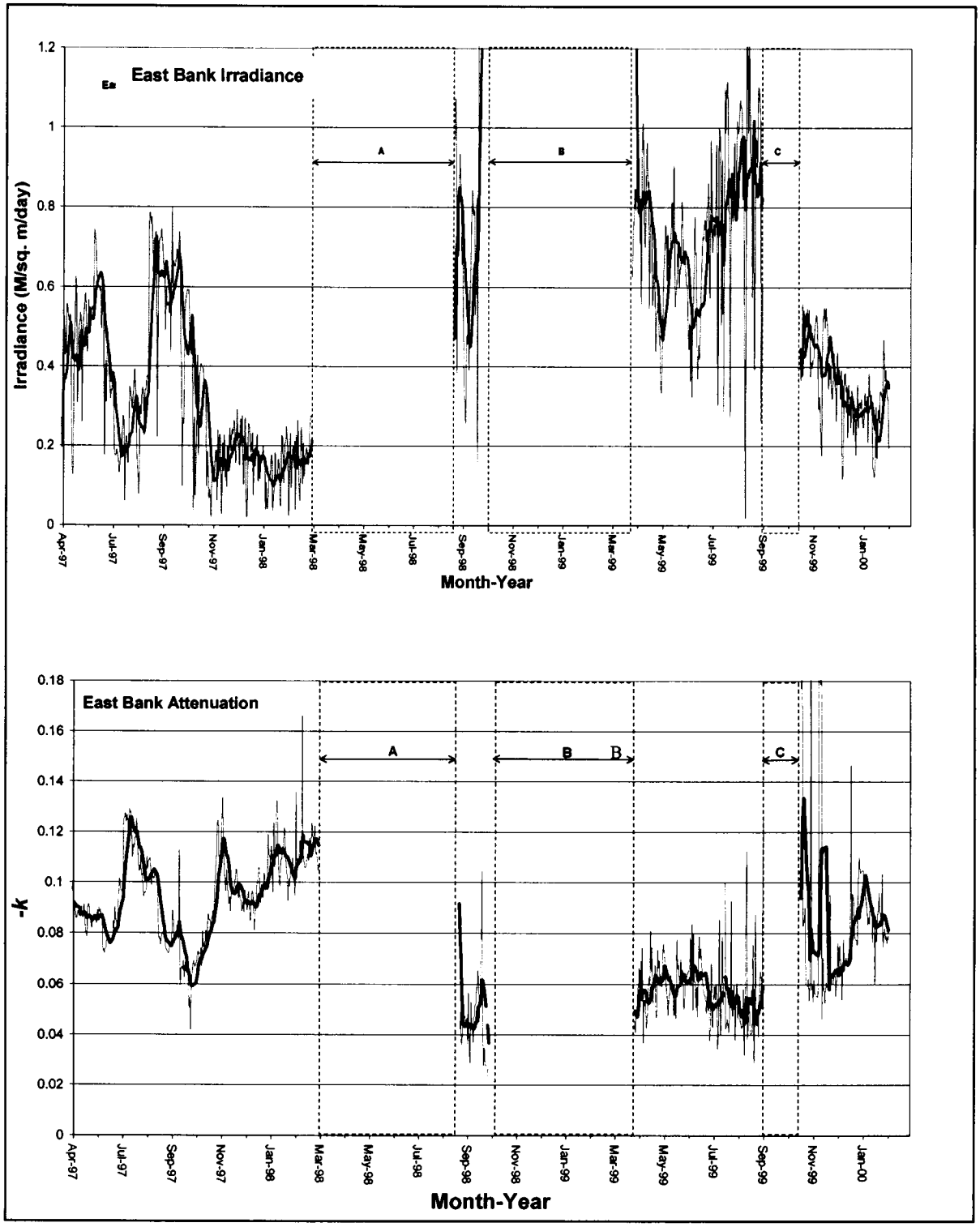


Figure 3.5.2.2. Daily mean PAR doses (M m^{-2} h^{-1}) at EFGB (upper) and attenuation (*-k)* with respect to platform (lower) monitoring station (23.8 m water depth) between March 1997 and February 2000. Light lines are daily averages; heavy lines are 10-day moving average (A, B, and C are data gaps).

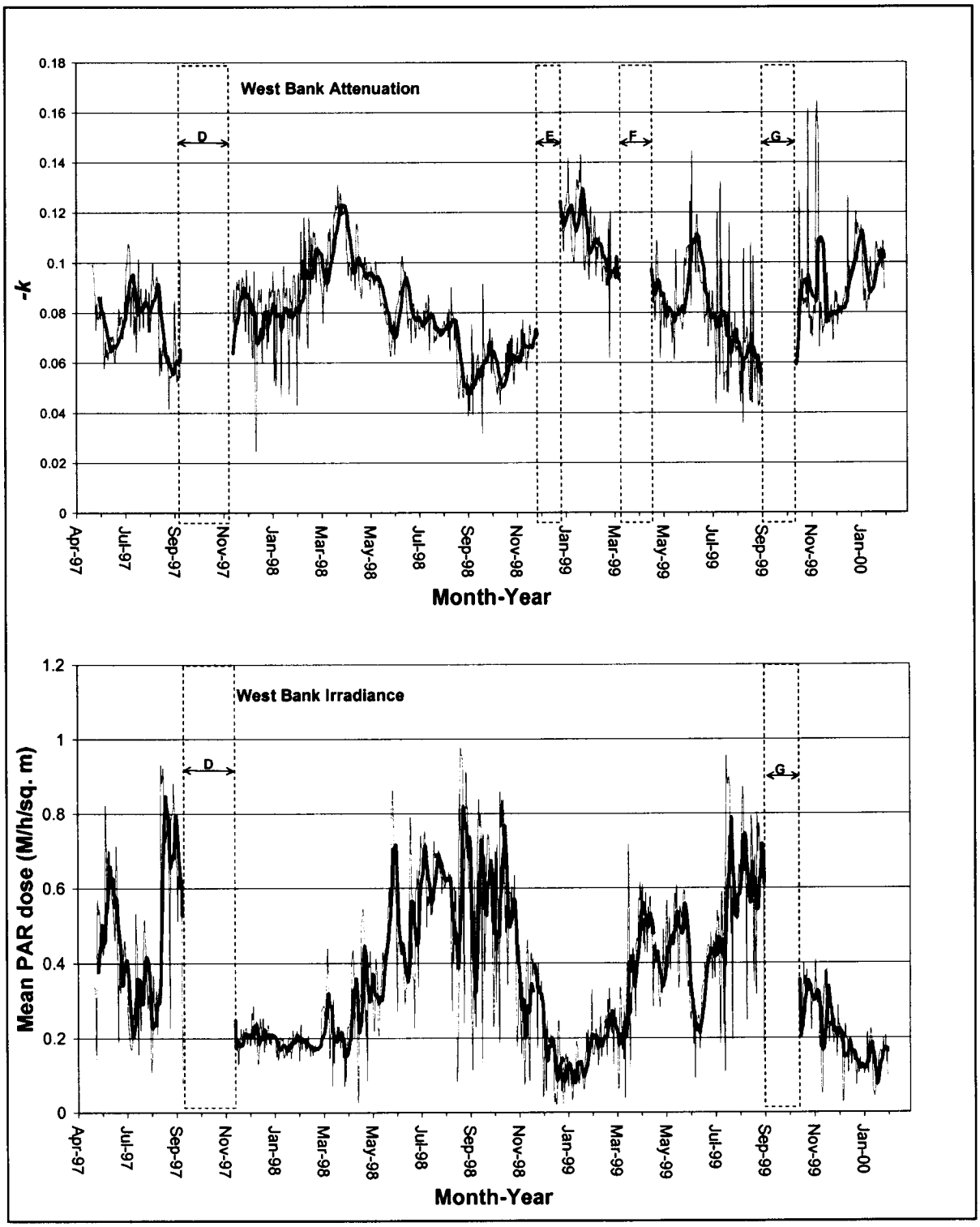


Figure 3.5.2.3. Daily mean PAR doses (M m^{-2} h^{-1}) at WFGB (upper) and attenuation (*-k)* with respect to platform (lower) monitoring station (23.8 m water depth) between April 1997 and February 2000. Light lines are daily averages; heavy lines are 10-day moving average (D, E, F, and G are data gaps).

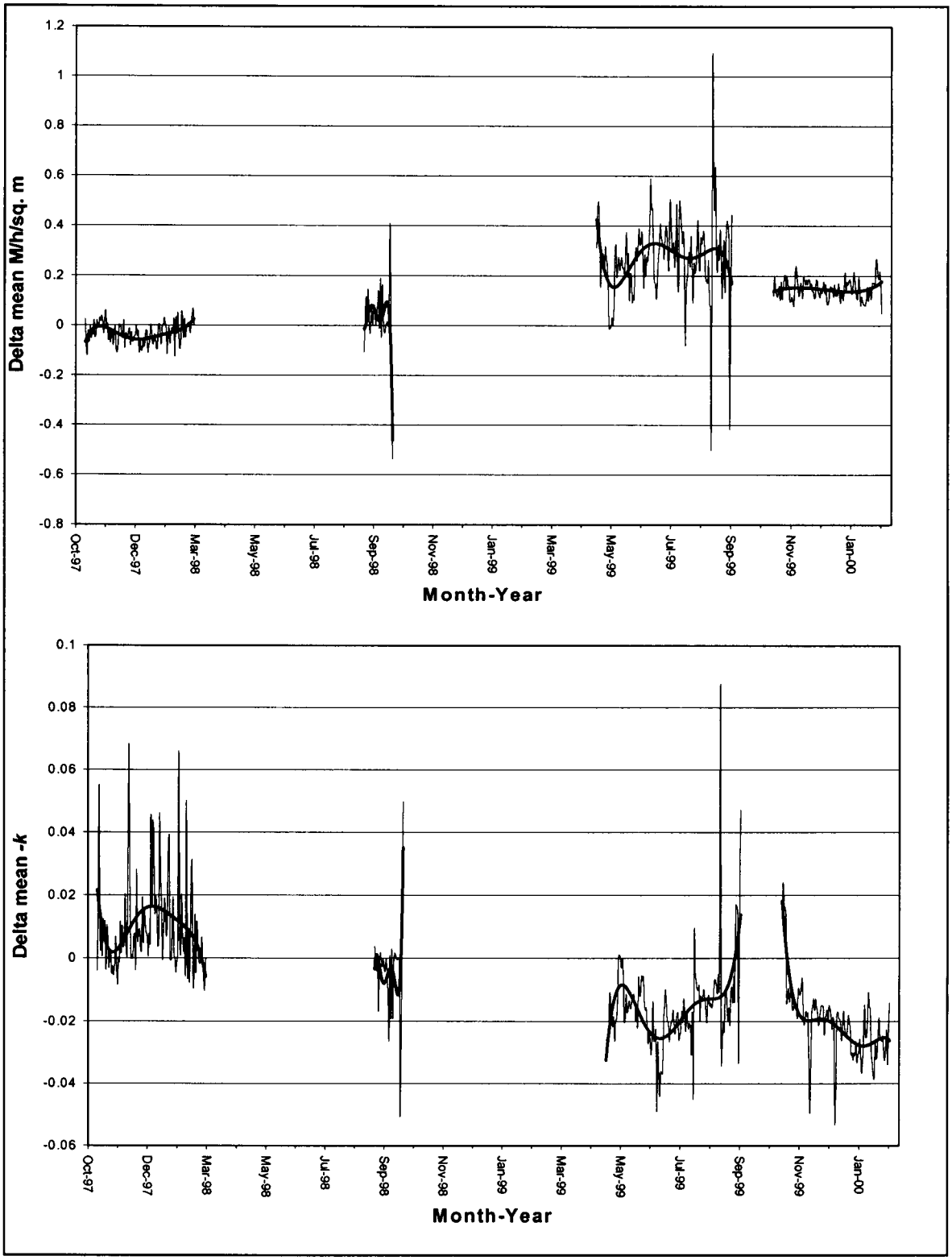


Figure 3.5.2.4. Differential (EFGB value minus WFGB value) comparison of mean hourly PAR dose (upper) and attenuation (lower) for intervals when synoptic data are available. Actual values are plotted with light lines; heavy lines are 5th order polynomial fit to data.

3.5.3 Temperature

Sea surface temperatures obtained from National Data Buoy Center (NDBC) buoy No. 42019 (Figure 3.5.3.1) indicate a mean minimum temperature of 19.4 °C in March of 1998 and a mean maximum of 32.3°C in July of 1998. Mean temperatures for 1999 were 19.7 °C (February) and 29.4°C (August). Data from light meters deployed near the mooring bolt was not included due to equipment malfunction. New methods and instruments for temperature data collection are being considered.

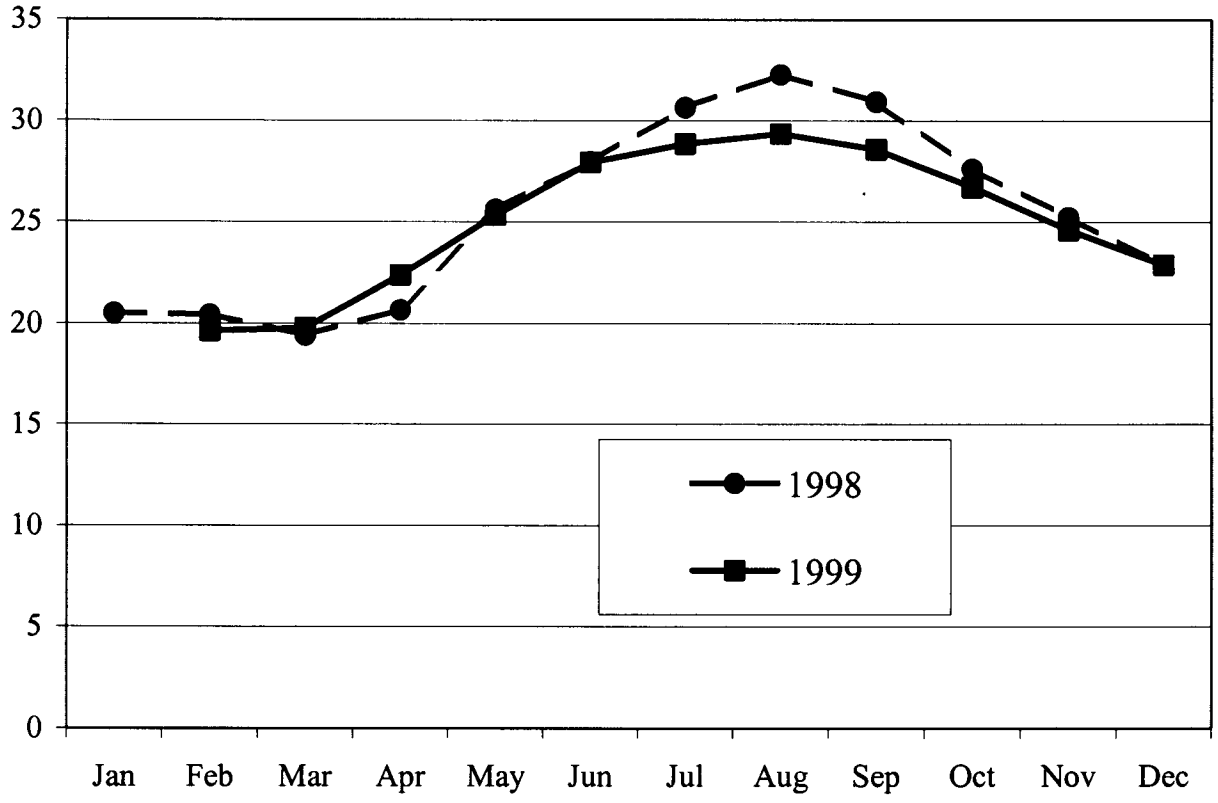


Figure 3.5.3.1. Monthly mean sea surface temperatures for 1998-1999 (NDBC buoy No. 42019 27° 92 N, 95° 35 W).

3.6 OUTSIDE RANDOM TRANSECTS

Random transects outside the designated study areas were compared to percent cover of pooled random transect data from past cruises (Table 3.6.0.1). No significant difference in percent cover of major components of the coral fauna was determined between the outside randoms and randoms from within the study sites. Several minor species did exhibit significant differences. *Madracis decactis* and *M. mirabilis* showed a significant increase in percent cover while *Mussa angulosa* and *Scolymia cubensis* showed a significant decrease in percent cover relative to the bounded study area.

Table 3.6.0.1

Mean percent cover (%) of outside random transects at the Flower Garden Banks, 1998-1999

Analyzed Component	PERCENT COVER			
	EFGB	Previous EFGB	WFGB	Previous WFGB
*Montastraea "annularis"**	33.6	29.0	31.2	27.1
Diploria strigosa	9.7	8.1	10.1	8.6
Porites astreoides	4.1	4.7	4.4	2.5
Montastraea cavernosa	2.3	3.8	3.7	2.9
Colpophyllia natans	3.3	2.3	2.0	2.0
Millepora alcicornis	1.3	1.7	1.1	1.4
Agaricia agaricites	0.3	0.6	0.3	0.4
Stephanocoenia intersepta	0.4	0.6	0.5	0.5
Madracis decactis	1.0	0.3	0.7	0.3
Siderastrea siderea	1.0	0.4	1.1	1.2
Mussa angulosa	<0.1	0.1	<0.1	0.1
Scolymia cubensis	0.0	0.1	0.0	<0.1
Porites furcata	<0.1	0.1	<0.1	<0.1
Madracis mirabilis	1.4	0.0	0.6	0.0
TOTAL CORAL	**58.2**	**53.1**	**55.7**	**47.0**
Reef Rock	17.4	46.7	18.6	49.0
Turf Algae	22.4	2.2	21.7	2.7
Sponge	0.0	1.4	0.0	1.0
Sand	1.0	0.0	2.0	0.1

*Montastraea annularis complex includes M. annularis, M. faveolata, and M. franskii

Non-coral species that exhibited significant differences in percent cover between random photographs and outside random photographs from previous cruises include reef rock and turf algae. Reef rock outside the study area was significantly reduced compared to previous cruises while turf algae cover was significantly greater than in previous studies.

3.7 SEA URCHIN SURVEYS

Three transects covering 200 m^2 were conducted at the EFGB resulting in a total count of seven *Diadema antillarum*. No transects were conducted at the WFGB due to inclement conditions.

3.8 VIDEO TRANSECTS

Following the established protocol for video documentation, linear transects were recorded following the perimeter boundary lines at each bank. The images collected appear consistent with the results of the encrusting, quadrat, and random photographic samples. The most notable observations were the stark white bleaching of the fire coral, *Millepora alcicornis*, particularly in the 1999 video. At the WFGB (1999 video), a loggerhead turtle was recorded with its carapace substantially covered with red turf algae.

4.0 DISCUSSION

4.1 GENERAL

This report presents the results of the 1998 and 1999 monitoring program. Attachments 1-5 are reports of non-contracted researchers joining the monitoring cruises to conduct investigations of the micromolluscan fauna, algal community structure, nutrient sources and pathways, and sediment pore water quality. Although some conditions that could be detrimental to the long-term health of the FGB were recorded (e.g. increase in algal biomass and incidences of coral disease) if they persisted, overall the monitoring data did not indicate any significant long-term negative conditions at the FGB.

4.2 CORAL GROWTH AND SUBSTRATE COVERAGE

Coral growth was measured as both accretionary growth (*Montastraea faveolata*) and encrusting (*Diploria strigosa*). Determined from radiographs of cores taken from *M. faveolata*, accretionary growth from 1985 through 1999, varied significantly within each bank and between banks during some but not all years. Duncan's Multiple Range Test (DMRT) defined seven statistical groupings of growth measurements 1985-99 at the EFGB and four statistical groupings of growth measurements at the WFGB. Between banks, ten of the 15 years (1985-99) had significant differences in growth rates. Mean accretionary growth at the EFGB was greater than at the WFGB every year during the period 1985-99. With a mean growth/yr (1985-99) of 6.80 mm and 5.13 mm at the EFGB and WFGB, respectively, the average colony of *M. faveolata* would have accumulated 10.2 cm and 7.7 cm of accretionary growth at the EFGB and WFGB, respectively. Regression analysis described a slightly positive, but non-significant slope for rate of accretionary growth at the EFGB and WFGB from 1985 to 1999.

Variability in annual growth rates of scleractinian corals is a general rule. Weber and White (1977) reported that growth rates are affected by genetic differences between colonies and environmental parameters such as temperature, light, depth, and light attenuation. Based on growth data from 1887 to 1979, Hudson and Robbin (1981) estimated annual growth rates of Flower Garden Bank colonies of *M. annularis* over time frames of 34 to 93 years (time frames determined by length of individual cores). They reported an annual growth of about 8.46 mm/yr with a range of 7.15-10.58 mm/yr (averaging the annual means of the 12 cores), substantially greater than that measured at the East and West FGB for the period 1985-99 (6.80 and 5.13 mm, respectively). The time frame 1985-99 is much shorter than the time frames Hudson and Robbin reported (34 to 93 years versus 15 years). This could be a contributing factor to the differences in growth rates reported herein and by Hudson and Robbin. Also, considering the variation in growth rates of individual coral colonies, the limited number of cores taken as part of the monitoring program could also bias the data when compared to data sets with more replicate cores.

Hudson (1981) investigated growth rates of *M. annularis* in the Key Largo, Florida marine sanctuary, reporting growth rates of 6.3 mm/yr at offshore fore-reef areas and 8.2 mm/yr at mid-reef over the period of 1928 to 1978. Weber and White (1977) reported accretionary growth rates of 3-12 mm/yr for *M. annularis* and *M. cavernosa* from Jamaica, Barbados, Key West, Belize and Panama. Using regression analysis, Weber and White (1977) predicted growth

rates at different temperatures: 25°C, 3.42 ± 1.20 mm/yr; 26°C, 4.36 ± 0.79 mm/yr; 27°C, 5.30 ± 0.51 mm/yr; 28°C, 6.25 ± 0.59 mm/yr; 29°C, 7.19 ± 0.95 mm/yr. Water temperatures at the FGB fluctuate seasonally generally between 18 and 30°C. Waters temperatures at the sites sampled by Weber and White would match the Flower Garden maximum but not be as cool as the Flower Garden minimum. Weber and White sampled in varying water depths recording faster growth rates for colonies near the surface (~ 3 m) than those in deeper water (14–40 m). Accretionary growth at the FGB falls solidly within the mid to upper range of growth rates reported by Weber and White for Caribbean corals despite the deeper water conditions of the Flower Gardens.

Huston (1985) reported that coral samples of *M. annularis* taken from Discovery Bay, Jamaica indicated growth rates decreased significantly with increasing depth; but *M. cavernosa* had its greatest growth rate at a water depth of 20 m. *M. annularis* typically grew 7–10 mm/yr in 5 – 15 m water depth. In water depths of 20–45 m, the growth rate declined to 1.4–2.0 mm/yr. One of the associations noted with the decrease in growth rate with depth was a change in growth form from rounded to flat. In contrast, *M. cavernosa* rate of growth ranged from 2–7 mm/yr at 5 – 10 m water depth and increased to 4–11 mm/yr at 20 m water depth.

Dodge and Lang (1983) used the Hudson and Robbin (1981) accretionary growth data to investigate potential correlations of water temperature and river discharge with rates of growth at the FGB. In general, Dodge and Lang found growth to be higher in years of warmer water temperatures and lower in years of increased river discharge from the Atchafalaya River. Using winter – spring (February – May) surface water temperatures, they described an overall decline in temperature and growth from 1950 to 1960, with a "marked depression" after 1957. Growth from the early 1960s to 1979 was variable and lower than pre-1957 rates.

Edinger *et al.* (2000) reported coral growth rates measured as vertical extension in areas contaminated by raw sewage discharge and areas free of sewage contamination. Although corals were dying in the contaminated areas, they found no correlation between water quality and growth rates in living colonies. Consequently, they concluded "*Massive coral growth rates may be poor indicators of coral reef health where coral reefs are subject to combined eutrophication and sedimentation.*"

Encrusting growth data suggests that conditions at the East and West FGB were less than optimum for growth of *D. strigosa* (Figure 4.2.0.1). Measurement of encrusting growth is a year-to-year direct comparison of living coral tissue (cm^2) in a demarcated photographic area. Of the 46 stations suitable for comparison on the EFGB in 1998, 45.6% showed a net tissue gain and 30 % displayed a net tissue loss (see Table 3.3.0.1). The cumulative tissue loss was greater than cumulative tissue gained (mean net loss = 0.14 cm^2/station) (Figure 4.2.0.2). In 6 of the 14 stations lost, a red turf algal mat replaced virtually all coral tissue. WFGB stations had a mean net gain of 0.54 cm^2/station in 1998. Of the 50 WFGB stations analyzed, 54% (27) had a net gain of tissue, 24% had a net loss, and 22% remained unchanged.

Diploria strigosa colonies fared better in 1999 at the EFGB despite the significant increase in the red turf algal biomass with a positive net growth rate (0.16 cm^2/station). WFGB colonies exhibited a negative net growth of 0.05 cm^2/station, which was a reduction from the 1998 net loss of 0.54 cm^2/station. Direct competition between the red turf algal mat and coral polyps was observed less frequently in 1999, but not totally absent.

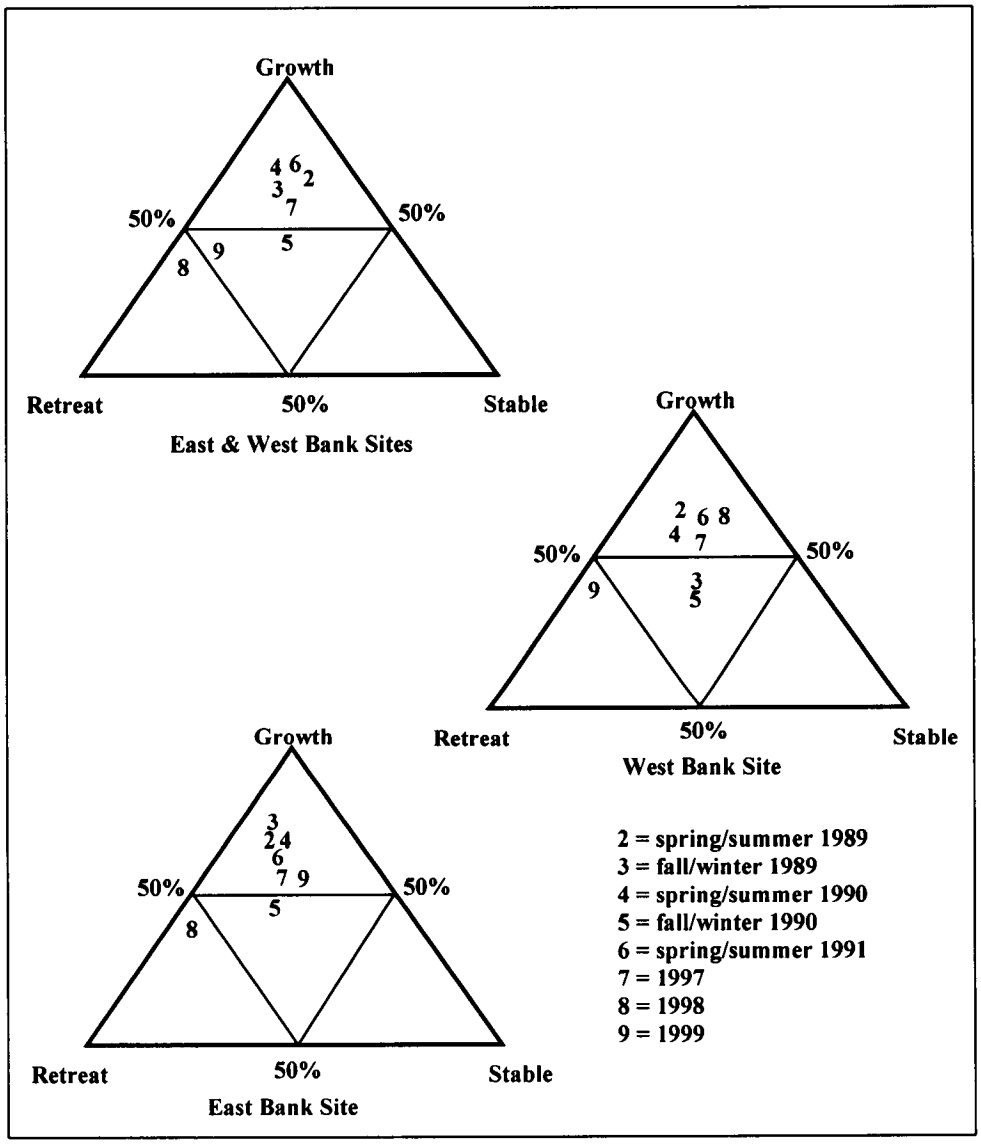


Figure 4.2.0.1. Ternary diagrams depicting the proportions of growing, retreating, and stable coral margins of *Diploria strigosa* colonies for the East and West Bank sites combined, East Bank site and West Bank site individually. A number within the upper portion of the triangle entitled Growth represents a year where mean tissue gain was significantly greater than mean tissue loss. A number in the lower left corner would represent a year where mean tissue loss was significantly greater than mean tissue gain. The central area of the triangle represents no significant change in the mean growth/retreat rate for a particular year. This differs from the lower right hand portion of the triangle labeled Stable. A year marked Stable represents a year when the mean rate of growth equals the mean rate of retreat.

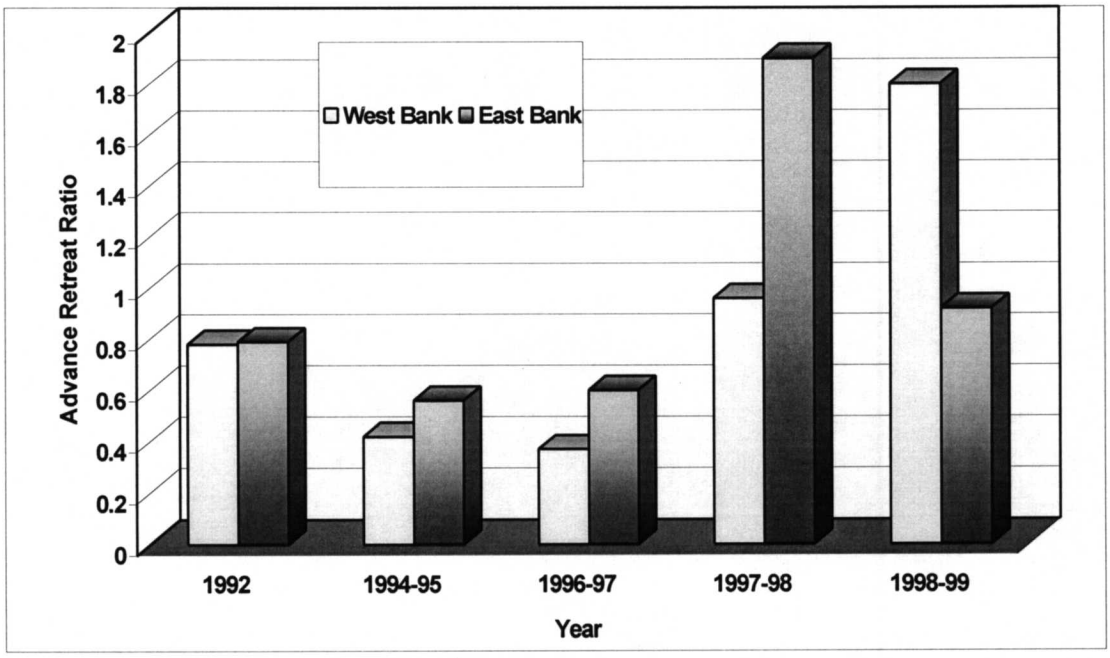


Figure 4.2.0.2. Advance to retreat ratios of *Diploria strigosa* for 1992 through 1999. Values above one represent net tissue loss; values below one represent net tissue gain.

Repetitive quadrat stations also indicated a loss of living coral tissue and an increase in algal cover. In 1998, 77 occurrences of algal encroachment into an area previously occupied by living coral tissue were recorded at the EFGB and 48 such occurrences were recorded at the WFGB. The number of "algal overgrowth" occurrences at the EFGB decreased in 1999 to 48 and to 19 at the WFGB.

Losses of coral tissue occurred for a variety of reasons including disease, bleaching, and sediment deposition. A red turf alga was observed in direct contact with the living coral tissue (Figure 4.2.0.3). Subsequently, one could conclude that the red turf algal mats were a primary cause of coral tissue loss. However, it was not determined if the algae caused the loss of tissue or if algae opportunistically occupied territory left vacant after some other agent caused the death of the coral tissue.

Aronson and Precht (2000a), reporting on the demise of Caribbean corals due to infections of white-band disease, stated that coral mortality precipitated the transition from predominantly coral cover to predominant cover by fleshy macroalgae. Antonius and Ballesteros (1998) reported blue-green algae overgrowing living coral in Carrie Bow Cay, Belize and off Key Largo, Florida. They also reported the red alga *Metapeyssonellia corallepida* and the brown alga *Lobophora variegata* overgrowing living coral tissue.

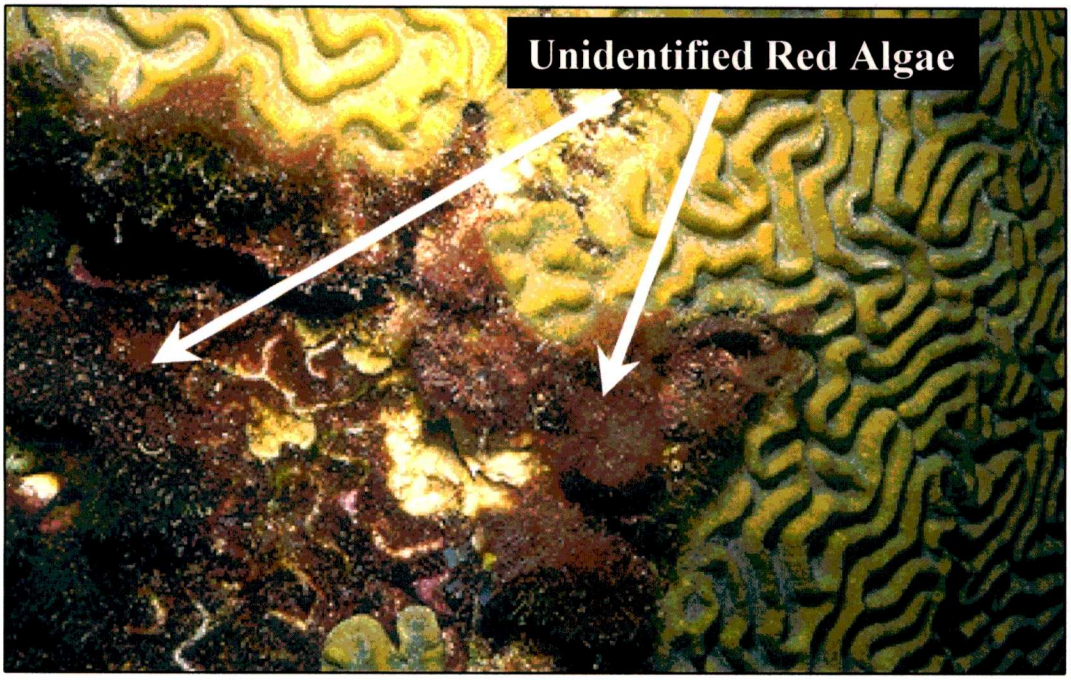


Figure 4.2.0.3. Unidentified encroaching red turf algae in direct competition with coral growth.

A notable observation in the 1999 random transect data was the significant increase in the percent cover of a red turf algal mat primarily at the expense of bare reef rock (Table 4.2.0.1). At the EFGB, from 1998 to 1999 the red turf algal mat coverage increased from 3.3 to 27.5%; concurrently, the mean percent of exposed reef rock decreased from 31.4-10.6%. At the WFGB, the red turf algal mat increased significantly from 3.2% (1998) - 20.7% (1999) and exposed reef rock decreased from 28.9%-20.7%. It is not clear if the fluctuations in algal biomass impacted living coral.

Consistent with past years, the *M. annularis* complex continued to be the dominant coral on both banks (Table 4.2.0.2) and *D. strigosa* was the second most dominant species. *Porites astreoides* had a significantly higher percent cover at the EFGB during 1998 and 1999. In 1998 *Colpophyllia natans* displayed a significantly greater percent cover and relative dominance at the WFGB than at the EFGB. These results were reversed in 1999 when EFGB populations were greater in both percent cover and relative dominance. This seemingly contradictory data is likely an anomaly of the sampling methodology and/or analysis. Although adequate to determine dominant species within the community, the sampling scheme used for the Flower Gardens monitoring may tend to under-represent non-dominant species. In order to provide an accurate assessment of nearly absent or unevenly distributed organisms, a more intense sampling strategy must be adapted.

Table 4.2.0.1.

Mean percent cover (%) of corals, reef rock, algae, sponge, and sand on random transects sampled 1992 and 1994-1999 survey cruises at the East and West Flower Garden Banks

EFGB PERCENT COVER								
Analyzed Component	**1992**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**All**
*Montastraea "annularis"**	24.1	26.9	35.7	30.4	28.0	34.4	31.4	30.1
Diploria strigosa	4.7	8.9	7.9	6.8	9.4	8.7	13.8	8.6
Porites astreoides	4.6	3.9	2.7	5.9	6.6	4.5	3.8	4.6
Montastraea cavernosa	1.5	4.8	3.2	6.0	3.7	3.7	2.7	3.7
Colpophyllia natans	2.1	1.6	3.8	1.0	3.1	1.7	4.0	2.5
Millepora alcicornis	1.3	2.5	1.7	2.3	0.8	1.5	1.8	1.7
Agaricia agaricites	0.5	0.9	0.3	1.0	0.2	0.4	0.2	0.5
Stephanocoenia intersepta	0.5	1.0	0.1	0.6	1.0	0.6	<0.1	0.5
Madracis decactis	0.5	0.4	0.1	0.5	<0.1	0.4	0.4	0.3
Siderastrea siderea	0.2	0.1	1.1	0.3	0.2	0.3	0.7	0.4
Mussa angulosa	0.1	0.2	0.1	<0.1	<0.1	0.1	0.1	0.1
Scolymia cubensis	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Madracis mirabilis	0.0	0.0	0.0	0.0	<0.1	0.3	0.2	0.1
TOTAL CORAL	**40.2**	**51.2**	**56.6**	**54.8**	**52.9**	**56.4**	**59.0**	**53.0**
Reef Rock	54.5	47.3	42.2	41.8	48.6	31.4	10.6	39.5
Algae	4.8	0.3	0.6	<0.1	5.2	3.3	27.6	6.0
Sponge	0.7	1.2	0.7	1.4	2.8	0.6	2.8	1.5
Sand	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
WFGB PERCENT COVER								
*Montastraea "annularis"**	23.0	25.0	31.0	34.0	22.6	39.6	33.3	29.8
Diploria strigosa	6.2	10.2	6.7	11.6	8.4	13.4	11.6	9.7
Porites astreoides	1.5	2.6	2.4	2.7	3.2	3.3	3.0	2.7
Montastraea cavernosa	0.9	3.2	2.3	4.7	3.3	3.6	2.5	2.9
Colpophyllia natans	3.1	2.8	1.0	1.7	1.2	2.4	1.0	1.9
Millepora alcicornis	0.8	1.9	1.9	1.5	0.9	1.1	0.9	1.3
Agaricia agaricites	0.4	0.4	0.5	0.3	0.4	0.2	0.2	0.3
Stephanocoenia intersepta	0.6	0.4	0.8	0.6	0.2	0.8	<0.1	0.5
Madracis decactis	0.2	0.3	0.3	0.1	0.6	0.3	0.5	0.3
Siderastrea siderea	0.4	0.0	4.1	0.2	1.4	2.3	1.5	1.4
Mussa angulosa	0.2	0.1	0.2	<0.1	0.2	0.1	0.2	0.1
Scolymia cubensis	<0.1	<0.1	0.0	<0.1	<0.1	<0.1	<0.1	<0.1
Madracis mirabilis	0.0	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1
TOTAL CORAL	**37.2**	**46.7**	**51.1**	**57.4**	**42.3**	**67.1**	**54.6**	**50.9**
Reef Rock	56.6	51.1	45.9	39.8	51.5	29.0	22.5	42.4
Algae	4.5	0.4	2.7	0.9	4.8	3.2	20.7	5.3
Sponge	1.5	1.6	0.3	1.0	0.7	0.9	0.8	1.0
Sand	0.3	0.2	<0.1	0.0	0.2	0.0	1.3	0.3

Table 4.2.0.2

Relative dominance (%), of all coral taxa on random transects sampled during 1992 and 1994-1999 monitoring cruises at the East and West Flower Garden Banks study sites

RELATIVE DOMINANCE EAST FLOWER GARDEN BANK								
Analyzed Component	**1992**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**All**
Montastraea annularis	57.33	51.69	61.36	55.6	64.5	55.43	53.26	57.02
Diploria strigosa	12.06	18.17	14.81	12.44	17.67	13.97	23.46	16.08
Porites astreoides	12.77	8.37	5.14	10.79	6.58	7.24	6.51	8.2
Montastraea cavernosa	3.38	8.63	5.82	10.97	3.73	6.06	4.56	6.16
Colpophyllia natans	6.41	2.94	6.65	1.74	3.11	2.67	6.82	4.33
Millepora alcicornis	3.23	4.81	3.10	4.20	1.82	2.45	2.98	0.37
Agaricia agaricites	1.38	1.85	0.58	0.97	0.46	0.67	0.31	0.88
Stephanocoenia intersepta	1.41	2.04	0.24	0.97	2.21	1.60	0.04	1.21
Madracis decactis	1.41	0.76	0.09	0.98	0.09	0.66	0.55	0.65
Siderastrea siderea	0.47	0.13	2.02	0.57	0.34	0.50	1.20	0.75
Mussa angulosa	0.14	0.39	0.13	0.10	0.18	0.20	0.15	0.18
Scolymia cubensis	0.02	0.28	0.02	0.06	0.46	0.00	0.03	0.12
Porites furcata	0.00	0.17	0.02	0.03	0.00	0.00	0.00	0.03
Madracis mirabilis	0.00	0.00	0.00	0.03	0.16	0.48	0.50	0.17
RELATIVE DOMINANCE WEST FLOWER GARDEN BANK								
Montastraea annularis	61.93	53.96	60.05	58.2	52.9	59.25	60.96	58.17
Diploria strigosa	16.15	21.27	12.68	19.92	19.56	20.01	21.14	18.67
Porites astreoides	4.07	6.13	4.81	4.53	7.48	4.91	5.58	5.35
Montastraea cavernosa	2.44	5.89	5.09	8.02	7.63	5.41	4.51	5.57
Colpophyllia natans	8.12	5.71	1.92	2.90	2.80	3.64	1.80	3.84
Millepora alcicornis	2.38	4.09	4.01	2.56	2.08	1.57	1.59	2.61
Agaricia agaricites	0.87	1.06	0.92	0.44	0.89	0.35	0.35	0.69
Stephanocoenia intersepta	1.97	0.85	1.60	0.99	0.50	1.17	0.02	1.01
Madracis decactis	0.55	0.64	0.63	0.16	1.30	0.07	0.90	0.61
Siderastrea siderea	1.04	0.00	7.90	3.40	3.20	0.01	2.67	2.60
Mussa angulosa	0.44	0.34	0.39	0.16	0.44	1.17	0.35	0.47
Scolymia cubensis	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Porites furcata	0.02	0.05	0.00	0.00	0.01	0.00	0.00	0.01
Madracis mirabilis	0.00	0.00	0.00	0.00	0.01	0.00	0.08	0.01

Fredericq *et al.* (Attachment 1) and Lehman and Albert (Attachment 2) produced a combined taxonomic list of 72 species of algae collected from the coral habitats of the FGB (Appendix A). Their separate lists had five species (*Entocladia viridis, Bryopsis pennata, Asparagopsis taxiformis, Anotrichium tenue,* and *Centroceras clavulatum*) and 16 genera in common. The dominant algal group reported by Fredericq et al. and Lehman and Albert was red turf algae, primarily of the genera *Centroceras, Ceramium*, and *Polysiphonia* (Order: Ceramiales). Lehman and Albert noted that substantial variations in biomass of the red turf algal mat occur in relatively short time scales.

Fredericq *et al.* noted the abundance of epiphytic blue-green algae, speculating that it may be indicative of increased nutrient loading. Dunton and Miller (Attachment 3), through analysis of $\delta^{15}N$, reported the Flower Garden habitats to be autogenous with cyanobacteria (i.e. blue-green algae) being the primary source of nitrogen. Lehman and Albert reported blue-green algae to comprise 7.5% and 11.0% of the samples taken at the East and West FGB, respectively. Measured ammonium and phosphate concentrations were low, and nitrate levels were consistent with concentrations reported for nearshore waters in southwestern Florida by Delgado and LaPointe (1994). Based on nutrient enrichment experiments with *Dictyota* sp., Dunton and Miller concluded that nutrient availability regulates algal productivity at the Flower Garden reefs. Lehman and Albert (Attachment 2) discussed the effect of temperature on alga of the order Ceramiales, noting that respiration rates can double with each $10^{o}C$ increase in temperature. Temperatures, based on a seven-year mean at the FGB, were described as ideal for the growth of red turf algae of the Order Ceramiales.

Dunton and Miller presented preliminary analysis of a trophic structure model. Although preliminary, this work supports the assumptions that, although nitrogen-fixing cyanobacteria (blue-green algae) are a major source of nitrogen, plankton is also a source of nitrogen input through the feeding activities of coral polyps and other planktivores.

At the FGB, algal growth appears to fluctuate rapidly and dramatically. Casual observations in February 2000 indicated that the algal density was significantly less than that observed during September 1999. Other than temperature and insolation, there is no data to test for correlation to varying algal density. The significant increase of red turf algae in 1999 at the expense of previously bare reef rock has not been conclusively explained.

Aronson and Precht (2000b) reported significant increases in macroalgae biomass in Discovery Bay, Jamaica, from the mid-1980s to 1996 during a period of depressed populations of *Diadema antillarum*. After 1996 the macroalgae cover was drastically reduced which correlated with a resurgence of the grazing herbivore *D. antillarum*. They did not observe any correlation of algal biomass and nutrient concentrations. At the FGB, populations of *D. antillarum* have been depressed since the mid-1980s (Dokken *et al.*, 1999). However, it must be noted that systematic quantification of *D. antillarum* populations did not start until 1998 and counts have occurred only during the annual monitoring cruises, which spend no more that 2.5 days at each FGB. Casual observations during June 1999 and during the August 1999 spawning period, indicated a substantially increased population of *D. antillarum*. Systematic counts in September 1999 during the monitoring cruise found *D. antillarum* populations to be once again depressed, suggesting some yet to be described population cycles and/or behavioral patterns.

Littler and Littler (1985) and Littler *et al.* (1991) presented a model which indicated that corals predominate at low nutrient and high grazing levels, coralline algae predominate at high nutrient and high grazing levels, algal turfs predominate at low nutrient and low grazing levels, and macroalgae predominate at high nutrient and low grazing levels. The conditions recorded at the FGB seem to agree with this model (i.e. algal turfs predominate at low nutrient and low grazing levels). In contrast to the Littler and Littler model, LaPointe (1997) and LaPointe *et al.* (1997) suggested that increasing and sustained nutrient concentrations in Discovery Bay and the Florida Keys exceeded threshold levels resulting in algal blooms and growth. The seemingly isolation of the FGB banks from on-shore nutrient impacts distinguish the Banks from the Florida Keys and Discovery Bay. We say seemingly since, although a terrestrial based impact has not been conclusively documented at the FGB, freshwater debris such as water hyacinths have been observed on the surface above the East Flower Garden Bank and on the seabed in late summer/early fall. Additionally, Dodge and Lang (1983) extrapolated negative correlations between discharge volume of the Atchafalaya River and the rate of coral growth at the FGB. They hypothesized that river discharge could affect both temperature and light attenuation with negative consequences on coral growth at the FGB. Freshwater debris and the correlations described by Dodge and Lang suggest that periodically, changing water currents reduce the isolation of the FGB from terrestrial based events.

Dunton and Miller (Attachment 3) provided new information and data on primary production and carbon flow in the trophic structure of the FGB. From Dunton and Miller, "*These preliminary data suggest that the primary nitrogen source in the Flower Gardens is autogenously produced by nitrogen-fixing cyanobacteria (e.g. benthic blue-green algal mats and/or pelagic Trichodesminum). In contrast, the primary nitrogen source at Stetson bank appears to be allochthonous, perhaps from coastal riverine inputs.*" The methodology of Dunton and Miller provided a mechanism for distinguishing between terrestrial based nutrient impacts and non-terrestrial impacts. The comparisons between the FGB and Stetson Bank provide a very dynamic contrast from which to assess the results of differing sources of nutrient impact.

Lehman and Albert (Attachment 2) noted that the biomass of the red turf alga (Order Ceramiales) could fluctuate monthly with changes in herbivore grazing pressures and/or water quality parameters. Although the cause was not known, an apparent reduction in cover and biomass of red turf algae was observed on the FGB after the September 1999 monitoring cruise. The work of Fredericq *et al.* (Attachment 1) and Lehman and Albert significantly expanded our knowledge of the algal flora of the FGB. Fredericq *et al.* reported at least five new species for the FGB and discussed similarities with Stetson Bank and Sonnier Bank. Lehman and Albert present a species by species discussion of dominance, coverage, biomass, and the ecology of the dominant red turf alga of the Order Ceramiales. From comparable depth ranges, Diaz-Pulido and Bula- Meyer (1997) recorded 86 species of alga on oceanic atolls in the southwestern Caribbean, double the number reported by either Fredericq *et al.* or Lehman and Albert. Recognizing that these were the initial collecting efforts of Fredericq *et al.* and Lehman and Albert on the FGB, it will be interesting to determine whether or not, like the stony corals, the biodiversity of algae at the FGB is low. These studies are crucial to developing a more comprehensive understanding of the ecosystem dynamics of the FGB and as a basis for building predictive models (Dokken *et al.*, 1999) for the health and productivity of the FGB.

4.3 DISEASE

Although disease continued to be a minor component of the FGB, it was present and occurred in some photographic stations (Figures 4.3.0.1, 4.3.0.2, 4.3.0.3, and 4.3.0.4). Identifications and naming herein are tentative in that only photographic comparisons were used to identify the "specific" disease. No laboratory studies were conducted to test Koch's postulates. Disease did not appear to be a dominant factor in the overall loss of tissue, but it was possible that the advance of the red turf algal mat discussed in Section 3.1 and 3.3 was mediated by disease.

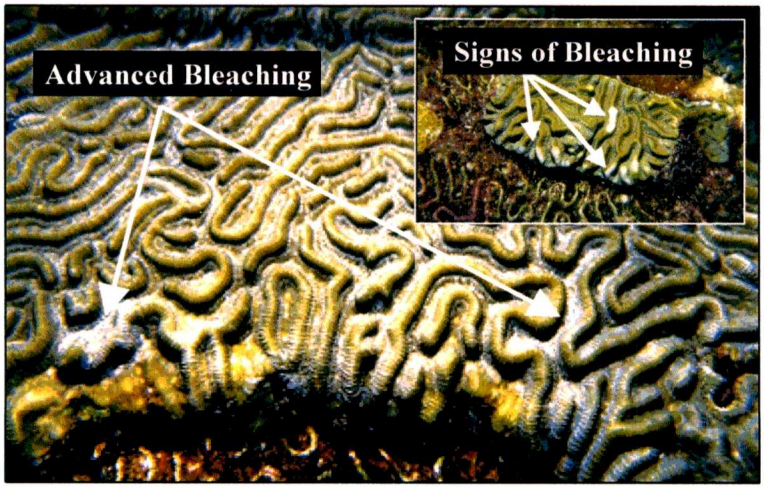


Figure 4.3.0.1. Advanced and early signs of bleaching in *Diploria strigosa* at the Flower Garden Banks.

Figure 4.3.0.2. Suspected ridgecrest mortality on *Diploria strigosa* at the Flower Garden Banks.

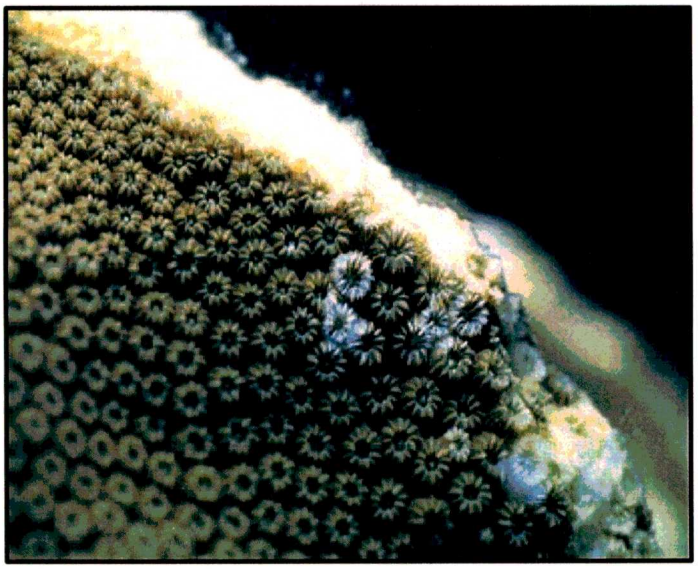
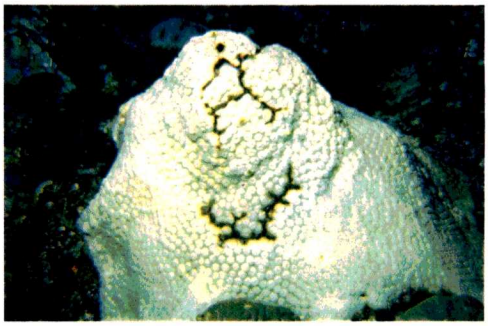


Figure 4.3.0.3. Unidentified anomaly on *Montastraea faveolata* at the Flower Garden Banks.

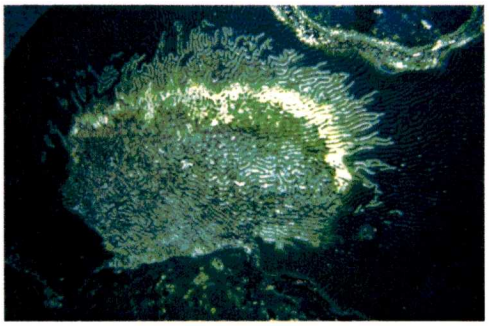
A comparatively dramatic condition of tissue loss of unidentified origin(s) occurred. Afflicting both *Montastraea* sp. and *Diploria* sp., it generally appeared as a stark white patch up to 0.25 m^2 in area in the middle of an otherwise healthy appearing coral colony. Close observation revealed a semitransparent film overlying the afflicted area and disintegration of the morphological structure of the skeleton. The cause of this condition was not apparent and, laboratory studies will be required to determine the cause. The reader is reminded that at the time of this study, disease was a minor component of the focus and further and more intense study of disease at the FGB should be undertaken to more accurately assess the conditions of the corals.

Unknown disease(s) attacking (a) *Montastraea annularis* and (b) *Diploria strigosa*.

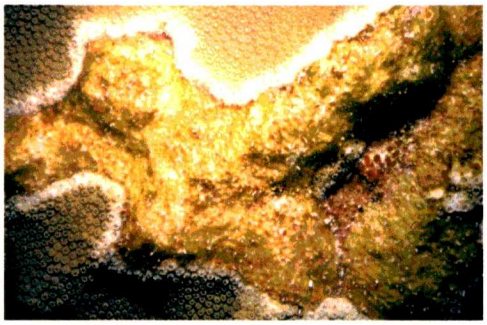
Parrot fish bite marks in *Stephanocoenia intersepta* (photo taken August 1993).

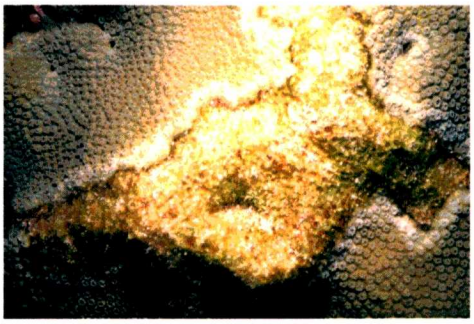


Bleaching on *Montastraea cavernosa* (photo taken august 1990).



Unknown disease on *Diploria strigosa* (photo taken June 1992).





Possible white plague disease attacking a colony of *Montastraea cavernosa*.

Figure 4.3.0.4. Photographic samples of impacted coral colonies.

Diseases of corals at the FGB have not been a priority focus, primarily because of the low rate of occurrence. Subsequently, the etiology of this potential threat to the FGB is not known. In a CNN.com nature report (8 March 2000), G. Shinn (U.S. Geological Survey) and D. Barber (Duke University) reported "dust balls" originating on the western coast of Africa traverse the Atlantic into the Caribbean Sea carrying bacteria, fungi, and viruses as well as inorganic contaminants such as iron. Shinn and Barber suggested that this could be a major threat to the reefs of the Caribbean Sea and adjacent waters.

Goreau *et al.* (1998), Hayes and Goreau (1998), Richardson, *et al.* (1998), and Ritchie and Smith (1998) presented discussions of the increasing occurrence and threat of diseases to Caribbean corals. Richardson (1998) reviewed published works on coral diseases. At the time of this review only aspergillosis, black band disease, white band disease type II, and plague type II had been demonstrated to have a characteristic microorganism or consortium of organisms involved. For only aspergillosis, black band disease, and plague type II was a disease pathogen(s) demonstrated. The mechanism causing death of the polyp was known only for black band disease, and only white band disease had been shown to restructure a reef on a regional scale. Various investigators had collectively proposed the identification of 13 diseases.

In contrast to the FGB, most reefs of the Caribbean are in near proximity to developed terrestrial areas. Because of the relative isolation of the FGB from shore side influences, these coral habitats provide a unique opportunity for comparative studies of disease etiology and the effects of environmental quality. Investigators of Texas A&M University-Corpus Christi have initiated more directed and comprehensive investigations of the diseases of the FGB corals.

4.4 TEMPERATURE

Temperature data was obtained from NDBC buoy 42019 approximately 60 nm south of Freeport Texas (27 ° 92 N, 95 ° 35 W). This installation records water temperature at a depth of approximately 1m. Since surface waters respond more quickly and dramatically to meteorological conditions, the annual temperature range is greater than the 7-year mean of bottom temperatures at the FGB (Figure 4.4.0.1). Graphing an average of long-term bottom temperatures and the surface temperatures of 1998 and 1999 we see that surface temperature and bottom temperature cycles almost perfectly mimicked each other. The only difference being that surface temperatures exhibited a 2-3°C greater range at both the high and low ends. From this we estimated that the bottom temperatures of 1998 and 1999 were very similar, if not almost identical to those of 1996 and 1997 (Dokken *et al.*, 1999).

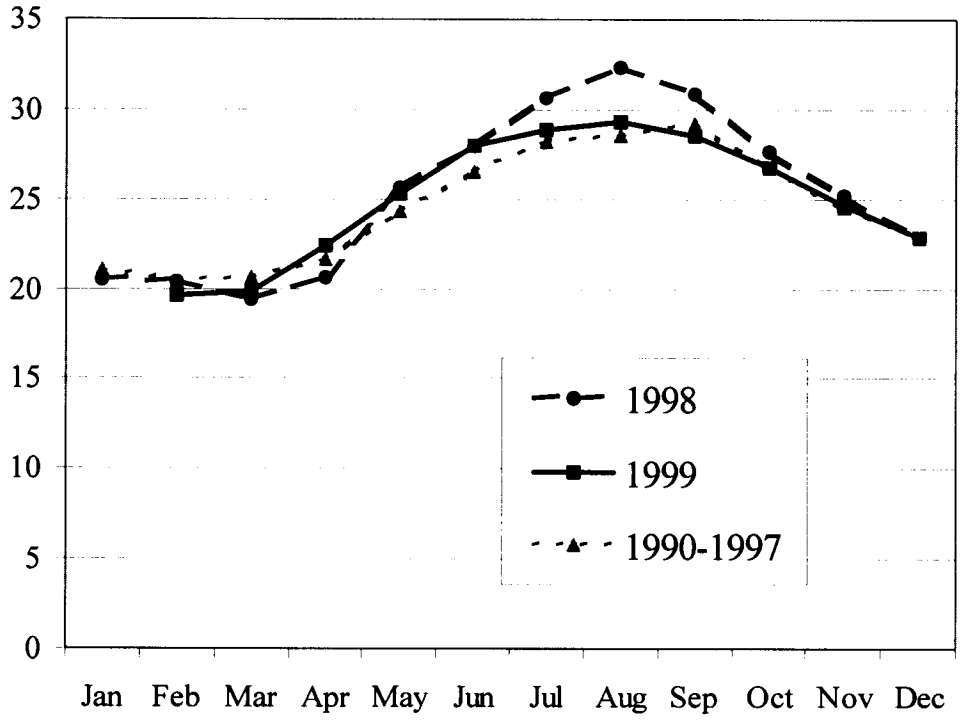


Figure 4.4.0.1. Monthly mean sea surface temperatures for 1997-1998 and monthly mean bottom temperatures for 1990-1997.

4.5 BLEACHING

At the Flower Garden Banks, bleaching was observed, but not as a "mass" bleaching event as reported globally in 1998 (Glynn, 1993;Hoegh-Goldberg, 1999). Bleaching at the FGB to date has been, unevenly distributed throughout the habitat and of short duration. As in 1998 (Dokken *et al.*, 1999), the fire coral (*Millepora alcicornis)* in 1999 seemed to be particularly susceptible to bleaching. In 1999, bleaching observed in 1998 followed by mortality was observed 26 times from the random photographs at the WFGB. In the 1996-97 monitoring study, bleaching correlated with a rise in water temperatures above 30°C, which typically occurs in the latter part of August.

Toren *et al.* (1998) reported research results that suggest that temperature is an indirect cause of bleaching, the real culprit being bacteria that becomes virulent at higher temperatures. Regardless, temperature has been shown to be a primary triggering agent, whether by indirect or direct routes of response. Hoegh-Guldberg (1999) presented a comprehensive discussion of bleaching and the known causative agents with long-term temperature models and projections of the impact upon corals. Generally, the three temperature models presented agree that within the next 100 years, ocean surface temperatures will raise 1–2°C. Hoegh-Guldberg further discusses and postulates on the physiological ability of corals and their symbiotic zooanthellae to acclimate and/or evolve adequately to tolerate higher temperatures. The predictions are not optimistic.

Within the next 20-30 years near annual mass bleaching events are predicted globally. By 2010, 2100 global distribution patterns of coral could be on a track of radical alteration.

Supposing these predictions hold true, the FGB may have a competitive edge to survival. As a deep-water reef, generally 25-50 m, the corals and zooxanthellae of the FGB may be adequately thermally isolated from the extremes of the surface temperatures to reduce or delay a stress response. At the FGB, water temperatures at the coral surface generally range from 20-33°C. The onset of bleaching occurs at about 30°C. Temperature peaks are generally short in duration occurring during the month of August. In the event of a global warming trend, it is not known for certain that the position of the FGB coral reefs will provide any survival advantage, but relative to near shore shallow water reefs, the possibility is an interesting scenario to consider. In such a case, the FGB could become an isolate repository of biodiversity and coral genetic material.

4.6 INSOLATION

Where direct comparisons are possible, there are distinct short- and long-term differences in the PAR (photosynthetically active radiation) doses recorded by the instruments at the East and WFGB monitoring sites (Figure 3.5.2.4). The differentials were calculated by subtracting the WFGB readings from the EFGB readings, so positive values in this graph indicate higher PAR doses at the EFGB. The abrupt shift to higher values at the EFGB station observed between October 1998 and May 1999 raises the question of whether there is a calibration difference between the two instruments. Removing the two instruments for a side-by-side re-calibration is recommended. However, the increased variability in PAR doses during summer months is not surprising considering the higher overall levels during this season and the consequent heightened effect of overcast days. Likewise, the trends in the attenuation data (Figure 3.5.2.4) are not consistent with drift in instrument calibration because of the slope of the trends changes sign over the course of the observation intervals. High-frequency (~weekly) variation in attenuation could be caused by weather or sea-state periods that produced different turbidity at the two sites. Additional data and data describing other aspects of water quality will be required to confirm this explanation.

Dosage of PAR is crucial for health in reef corals in a positive and negative sense (Hoegh-Guldberg, 1999). Photosynthesis in coral zooanthellae depends on adequate light levels, but over-exposure to PAR can be a factor in coral bleaching, albeit this problem is more pronounced in shallow, fringing reefs. Just as with temperature, the water depth of the FGB will buffer PAR intensity.

Analysis and interpretation of insolation data have been presented in Dokken *et al.* (1999) (Figure 4.6.1). The plot shows the extinction coefficient $-k$ estimated from PAR sensors deployed at the East FGB. Higher values for $-k$ in this plot indicate reduced light availability at the seafloor (27 m depth) where the sensor is deployed. The result is useful in that it clearly shows the onset of summer conditions in the FGB. Abrupt transitions in July and August may signal transitions from coastal to offshore conditions. PAR intensity influences primary productivity in the water column and within the coral tissues and benthic algae. Without additional information, however, it is difficult to determine whether decreased light penetration at the FGB results from plankton blooms or an influx of turbid coastal water. Synoptic records

of currents, temperature, salinity, turbidity, and dissolved oxygen would broaden the potential interpretations of monitoring data. If they were available real-time, such data could warn of harmful events such as hypoxia and high temperatures and would have practical value for recreational divers planning trips to the Sanctuary.

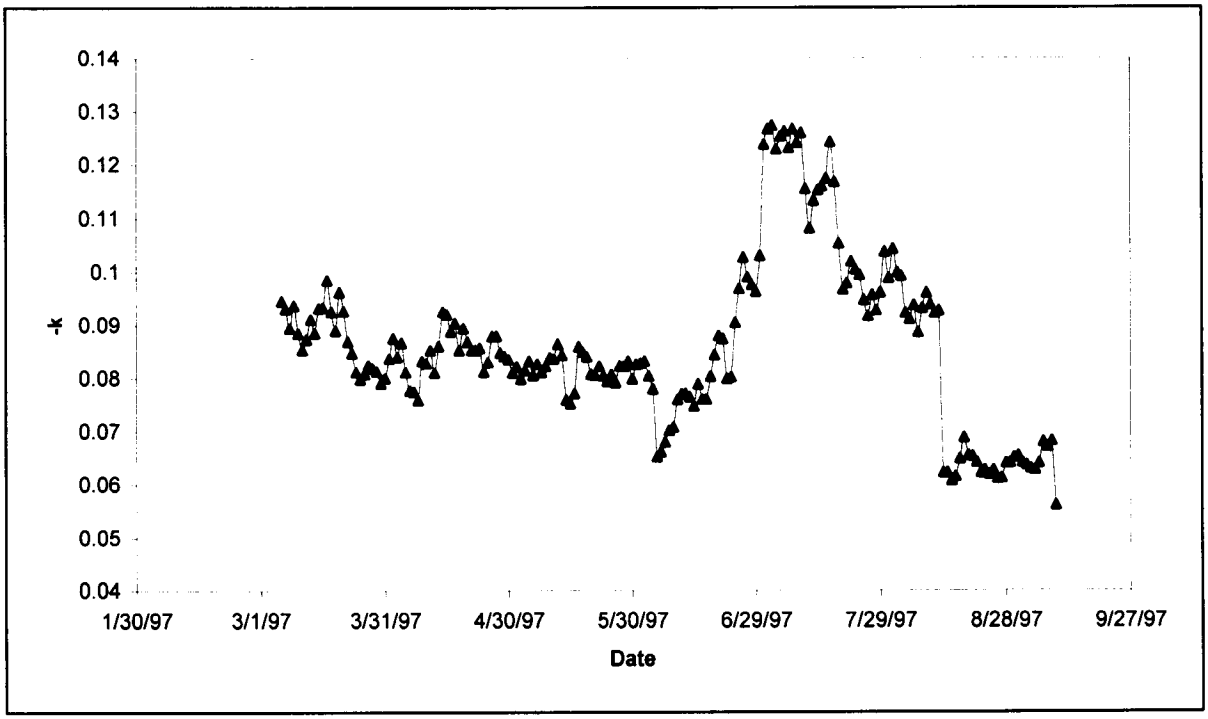


Figure 4.6.0.1. Light attenuation at the East Flower Garden Bank estimated from comparison of a PAR sensor deployed at 27 m depth on the bank and a reference sensor deployed on a near-by platform (Dokken *et al.*, 1999). Increased values of *-k* indicate reduced light availability at the seafloor.

4.7 WATER QUALITY

At the remote sampling location of the FGB, consistent with the reported data of Dokken *et al.* (1999), it was anticipated that water concentrations of polycyclic aromatic hydrocarbons (PAH) and organic contaminants would be low. The pesticide and PAH concentrations reported herein support this expectation. Procedural blanks prepared at Texas A&M University Geochemical Environmental Research Group (GERG) have much lower levels of analytes than the field/dialyses blanks. In order to determine if the dialyses process is adding additional contaminants to the field blanks, future samples will be dialyzed at GERG. Also, all Semipermeable Membrane Devices (SPMD) will be dialyzed and analyzed separately. This will allow for the determination of the effect that holes in the SPMDs have on analyte concentrations. For example, many programs using SPMDs discard SPMDs with holes. Another problem with the current deployment scheme is the extended period that the SPMDs are deployed. Most programs only leave the SPMD deployed for a month or less. Bio-fouling of the SPMD may be limiting their dialyses rate (e.g. the estimated rate of 4 l/day

may not be correct). If possible, SPMDs will be deployed for shorter time periods. In spite of the limitations of the SPMDs stated above, they have provided information confirming the low concentrations (25×10^{-15} to 5×10^{-12}) of organic contaminants at these remote locations.

In 1998 the research team attempted to complete SPMD collections near the water surface and surface of the seabed. For the surface collections, the SPMD canisters were attached to mooring buoys approximately 3 m below the surface. However, upon returning in March 1999 to collect these SPMD samples, the researchers discovered that all surface installations were gone as well as one bottom installation. Subsequently, only bottom installations were reinstalled. For continued application of SPMDs, it is recommended that mooring points isolated from the boat mooring buoys be installed and submerged buoys attached. This should reduce the likelyhood of loss to commercial boat traffic and diver interference.

Nipper and Carr (Attachment 5) added new dimensions to the investigations of water quality with their toxicity testing of pore water. Although the dynamics of the FGB ecosystem (Dokken *et al.*, 1999) are poorly understood, one must assume that the benthic infauna and flora (Hawkins and Lewis, 1982) plays a significant role in the overall trophic structure. The findings of Nipper and Carr that the pore waters of the FGB were non-toxic, an indication that these waters are not contaminated with organic or inorganic pollutants to a toxic degree, provide one more indicator of the health of the habitat. This corroborated the results of the SPMD studies. It is recommended that pore water toxicity testing be made an integral part of the overall monitoring strategy.

4.8 MICROMOLLUSCS

J. W. Tunnell and N. Barrera (Attachment 4; Barrera, 2001), through descriptions of the micromolluscan fauna, have increased the known indigenous fauna of the FGB by 100 species. In their report they discuss the correlation of micromolluscan assemblages to environmental quality, stating that micromolluscs can be used as indicators of habitat health.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The Flower Garden Banks' coral reef habitats remain healthy and productive, particularly in comparison to other reefs of the Mexican Gulf of Mexico, the Florida Keys, and the Caribbean Sea. However, some negative shifts in the monitoring parameters were recorded (i.e. encrusting growth, algal biomass, and possible disease occurrence). It is not known what the impact of these shifts will be or whether they are short-term anomalies or the first steps of a long-term trend. Subsequently, continued close scrutiny is crucial. The 2000 monitoring data will be critical in assessing the true meaning of the 1998 and 1999 results. Of particular interest will be the status of the algal bloom and incidence of disease. The co-principal investigators have extended invitations to "guest scientists" (see Appendices 2 through 6) to continue their work on algal composition, nutrient flows, and pore water toxicity.

The work of Dunton and Miller (Attachment 3) produced some particularly interesting comparative results between the FGB and Stetson Bank. Describing Stetson Bank to be most influenced by terrestrial/coastal sources of nutrients and the FGB being "autogenous" in meeting nutrient requirements. Expansion of comparative studies between Stetson Bank and the FGB would help clarify understanding of the FGB dynamics.

In comparison to most reefs of the Mexican Gulf, southern Florida, and the Caribbean Sea, the FGB are unique. They are relatively isolated from terrestrial based impacts, they have 25 m of water column above them which may serve as a buffer to extremes of surface temperatures and solar radiation (PAR), and the offshore seabed in the area of the FGB is intensely explored and mined for the production of oil and gas, the closest productions wells being within 1.5 km of the East Flower Garden Bank. The FGB are isolated from other coral habitats making direct transmission of disease pathogens less likely. As such, the FGB are important habitats in the study of coral reef sustainability versus anthropogenic impacts.

To improve upon management's ability to recognize and respond to potentially detrimental occurrences, the ecosystem dynamics of the FGB need to be further researched, described, and modeled. Referring the reader to Attachments 1 through 5, the co-principal investigators have endeavored to integrate additional scientists and research focus into the monitoring study. By doing so, we have advanced efforts to more completely describe a conceptual model of ecosystem dynamics (Figure 5.0.1). As our knowledge of the ecosystem dynamics increases, dynamic models can eventually be created to show cause and effect relationships and support management efforts with predictive capabilities. The co-principal investigators recommend that:

1) The monitoring program be continued.
2) The monitoring program be expanded to include algal studies, nutrient flows in the trophic structure, nutrient concentrations in the water column, pore water toxicity, and detailed studies of disease. If necessary, the budget should be adjusted to accommodate these studies.
3) The *in situ* water quality monitoring instrumentation be upgraded and the suite of water quality parameters measured be expanded to include dissolved oxygen, salinity, pH, turbidity, nitrites, nitrates, ammonium, and phosphates. If necessary, the budget should be adjusted to accommodate these upgrades.

4) Sample no less than four times per year those flora/faunal components and water quality parameters that can undergo short term fluctuations (i.e. algal biomass, bleaching, herbivore populations, and contaminant concentrations).
5) Expand monitoring program to include Stetson Bank to both monitor the health and sustainability of the Stetson Bank ecosystem and as a more terrestrially influenced habitat against which to compare and contrast the FGB.

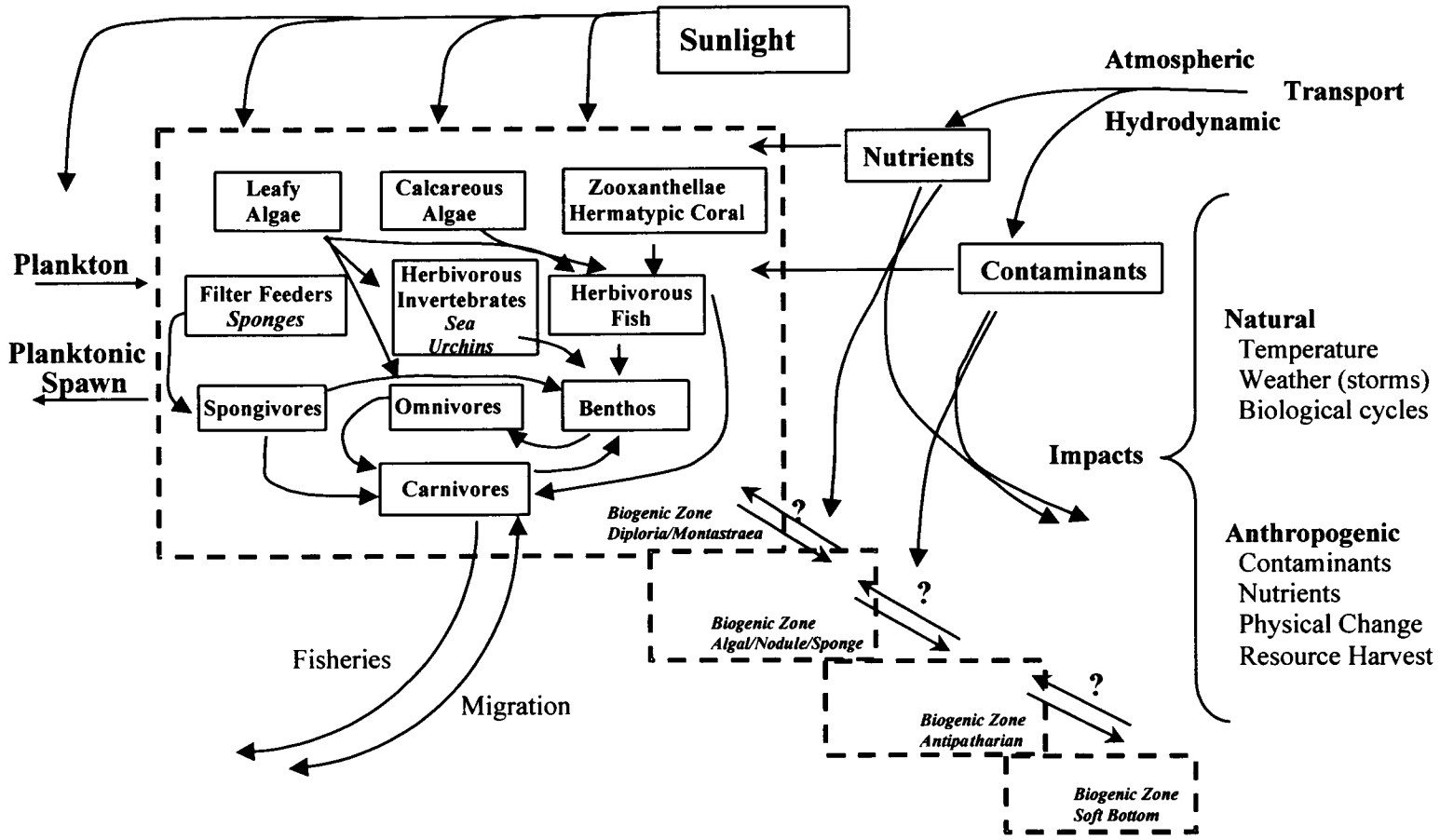


Figure 5.0.0.1. Preliminary conceptual model of trophic dynamics of the Flower Garden Banks' ecosystem. Arrow indicate principal direction of energy/nutrient flow. Nutrients/energy are obtained through photosynthesis grazing, predation, filter feeding, and reduction of waste products (e.g., fecal matter; after Dokken *et al.*, 1999).

6.0 LITERATURE CITED

Antonius, A. and E. Ballesteros. 1998. Epizoism: a new threat to coral health in Caribbean reefs. University de Costa Rica. Rev. Biol. Trop. 46 Supl. 5:145-156.

Aronson, R. B. and W.F. Precht. 2000a. White-band disease and the changing face of Caribbean coral reefs. Hydrobiologia. 00:1-14.

Aronson, R. B. and W.F. Precht. 2000b. Herbivory and algal dynamics on the coral reef at Discovery Bay, Jamaica. Limnol. Oceanogr. 45(1):251-255.

Barrera, N. 2001. Micromolluscan assemblages on the Flower Garden Banks, northwestern Gulf of Mexico, M.S. Thesis. Texas A&M University-Corpus Christi. Corpus Christi, TX. 90 p.

Bright, T. and L. Pequegant. 1974. Biota of the West Flower Garden Bank. Gulf Publishing Co., Houston, Texas.

Bright, T.J., D.W. McGrail, R. Rezak, G.S. Boland, and A.R. Trippet. 1985. The Flower Gardens: A compendium of information. U.S. Dept. of Int. Minerals Management Service, Gulf of Mexico. OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 85-0024. 103 p.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and T.S. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: a comparison to other western Atlantic reefs. Bull. Mar. Sci. 24(3):461-476.

Brower, J.E., J.H. Zar, and C.N. von Ende. 1998. Field and laboratory methods for general ecology. WCB McGraw Hill, Boston, Massuchusetts. 273 p.

Continental Shelf Associates. 1996. Long-term monitoring at the East and West Flower Garden Banks. U.S. Dept. of the Int., Minerals Management Service, Gulf of Mexico. OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 96-0046. 79 p.

Delgado, O. and B.E. LaPointe. 1994. Nutrient-limited productivity of calcareous versus fleshy macroalgae in the eutrophic, carbonate-rich tropical marine environment. Coral Reefs 13:151-159.

Diaz-Pulido, G. and G. Bula-Meyer. 1997. Marine algae from oceanic atolls in the southwestern Caribbean (Albuquerque Cays, Courtown Cays, Serrana Bank, and Roncador Bank). Atoll Res. Bull. 448:18

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. Limnol. Oceanogr. 28(2):228-240.

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

Edinger, E.N., G.V. Limmon, J. Jompa, W. Widjatmokos, J.M. Heikoop, and M.J. Risk. 2000. Normal coral growth rates on dying reefs: are coral growth rates good indicators of reef health? Mar. Poll. Bull. 40(5):404-425.

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 Int. Minerals Management Service, Gulf of Mexico. OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 92-0006. 206 p.

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

Goreau, T.J., J. Cervino, M. Goreau, R. Hayes, M. Hayes, L. Richardson, G. Smith, K. DeMeyer, I. Nagelkerken, J. Garzon-Ferrera, D. Gil, G. Garrison, E.H. Williams, L. Bunkley-Williams, C. Quirolo, K. Patterson, J.W. Porter, and K. Porter. 1998. Rapid spread of diseases in Caribbean coral reefs. University de Costa Rica. Rev. Biol. Trop. 46 Supl. 5:157-171.

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

Hawkins, C.M. and J.B. Lewis. 1982. Benthic primary production on a fringing coral reef in Barbados, West Indies. Aquat. Bot. 12:355-363.

Hayes, R.L. and N.I. Goreau. 1998. The significance of emerging diseases in the tropical coral reef ecosystem. University de Costa Rica. Rev. Biol. Trop. 46 Supl. 5:173-185.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world's coral reefs. Mar. Freshwater Res. 50:839-866.

Hudson, J.H. 1981. Growth rates in *Montastraea annularis*, a record of environmental change in Key Largo coral reef marine sanctuary. Fl. Bull. Mar. Sci. 31:444-459.

Hudson, J.H. and D.M. Robbin. 1981. Effects of drilling mud on the growth rate of the reef-building coral *Montastraea annularis*. p. 455-470 *in* R.A. Geyer (ed.) Marine Environmental Pollution. Elsevier Oceanogr. Ser. 27A.

Huston, M. 1985. Variation in coral growth rates with depth at Discovery Bay, Jamaica. Coral Reefs 4:19-25.

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

LaPointe, B.E. 1997. Nutrient thresholds for bottom-up control of macroalgal blooms on coral reefs in Jamaica and southeast Florida. Limnol. Oceanogr. 42(5):1119-1131.

Littler, M.M. and D.S. Littler. 1985. Factors controlling relative dominance of primary producers on biotic reefs. Proc. 5th Int. Coral Reef Symp., Tahiti 4:35-9.

Littler, M.M., D.S. Littler, and E.A. Titlyanov. 1991. Comparisons of N- and P-limited productivity between high granitic islands vs. low carbonate atolls in the Seychelles Archipelago: a test of the relative-dominance paradigm. Coral Reefs 10:199-209.

McGrail, D.W., M. Carnes, D. Horne, T. Cecil, J. Hawkins, and F. Halper. 1982. Water and sediment dynamics at the Flower Garden Banks. p. 103-226, *in* D.W. McGrail, R. Rezak, and T.J. Bright (eds.) Environmental studies at the Flower Gardens and selected banks. Final Report to MMS. Contract #AA851-CTO-25. NTIS Order No. PB83-101303.

Pattengill, C.V., B.X. Simmons, and S.R. Gittings. 1997. Reef fish trophic structure at the Flower Garden Banks and Stetson Bank, NW Gulf of Mexico.: Proc. 8th Int. Coral Reef Symp., Panama 1:1023-28.

Rezak, R. 1981. Geology pp. 23-59, *in* R. Rezak and T.J. Bright (eds.) Northern Gulf of Mexico Topographic Features Study. Final Report to the U.S. Dept. of Int., Bureau of Land Management. Contract #AA551-CT8-35. Vol. 1. NTIS Order No. PB81-248650:23-59.

Rezak, R.,T. J. Bright, and D.W. McGrail. 1985. Reefs and banks of the northwestern Gulf of Mexico: Their geological, biological, and physical dynamics. John Wiley and Sons, New York, NY. 259 p.

Richardson, L.L. 1998. Coral diseases: what is really known? Trends in Ecology and Evolution 13(11):438-443.

Richardson, L.L., W.M. Goldgerg, R.G. Carlton, and J.C. Halas. 1998. Coral disease outbreak in the Florida Keys: plague type II. University de Costa Rica. Rev. Biol. Trop. 46 Supl. 5:187-198.

Ritchie, K.B. and G.W. Smith. 1998. Type II white band disease. Univ. de Costa Rica. Rev. Biol. Trop. 46 Supl. 5:199-203.

Toren, A., L. Laundau, A. Kushmaro, Y. Loya, and E. Rosenberg. 1998. Effect of temperature on the adhesion of Vibrio AK-1 to *Oculina patagonica* and coral bleaching. Appl. Environ. Microbiol. 64:1379-84.

Weber, J.E. and E.W. White. 1977. Caribbean reef corals *Montastraea annularis* and *Montastraea cavernosa* – long term growth data as determined by skeletal x-radiography. p. 171 – 179. *in* S.H. Frost *et al.* (ed.), Reefs and related carbonates – ecology and sedimentation. Am. Assoc. Pet. Geol. Stud. Geol. 4.

Weil, E. and N. Knowlton. 1994. A multi-character analysis of the Caribbean coral *Montastraea annularis* (Ellis & Solander, 1786) and its two sibling species, *M. faveolata* (Ellis & Solander, 1786) and *M. franksii* (Gregory, 1895). Bull. Mar. Sci. 55(1):151-175.

7.0 Appendix A. Comparison of algae identified by Fredericq *et al.* and Lehman and Albert at the Flower Garden Banks, 1998-1999 (■ denotes observation, denotes no observation)

Species	Fredricq *et al.*	Lehman and Albert
Amphiroa fragilissima		■
Anotrichium antillanum	■	
Anotrichium tenue	■	■
Antithamnionella sp.		■
Asparagopsis taxiformis	■	■
Audouinella sp.	■	
Boodleopsis pusilla	■	
Botryocladia occidentalis		■
Bryopsis pennata	■	■
Callithamnion sp.		■
Callithamnioniella tingitana	■	
Caulerpa microphysa	■	■
Centroceras clavulatum	■	■
Ceramium flaccidum	■	*Ceramium* sp.
Chaetomorpha sp.		■
Chondria sp.		■
Chrysymenia enteromorpha		■
Cladophora sp.	■	■
Corallina sp.		■
Crouania attenuata	■	
Crustose coralline #1	■	
Crustose coralline #2	■	
Crustose coralline #3	■	
Dasya sp.		■
Derbesia sp.		■
Dictoyota cervicornis	■	*Dictoyota* sp.
Dictyopteris membranaceae		■
Dictyota pfaffii	■	
Dictyota pulchella	■	
Dudresnaya sp.		■
Ectocarpus sp.	■	
Enteromorpha sp.		■
Entocladia viridis	■	■
Erythrocladia endophloea	■	*Erythrocladia* sp.
Erythrotrichia carnea	■	*Erythrotrichia* sp.

Appendix A (continued)

Gelidium pusillum	■	*Gelidium* sp.
Griffithsia globulifera		■
Griffithsia herteromorpha	■	
Herposiphonia secunda cf. *tenella*	■	*Herposiphonia* sp.
Hydrolithon farinosum	■	
Hypnea volubilis	■	*Hypnea* sp.
Hypoglossum rhizophorum	■	
Hypogolssum hypoglosoides		■
Jania adhaerens		■
Jania capillacea	■	
Laurencia chondrioides	■	
Lobophora variegata		■
Lyngbya sp.		■
Martensia hickersonii	■	
Myriogramme sp.		■
Oscillatoria sp.		■
Plenosporium flexuosum		■
Pneophyllum lejolisii	■	
Polyphysa polyphysoides		■
Polysiphonia flaccidissima	■	*Polysiphonia* sp.
Polysiphonia tepida	■	
Ptilothamnion occidentale		■
Rhodymenia divaricata		■
Sahlingia subintegra	■	
Sargassum natans	■	
Schizothrix mexicana	■	
Schizothrix calcicola	■	
Spatoglossum schroederi		■
Sphacelaria rigidula	■	
Spirulina sp.		■
Spyridia sp.		■
Taenioma nanum	■	
Ulothrix flacca		■
Ulvella lens	■	
Wrangelia argus	■	
Wurdemannia miniata	■	

8.0 ATTACHMENT 1

LIST OF TAXONOMIC MACROALGAE COLLECTED DURING THE 1999 MONITORING CRUISE AT THE EAST AND WEST FLOWER GARDEN BANKS SEPTEMBER 15-20, 1999

Suzanne Fredericq, Naomi Phillips, Showe-Mei Lin, Brigitte Gavio and Fred Gurgel
Department of Biology, University of Louisiana at Lafayette, Lafayette LA 70504-2451

INTRODUCTION

Historically the Flower Garden Banks (FGB) have been categorized as biologically diverse communities comprised of seven biotic zones. The reefs are found on the 100 meter isobath on the Outer Continental Shelf. The tops of the reefs start at 15-20 m and end on the soft bottom at ~130 meters. The region from the reef top to 36 m has been categorized as the *Diplora-Montastraea-Porites* zone with minimal primary productivity (Rezak *et al.*, 1985). The *Madracis*-Leafy Algae zone starts at 28 m and ends at 46 m (Rezak *et al.*, 1985). These two zones are readily accessible to scuba divers using compressed air.

As to algal community composition, few studies have attempted to determine the benthic macroalgal diversity of these communities (Eiseman and Blair, 1982; Kapraun, 1974). Kapraun's (1974) work included seven species collected from the East Flower Garden Banks during fish and invertebrate studies at 20 m depth using SCUBA. Eiseman and Blair's (1982) study was based on a series of submersible dives to 68 m depth with 41 species collected. Thirty-three of these species represented new records or range extensions for the northwestern Gulf of Mexico.

The objective of this investigation is to thoroughly determine algal biodiversity on the FGB during the late summer period creating a comprehensive baseline for algal biodiversity.

METHODS

Researchers from the Biology Department, University of Louisiana at Lafayette, participated in two cruises to the East and West Flower Garden Banks in late summer 1999. Researchers collected all visible marine macroalgae on the reefs to 34 m (primarily the *Diplora-Montastraea-Porites* zone) during a total of eight dives. Collections from these two cruises were compiled to create a more comprehensive species list. Most of the algae were collected from the EFGB because weather conditions did not permit much collecting at the WFGB.

Algae were pre-sorted on board and partially processed during the cruise. Vouchers were preserved in silica-gel, and in 95% alcohol for molecular studies, and in diluted 5% formalin-seawater for morphological characterization. Small turf algae were preserved in 70% Karo on microscope slides. Specimens have been identified and archived in the LAF Herbarium of the University of Louisiana at Lafayette. Total DNA of corresponding archived silica-gel-fixed or alcohol-preserved material will be extracted and gene sequences generated for future molecular analyses.

RESULTS

A total of 44 taxa of the Division Chlorophyta (green), Division Phaeophyceae (brown), Division Rhodophyta (red) algae, and Cyanobacteria were identified (Table 1).

The species, *Martensia* hickersonii (new), and four unusual macroalgal records are newly reported for both the NW Gulf of Mexico and the FGB, i.e. *Boodleopsis pusilla, Crouania attenuata*, *Taenioma nanum*, and *Wrangelia argus*. Most other algae cited herein are also new records, but have been reported at Stetson Bank and Sonnier Banks in Fredericq *et al.* (In review). A new record for the FGB but not the northwestern Gulf of Mexico includes *Centroceras clavulatum*.

DISCUSSION

Preliminary observations at depths ranging from 17 to 30 m accurately follow Rezak *et al.* (1985) historical categorization, however, we found very little evidence of a "leafy algal zone." A coral-dominated community exists at these depths with benthic macroalgae comprising only a minor, yet important component of the overall community. Macroalgae appear to be in competition for space with corals, and consequently grow mostly in crevices and sandy interfaces. Solitary foliose algae were rare with most of the algal community composed of turf-like components. Though the turf algae are more diverse, the FGB share many common species with Sonnier and Stetson banks where benthic marine algae are major community components (Fredericq *et al.*, in review). Something not noted in earlier observations of these communities is an abundance of epiphytic blue-green algae observed invading coral heads.

ACKNOWLEDGMENTS

Participants

Brigitte Gavio
Ph.D. Graduate Student
e-mail: bxg0535@louisiana.edu
Tel: 337/482-5057
FAX: 337/482-5660
http://morayeel.usl.edu/USLSeaweedsLab/phycomirth.html

Fred Gurgel
Ph.D. Graduate Student
e-mail: fred@louisiana.edu

We would like to thank Dr. Quenton Dokken and Mr. Carl Beaver, Center for Coastal Studies, Texas A & M University-Corpus Christi, and Ms. Emma Hickerson and Mr. George Schmahl, from the Flower Garden National Marine Sanctuary, for their support and interest in this project. We also thank the crew of the M/V Spree for their assistance.

Table 1

Species checklist of the macroalgae collected from the East and West Flower Garden Banks during the 1999 long-term monitoring cruise

RECORD	COMMENTS
CYANOBACTERIA Fam. Oscillatoriaceae *Schizothrix calcicola* (C. Agardh) Gomont *Schizothrix mexicana* Gomont	
DIVISION CHLOROPHYTA ORDER ULVALES Fam. Ulvellaceae *Entocladia viridis* Reinke	epiphytic (entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)
Ulvella lens P. et H. Crouan	epiphytic (entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)
ORDER CAULERPALES Fam. Udoteaceae *Boodleopsis pusilla* (Collins) W.R. Taylor, A.B. Joly et Bernat.	NEW RECORD for NW Gulf of Mexico and FGB
Fam. Caulerpaceae *Caulerpa microphysa* (Weber van Bosse) Feldmann	(also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
ORDER CLADOPHORALES Fam. Cladophoraceae *Cladophora* sp.	(entangled in small turfs)
ORDER BRYOPSIDALES Fam. Bryopsidaceae *Bryopsis pennata* Lamx.	(entangled in small turfs) (also found at Stetson Bank; Fredericq *et al.*, in review)
DIVIVISION PHAEOPHYTA ORDER ECTOCARPALES Fam. Ectocarpaceae *Ectocarpus* sp.	epiphytic (entangled in small turfs)
ORDER SPHACELARIALES *Sphacelaria rigidula* Kütz	(entangled in small turfs) (also found at Stetson Bank; Fredericq *et al.*, in review)

Table 1

Species checklist of the macroalgae collected from the East and West Flower Garden Banks during the 1999 long-term monitoring cruise (continued)

RECORD	COMMENTS
ORDER DICTYOTALES Fam. Dictyotaceae *Dictyota cervicornis* Kützing	(also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Dictyota pulchella Hornig & Schnetter	(also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Dictyota pfaffii Schnetter (iridescent)	(also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
ORDER FUCALES Fam. Sargassaceae *Sargassum natans* (L.) Gaillon,	pelagic (also found pelagically at Stetson and Sonnier Banks; Phillips & Fredericq, in review)
DIVISION RHODOPHYTA ORDER ERYTHROPELTIDALES Fam. Erythrothrichiaceae *Erythrotrichia carnea* (Dillwyn) J. Agardh	epiphytic (entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Erythrocladia endophloea Howe	epiphytic (entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Sahlingia subintegra (Rosenv.) Kornmann	epiphytic (entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, 2000)
ORDER ACROCHAETIALES Fam. Acrochaetiaceae *Audouinella* sp.	Epiphytic (entangled in small turfs)
ORDER GELIDIALES Fam. Gelidiaceae *Gelidium pusillum* (Stackhouse) Le jolis	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
ORDER BONNEMAISONIALES Fam. Bonnemaisoniaceae "*Falkenbergia*" sporophytic stage of *Asparagopsis taxiformis* (Delile) Trevisan	(entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)

Table 1

Species checklist of the macroalgae collected from the East and West Flower Garden Banks during the 1999 long-term monitoring cruise (continued)

RECORD	COMMENTS
ORDER GIGARTINALES Fam. Hypneaceae *Hypnea volubilis* Searles in C.W. Schneider & Searles	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Fam. Wurdemanniaceae *Wurdemannia miniata* (Spreng.) Feldmann & Hamel	(entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)
ORDER CORALLINALES Fam. Corallinaceae *Jania capillacea* Harv.	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
crustose coralline#1,	identification in progress
crustose coralline #2	identification in progress
crustose coralline #3	identification in progress
Hydrolithon farinosum (Lamouroux) Penrose et Y.M. Chamberlain	epiphytic (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Pneophyllum lejolisii (Rosanoff) Chamberlain	epiphytic, forming thin, extended crusts (also found at Sonnier Bank; Fredericq *et al.*, in review)
ORDER CERAMIALES Fam. Ceramiaceae *Anotrichium tenue* (C. Ag.)	(also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Antithamnion antillanum Børgesen	epiphytic (entangled in small turfs) (also found at Stetson Bank; Fredericq *et al.*, in review)
Callithamnioniella tingitana (Schousboe ex Bornet) Feldmann-Mazoyer	(entangled in small turfs) (also found at Stetson Bank; Fredericq *et al.*, in review)
Ceramium flaccidum (Kütz.) Ardissone	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
**Centroceras clavulatum*(C. Ag.) J. Agardh	(most specimens without spines at the node) New Record FGB
***Crouania attenuata* (Bonnemaison) J. Agardh	New Record FGB

Table 1

Species checklist of the macroalgae collected from the East and West Flower Garden Banks during the 1999 long-term monitoring cruise (continued)

RECORD	COMMENTS
Griffithsia heteromorpha Kütz.	(entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)
***Wrangelia argus* (Mont.) Mont.	
Fam. Delesseriaceae *Hypoglossum rhizophorum* Ballantine et Wynne	(also found at Stetson Bank; Fredericq *et al.*, in review) (EFGB)
****Martensia hickersonii* Lin et Fredericq, sp. nov. (in preparation)	(EFGB)
***Taenioma nanum* (Kützing) Papenfuss	(entangled in small turfs) (WFGB)
Fam. Rhodomelaceae *Herposiphonia secunda f. tenella* (C. Ag.) M.J. Wynne	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Laurencia chondrioides BØrgesen	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Polysiphonia flaccidissima Hollenberg,	(entangled in small turfs) (also found at Stetson and Sonnier Banks; Fredericq *et al.*, in review)
Polysiphonia tepida Hollenberg	(entangled in small turfs) (also found at Sonnier Bank; Fredericq *et al.*, in review)

*NEW RECORD for the FGB
**NEW RECORD for the northwestern Gulf of Mexico and FGB
***NEW SPECIES honoring Ms. Emma Hickerson, Research Coordinator of the Flower Garden Banks National Marine Sanctuary, for her interest in our documentation of marine algal diversity.

LITERATURE CITED

Eiseman N.J. and S.M. Blair. 1982. New records and range extensions of deepwater algae from the East Flower Garden Bank, northwestern Gulf of Mexico. Contrib. Mar. Sci. 25:21-26.

Fredericq S., N. Phillips, and B. Gavio. *In review.* Preliminary observations on the macroalgae inhabiting the deep-water hard bank communties in the northwestern Gulf of Mexico. Gulf of Mex. Sci.

Kapraun D.F. 1974. Seasonal periodicity and spatial distribution of benthic marine algae in Louisiana. Contrib. Mar. Sci. 18:139-167.

Phillips N. and S. Fredericq. *In review.* Biogeographic and phylogenetic investigations of the pan-tropical genus *Sargassum* (Fucales, Phaeophyceae) with respect to Gulf of Mexico species. Gulf of Mex. Sci.

Rezak R., T.J. Bright, and D.M. McGrail. 1985. Reefs and banks of the northwestern Gulf of Mexico: their geography, biogeography, and physical dynamics. John Wiley & Sons, New York, NY, 259p.

9.0 ATTACHMENT 2

ALGAL COMMUNITY STRUCTURE OF THE EAST AND WEST FLOWER GARDEN BANKS, NORTHWESTERN GULF OF MEXICO

Roy L. Lehman and Erin M. Albert
Texas A&M University-Corpus Christi, Center for Coastal Studies
6300 Ocean Drive, Corpus Christi, TX 78412 USA

PROJECT SUMMARY

The Flower Garden Banks (FGB) are located approximately 200 km south of the coast between Texas and Louisiana, on the Outer Continental Shelf, at a depth of approximately 100-140 meters. Sampling was conducted at an average depth of 21 meters. The algal community has not been comprehensively evaluated and only checklists of a few dominant macroalgal species have been reported. The current study utilizes both destructive and non-destructive techniques to characterize the algal community structure. Harvest and photogrammetric samples were collected during two extended trips to the FGB in October 1998 and March 1999. Forty 0.25 m^2 quadrats of algal standing stock were randomly collected, curated, and stored for further evaluation. Photogrammetric samples (161) were obtained using an underwater camera. Each transparency represented a 0.25 m^2 quadrat that was evaluated by projection onto an actual sized grid of 25 random points. A total of 4,025 points of information were identified and used to calculate percent composition and cover. Harvest sampling was used to characterize the algal composition of the 'red algal mat' which was the dominant feature comprising 38.4 % of the photogrammetric samples. Harvest samples were also used to determine species richness, abundance (composition), and biomass. A total of 44 species were identified from the samples. The 'red algal mat' was primarily composed of members of the Order Ceraminales and was represented by *Centroceras clavulatum, Ceramium, Hypoglossum, Polysiphonia*, and *Anotrichium.*

METHODS

Ecological field methods followed those described by Littler *et al.* (1989) and Brower *et al.* (1989). A herbarium voucher collection of benthic macroalgae was completed. Voucher specimens of macroalgal samples were also preserved in 2% gluteraldehyde and microscopic material was preserved on microscope slides sealed with Flo-Tex.

Photogrammetric and harvest samples were collected during two extended trips to the FGB in October 1998 and March 1999. Random quadrats were photographed using a Nikonos V equipped with a 28 mm lens, close-up kit, and Nikonos SB105 strobe. Each transparency represented a 0.25 m^2 quadrat that was evaluated by projecting onto a grid containing 25 random points (modified point quadrat). They were evaluated based on bare substrate, blue-green algae, green algal mat, red algal mat, coralline algae, or live coral coverage. Values are expressed as the number of "hits" for each species/feature divided by the total number possible. This number varied with each bank and season measured. A total

of 4,025 points were identified and used to calculate percent composition, species richness, dominance, diversity, and cover. Samples were used to generate precisely detailed and highly reproducible quantitative information, including cover, density, frequency, and diversity (Littler *et al.*, 1989). Diversity and other indices were calculated from the relative abundance of algae and total species observations. These values were determined for each bank and sampling season using the Shannon Index (H', natural log; Shannon, 1948), Richness, Evenness (J'; Pielou, 1966), and Simpson's Index of Dominance (Simpson, 1949). Relative Community Similarity as determined by species/features abundances at both banks from each season were compared using Morisita's Index of Community Similarity and total percent similarity (Morisita, 1959). Morista's Index is based on Simpson's Index of Dominance and determines the probability that two randomly selected individuals will be the same species. The range of results are 0 (no similarity) to approximately 1.0 (identical). It has the desirable characteristic of being affected by neither the size of the sample nor the diversity.

Macroalgal mat samples were harvested from both banks using paint scrapers and placed into nylon net bags. A total of forty 0.25 m^2 quadrats of algal standing stock were randomly collected, curated, and stored for further evaluation. This sampling was used to characterize algal composition of the 'red algal mat'. For quantification of microalgae, especially when found in high abundance (e.g. turfs or mats of filamentous algae), the photogrammetric method is straightforward if voucher (destructive) sampling has been completed, processed, species identified, and compared (Littler *et al.*, 1989).

RESULTS

Harvest and photogrammetric samples collected from the FGB were evaluated at the Center for Coastal Studies, Texas A&M University-Corpus Christi. A systematic list of marine algae from the EFGB and WFGB has been compiled (Appendix I and II). The systematic organization conforms to the taxonomic arrangement and names incorporated primarily by Wynne (1998). Schneider and Searles (1991) and Taylor (1960) were referenced when species were encountered that were uncommon to the region.

PHOTOGRAMMETRIC SAMPLING

The feature 'red algal mat' had the greatest coverage comprising 38.4% of all photogrammetric samples (Figures 1 and 2), followed by bare substrate (14.6%), coralline algae (9%), green algal mat (8.1%) and blue-green algae (4%). Total species richness was 25, with the EFGB having the highest number (19; in 1998) and lowest number (14; in 1999) (Table 1).

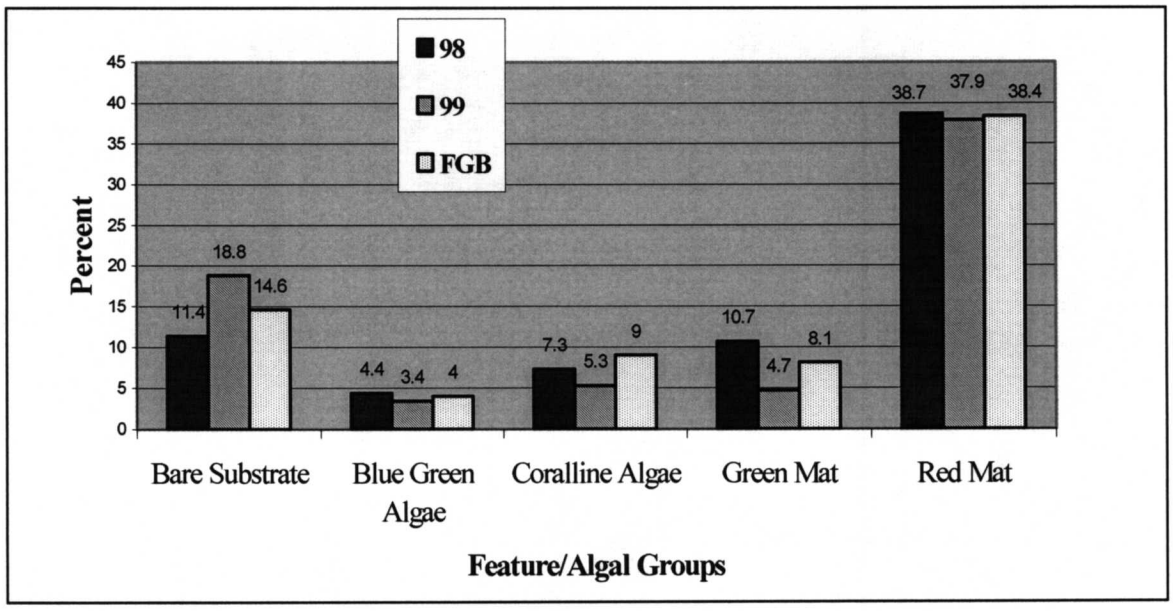


Figure 1. Mean percent algal coverage of photogrammetric samples from the Flower Garden Banks. Yearly totals and overall total at Flower Garden Banks are represented.

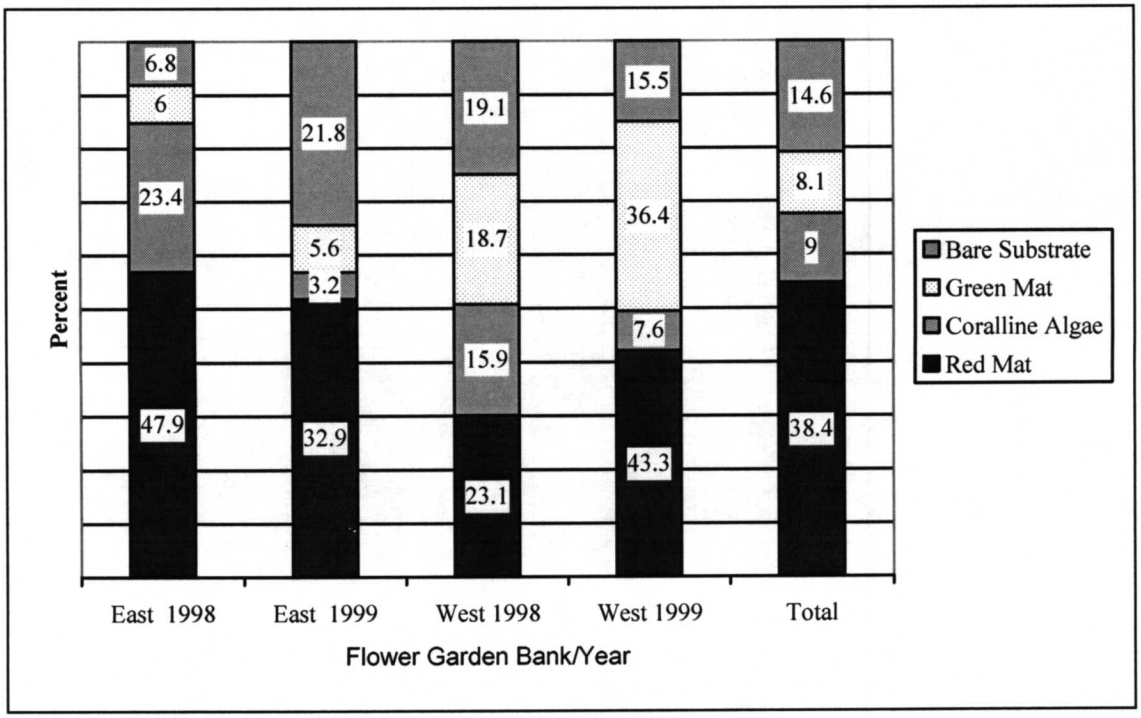


Figure 2. A comparison of results from photogrammetric sampling of the Flower Garden Banks, 1998-1999.

Table 1

Species richness, diversity, (dominance and evenness) between the East and West Flower Gardens Banks, 1998-1999

Bank/ Year	Species Richness	Shannon's Diversity	Shannon's Evenness	Simpson's Dominance	Simpson's Evenness
WFGB 1998	15	2.10	0.77	0.15	0.93
EFGB 1998	19	1.90	0.65	0.26	0.77
WFGB 1999	16	1.94	0.70	0.23	0.82
EFGB 1999	14	2.06	0.78	0.18	0.88
Total	25	2.20	0.68	0.19	0.84

Diversity is usually considered for a certain subcommunity at a time (as in this study) rather than an entire ecological community. Greater differences among organism sizes make diversity measures, based on cover, difficult to interpret in large-scale studies.

Shannon's Diversity Indices and Evenness indicates little difference in diversity between year sampled and/or EFGB and WFGB (Table 1). In October 1998, the WFGB had the greatest diversity (H' = 2.10) but was lower than the results of all sampling combined (H' = 2.20). It is evident that the level of diversity is reduced due to the depth of water in which the FGB are located. The preponderance of algae were from the Division Rhodophyta, which are capable of photosynthesis at greater depths. This supports the opinion that water depth is a limiting factor in diversity of the FGB.

Morisita's Index of Community Similarity indicated that the EFGB and WFGB in 1999 and a total of EFGB and WFGB from 1998 and 1999 were almost identical (0.94) (Table 2). Percent (Proportional) Similarity supported these results.

The association of corals with algal mat community was investigated to determine if particular coral species had a partiality with the red algal mat. Photogrammetric samples were evaluated and corals identified to species. Within all quadrats, each time a coral species was encountered, the presence or absence of the red algal mat was assessed. A proportion of coral species to total red algal mat was computed. *Montastraea cavernosa* was most often associated with the red algal mat (54.2%) with *Diploria strigosa* following at 27.1 percent. Additional important corals that were also associated with the red algal mat were *Diplora strigosa* (11.9%) and *Montastraea annularis* (10.1%).

Table 2

Community similarity (percent similarity and Morisita's Index) at the East and West Flower Garden Banks, 1998-1999

Banks/Years	Percent Similarity	Morisita's Index
EFGB 98 vs. WFGB 98	53.01	0.72
EFGB 99 vs. WFGB 99	72.26	0.94
EFGB 98 vs. EFGB 99	61.54	0.85
WFGB 98 vs. WFGB 99	58.94	0.79
EFGB vs. WFGB (Total)	73.59	0.94

HARVEST SAMPLING

Harvest samples were evaluated to characterize the composition of the prevalent 'algal mat' that is found at the coral/algal interface. A 'red algal mat' was the dominant algal and non-algal coverage comprising 38.4 % of all photogrammetric samples. The mat was composed primarily of members of the Order Ceramiales comprising 37.6 % of coverage and was represented by the genera *Centroceras*, *Ceramium*, and *Polysiphonia* (Table 2.2.0.1 and Figure 2.2.0.1).

The Order Ceramiales was also the dominant group at the two banks; 38.3% at the EFGB, and 36.9% at the WFGB (Table 3and Figure 3). Table 3 separates each order according to frequency at which they were found at each bank. The EFGB and WFGB were represented by 13 and 14 algal orders, respectively.

A total of 44 species were identified from harvested samples collected from the FGB (Table 4). *Bryopsis pennata* and *Derbesia*, both in the Order Caulerpales, composed 12.0% of the 'green algal mat' on the EFGB and 11.0% on the WFGB. The rhodophyte, *Jania adherens*, was the most common coralline alga found at both banks with coverage of 6.1% at the WFGB and 7.1% at the EFGB.

Blue-green algae (Cyanobacteria; primarily Oscillatoriales) were common in samples, representing 7.5% at the EFG, and 11.0% at the WFG. Oscillatoriales was represented by only a few species with *Lyngbya* the most often encountered at both banks. Table 3 shows the algal species and percent composition of algal coverage in all samples collected. There was a total of 44 species, representing 15 orders identified from the harvested samples (Appendices a and b).

Table 3

Algal orders with percentage represented at the East Flower Garden Banks and West Flower Garden Banks

ORDER	EFGB (%)	WFGB (%)
Ulotrichales	2.6	3.4
Ceramiales	38.3	37.3
Rhodymeniales	3.0	3.4
Oscillatoriales	7.5	13.3
Gigartinales	0.0	2.7
Gelidiales	0.0	1.1
Unknown	3.8	6.1
Dasycladales	1.5	0.0
Ulvales	1.5	2.7
Caulerpales	12.0	11.0
Cladophorales	5.6	3.4
Dictyotales	10.2	6.1
Compsopgonales	1.9	0.0
Bonnemaisoniales	4.1	2.7
Corallinales	7.9	6.5
Bacillariales	0.0	0.4
Total	**100.0**	**100.0**

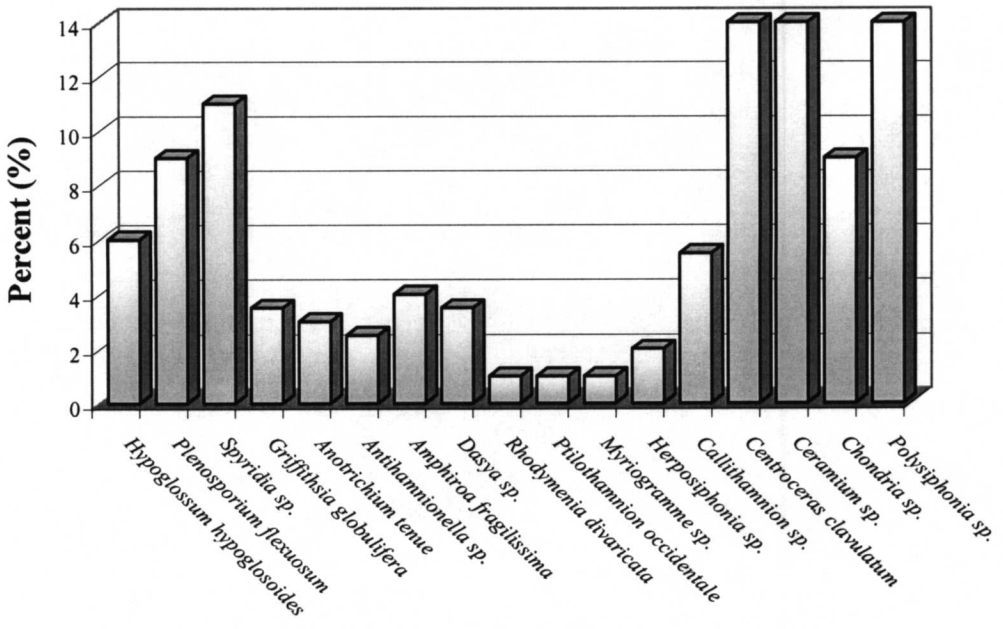


Figure 3. Algae species representing the Order Ceremiales.

Table 4

Percentage of each algal species from the East and West Flower Garden Banks (1998-1999) contributing to total coverage

SPECIES	EFGB (%)	WFGB (%)
Asparagopsis taxiformis	4.1	2.7
Hypoglossum hypoglosoides	1.9	2.7
Plenosporium flexuosum	3.0	3.8
Spyridia sp.	3.4	4.9
Griffithsia globulifera	0.0	2.7
Anotrichium tenue	0.0	2.3
Antithamnionella sp.	1.5	0.4
Erythrocladia sp.	0.4	0.0
Erythrotrichia sp.	1.5	0.0
Spirulina sp.	0.0	0.8
Bryopsis pennata	6.0	6.5
Dictyota sp.	3.8	3.0
Lobophora variegata	4.5	1.5
Spatoglossum schroederi	1.9	0.4
Ulothrix flacca	2.6	3.4
Polyphysa polyphysoides	1.5	0.0
Enterocladia virdis	0.8	0.0
Enteromorpha sp.	0.8	2.7
Chaetomorpha sp.	0.8	0.0
Cladophora sp.	4.9	3.4
Amphiroa fragilissima	3.4	0.0
Derbesia sp.	6.0	3.4
Corallina sp.	0.4	0.0
Jania adherens	7.1	6.1
Dasya sp.	1.1	1.5
Botryocladia occidentalis	1.1	1.1
Chrysymenia enteromorpha	1.5	2.3
Rhodymenia divaricata	0.8	0.0
Lyngbya sp.	7.5	5.7
Oscillatoria sp.	0.0	6.8
Caulerpa sp.	0.0	1.1
Dictyopteris membranaceae	0.0	1.1
Ptilothamnion occidentale	0.0	0.4
Myriogramme sp.	0.0	0.4
Herposiphonia sp.	0.0	1.5
Dudresnaya sp.	0.0	1.9
Hypnea sp.	0.0	0.8
Gelidium sp.	0.0	1.1
Diatom mat	0.0	0.4
Callithamnion sp.	1.5	2.3
Centroceras clavulatum	7.5	2.7
Ceramium sp.	6.4	3.8
Chondria sp.	3.8	2.7
Polysiphonia sp.	4.9	5.3
Unknown	3.8	6.5

DISCUSSION

It is difficult to determine cause or effect relationships of algal populations on the ecological health of the Flower Garden Banks or a particular coral species with the limited opportunity for monthly sampling. It is necessary at each and every opportunity to make grab samples of algal material, especially when it is at an interface with live coral species. The algal material should be photographed *in situ* and samples collected, preserved in 2% gluteralderhyde, and returned to the laboratory for identification and evaluation. Coral species, depth, temperature, and other environmental factors at the site should be recorded.

The Order Ceramiales is an annual algal group that dominates as opportunists at sites with irregularly fluctuating conditions (i.e., temperature) (Luning, 1990). These opportunists are quick growing algae that are the first multicellular organism to appear on bare, nonliving, or damaged substrates. These annual algae may be regarded as plants that exhibit variable biomass. The biomass may be high one month and low in the next month, especially after herbivorous attacks or changes in environmental conditions. Measurements of respiration rates in members of the Order Ceramiales indicate that a doubling effect results with each 10°C increase in temperature (Kanwisher 1966). Guimaraens and Coutinho (1996) evaluated the effect of an upwelling region near Rio de Janeiro, Brazil on the spatial and temporal variation of benthic marine algae. The survey of benthic algae recorded groups including the Ceramiales, with temperature affinities occurring in sites directly influenced by upwelling waters. These data show water temperature affects distribution and abundance of benthic marine algae enabling warm temperate species (18-20°C) to survive under otherwise tropical conditions. A seven-year mean of water temperatures recorded at a depth of 24 m at the WFGB resulted in a range of 9-11°C. Mean low temperatures at the WFGB during February were 18-20°C and highs were in July-August (29-30°C) (Lugo-Fernandez 1998). This indicates that the FGB are in a temperature regime that provides optimum conditions for growth of the red algal mat composed primarily of members of the Order Ceramiales. The increased growth of these algae may be a larger environmental problem, possibly global, that would be practically impossible to mediate. The best action is to monitor changes over time to determine the magnitude of the influence or amount of damage to the reef. Little is known about the community dynamics of benthic marine algae and their effect on the character of biotic reefs. Information on the role of inter- and intraspecific competition, recruitment, natality, and mortality phenomena is lacking and it is difficult to make definitive statements concerning the role of algae and their effect on other organisms (i.e., corals).

LITERATURE CITED

Brower, J.E., J. Zar and C.N. vonEnde. 1989. Field and laboratory methods for general ecology. WCB/McGraw-Hill, St. Louis, Missouri. 273 p.

Guimaraens, Mariana and Ricardo Coutinho. 1996. Spatial and temporal variation of benthic marine algae at the Cabo Frio upwelling region, Rio de Janeiro, Brazil. Aquat. Bot. 52:283-299.

Kanwisher, J.W. 1966. Photosynthesis and respiration in some seaweeds. *in*: Some Contemporary Studies in Marine Science (Barnes, R., ed.), Academic Press, New York, NY. 407-420.

Littler D.S., M.M. Littler, K.E. Bucher, and J.N. Norris. 1989. Marine plants of the Caribbean: a field guide from Florida to Brazil. Smithsonian Institution Press, Washington, D.C. 249 p.

Lugo-Fernandez, Alexis. 1998. Ecological implications of hydrogeography and circulation to the Flower Gardens and Stetson Banks, northwest Gulf of Mexico. Gulf of Mex. Sci. 2:144-160.

Luning, Klaus. 1990. Seaweeds. Their environment, biogeography, and ecophysiology. John Wiley and Sons, Inc., New York, NY. 527 p.

Morisita, M. 1959. Measuring of interspecific association and similarity between communities. Mem. Fac. Sci. Kyushu Univ., Ser. E (Biol.) 3:65-80.

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. J. Theoret. Biol. 13:131-144.

Schneider C.W. and R.B. Searles. 1991. Seaweeds of the southeast United States, Cape Hatteras to Cape Canaveral. Duke University Press, Durham, NC. 553 p.

Shannon, C.E. 1948. A mathematical theory of communication. Bell Sys. Tech. J. 27:379-423, 623-656.

Simpson, E.H. 1949. Measurement of diversity. Nature 163:688.

Taylor W.R. 1960. Marine algae of the eastern tropical and subtropical coasts of the Americas. University of Michigan Press, Ann Arbor, Missouri. 870 p.

Wynne, M.J. 1998. A checklist of benthic marine algae of the tropical and subtropical western Atlantic: first revision. Gebruder Borntraeger, Berlin, Germany. 155 p.

Appendix a. Taxonomic list of algae collected from EFGB, northwestern Gulf of Mexico, October 1999.

Division CHLOROPHYTA

Order Ulotrichales
Family Ulotrichaceae
Ulothrix flacca (Dilwyn) Thuret

Order Dasycladales
Family Polyphysaceae
Polyphysa polyphysoides (P. and H. Crouan in Maze and Schramm) Schnetter

Order Ulvales
Family Ulvellaceae
Entocladaia virdis Reinke

Family Ulvaceae
Enteromorpha sp.

Order Caulerpales
Family Bryopsidaceae
Bryopsis pennata Lamouroux
Derbesia sp.

Order Cladophorales
Family Cladophoraceae
Chaetomorpha sp.
Cladophora sp.

Division PHAEOPHYTA

Order Dictyotales
Family Dictyotaceae
Dictyota dichotoma (Hudson) Lamouroux
Dictyota sp. (2 species)
Lobophora variegata (Lamouroux) Womersley
Spatoglossum schroederi (C. Agardh) Kützing

Appendix a. Taxonomic list of algae collected from EFGB, northwestern Gulf of Mexico, October 1999 (continued).

Division RHODOPHYTA

Order Compsopogonales
Family Erythropeltidaceae
Erythrocladia sp.
Erythrotrichia sp.

Order Bonnemaisoniales
Family Bonnemaisoniaceae
Asparagopsis taxiformis (Delile) Trevisan

Order Corallinales
Family Corallinaceae
Amphiroa fragilissima (Linnaeus) Lamouroux
Corrallina sp. (3 species)
Jania adhaerens Lamouroux

Order Ceramiales
Family Ceramiaceae
Anotrichium tenue (C. Agardh) Nägeli
Antithamnion sp.
Antithamnionella sp.
Callithamniella sp.
Callithamnion sp.
Centroceras clavulatum (C. Agardh) Montagne
Ceramium sp. (2 species)
Plenosporium flexuosum (C. Agardh) De Toni
Rhododictyon bermudense W. R. Taylor
Spyridia sp. (2 species)
Family Delesseriaceae
Hypoglossum hypoglossoides (Stackhouse) Collins et Hervey

Family Dasyaceae
Dasya sp.

Family Rhodomelaceae
Chondria sp.
Polysiphonia sp. (3 species)

Order Rhodymeniales
Family Rhodymeniaceae
Botryocladia occidentalis (Børgesen) Kylin
Chrysymenia enteromorpha Harvey
Rhodymenia divaricata Dawson

Appendix a. Taxonomic list of algae collected from EFGB, northwestern Gulf of Mexico, October 1999 (continued).

Division CYANOPHYTA

Order Oscillatoriales

Family Oscillatoriaceae

Lyngbya sp.
Oscillatoria sp.
Schizothrix calcicola (C. Agardh) Gomont
Unknown (3 species)

Appendix b. Taxonomic list of algae collected from WFGB, northwestern Gulf of Mexico, October 1999.

Division CHLOROPHYTA

Order Ulotrichales
Family Ulotrichaceae
Ulothrix flacca (Dilwyn) Thuret

Order Ulvales
Family Ulvaceae
Enteromorpha sp.

Order Caulerpales
Family Bryopsidaceae
Bryopsis pennata Lamouroux
Derbesia sp.

Family Caulerpaceae
Caulerpa sp.

Order Cladophorales
Family Cladophoraceae
Cladophora sp.

Family Anadyomenaceae
Anadyomene stellata (Wulfen) C. Agardh (collected during deep dive)

Division PHAEOPHYTA

Order Dictyotales
Family Dictyotaceae
Dictyota dichotoma (Hudson) Lamouroux
Dictyota sp. (2 species)
Dictyopteris membranacea (Stackhouse) Batters
Lobophora variegata (Lamouroux) Womersley
Spatoglossum schroederi (C. Agardh) Kützing

Division RHODOPHYTA

Order Bonnemaisoniales
Family Bonnemaisoniaceae
Asparagopsis taxiformis (Delile) Trevisan

Order Corallinales
Family Corallinaceae
Corrallina sp. (3 species)
Jania adhaerens Lamouroux

Appendix b. Taxonomic list of algae collected from WFGB, northwestern Gulf of Mexico, October 1999 (continued).

Order Ceramiales

Family Ceramiaceae

Anotrichium tenue (C. Agardh) Nägeli
Antithamnionella sp.
Callithamniella sp.
Callithamnion sp.
Centroceras clavulatum (C. Agardh) Montagne
Ceramium sp. (2 species)
Griffithsia globulifera Kützing
Plenosporium flexuosum (C. Agardh) De Toni
Ptilothamnion occidentale Searles
Spyridia sp. (2 species)

Family Delesseriaceae

Hypoglossum hypoglossoides (Stackhouse) Collins et Hervey
Hypoglossum sp.
Myriogramme sp.

Family Dasyaceae

Dasya sp.

Family Rhodomelaceae

Chondria sp.
Herposiphonia tenella (C. Agardh) Nägeli
Herposiphonia sp.
Polysiphonia sp. (3 species)

Order Rhodymeniales

Family Rhodymeniaceae

Botryocladia occidentalis (Børgesen) Kylin
Chrysymenia enteromorpha Harvey
Chrysymenia sp.

Order Gigartinales

Family Dumontiaceae

Dudresnaya sp.

Family Hypneaceae

Hypnea sp.

Order Gelidiales

Family Belidiaceae

Gelidium sp.

Appendix b. Taxonomic list of algae collected from WFGB, northwestern Gulf of Mexico, October 1999 (continued).

Division CYANOPHYTA

Order Oscillatoriales

Family Oscillatoriaceae

Lyngbya sp.
Oscillatoria sp.
Schizothrix calcicola (C. Agardh) Gomont
Spirulina sp.
Unknown (3 species)

10.0 ATTACHMENT 3

FOOD WEB STRUCTURE AND MACROALGAL PRIMARY PRODUCTION AT THE EAST AND WEST FLOWER GARDEN BANKS

Ken Dunton and Harlin Miller
The University of Texas Marine Science Institute
750 Channelview Drive
Port Aransas, TX 78373-5015

PROJECT SUMMARY

A conceptual model describing both abiotic controls on primary production and carbon flow from producers to consumers is being developed for the Flower Garden Banks (FGB) community. The dominant benthic producers in the community are hermatypic corals, macroalgae, and cyanobacteria, and each is isotopically distinct. Macroalgal carbon production exceeds that of cyanobacteria, and there is little evidence that cyanobacteria are directly consumed. Nevertheless, the cyanobacterial mats, that sporadically cover coral heads, appear to be critical to the nutrient dynamics of the system. $\delta^{15}N$ evidence suggests that benthic cyanobacteria likely fix nitrogen, which ultimately leaches into the water column and is assimilated by eukaryotic algae. Since there is ample light for photosynthesis, even at 20 m depth, macroalgal production is likely controlled by nutrient availability. Further, there are indications that nitrogen limits the system to a greater degree than phosphorus.

The stable nitrogen isotopic signatures ($\delta^{15}N$) of benthic algae and fauna collected at the FGB and Stetson Bank reef systems, located only 60 km apart in the northern Gulf of Mexico, suggest that the nitrogen sources for these two reef habitats are distinctly different. Algae from the FGB, for example, have $\delta^{15}N$ values averaging 2‰, compared to nearly 5‰ for the same species from Stetson Bank. Furthermore, values for the FGB match the $\delta^{15}N$ signatures of benthic algae from the outer shelf reef of Australia's Great Barrier Reef, whereas the values for Stetson Bank are indistinguishable from aquatic plants and algae of Texas estuarine systems. These preliminary data suggest that the primary nitrogen source at the FGB is autogenously produced by nitrogen-fixing cyanobacteria (e.g. benthic blue-green algal mats and/or pelagic *Trichodesmium*). In contrast, the primary nitrogen source at Stetson Bank appears to be allochthonous, perhaps from coastal riverine inputs.

INTRODUCTION

Over the last few decades algal proliferation as a result of coastal nutrient-loading has affected coral reefs worldwide. At nearly 200 km off the Texas coast, the FGB is a unique coral community seemingly removed from coastal eutrophication. However, the oceanic reef subsists down-plume of the Mississippi River that discharges large amounts of fertilizer and human wastewater into the Gulf of Mexico (Turner and Rabalais, 1991; Rabalais *et al.*, 1998). Preliminary investigations into the bottom-up (abiotic) controls of primary production and into basic food web structure at the FGB were begun on our first 11-16 October 1998 cruise and continued thereafter.

The major objectives of the initial cruises were to identify dominant and potentially nuisance macroalgal species, to conduct two *in situ* primary production experiments, and to determine general trophic structure of the reef community.

METHODS

The first experiment, a diel light incubation, compared carbon uptake rates (using ^{13}C bicarbonate) of two *Dictyota* species and a cyanobacterial mat. The second field experiment investigated nutrient limitation on macroalgal production in the ecosystem. Lastly, natural abundance of carbon and nitrogen stable isotopes were compared in tissue samples of resident primary producers, i.e., corals (*Diploria, Montastraea, and Scolymia*), macroalgae (Rhodophytes, Phaeophytes, Chlorophytes, Cyanophytes) and particulate organic matter (POM) in the water column. From ^{13}C and ^{15}N signatures of the primary producers, hypotheses about basic trophic interactions of the coral reef community can be formulated. The ultimate goal of the project will be to determine whether anthropogenically derived nutrients can potentially influence the structure of the FGB coral reef community.

RESULTS

OBSERVATIONS OF MACROALGAE AT THE FLOWER GARDENS CORAL REEF

Determination of coral reef susceptibility to opportunistic algae begins with a general understanding of the present macroalgal community. Two species of the brown alga, *Dictyota*, were conspicuous at both banks. The larger *Dictyota* species was tentatively identified as *D. dichotoma*, and the smaller species as *D. divaricata*. Lehman and Albert address macroalgae systematics in further detail (See Appendix 2). An interesting colonial cyanobacteria (unidentified) was observed intermittently covering coral polyps with a purplish-red, gelatinous mat (slippery to touch). These three algal species were chosen for comparative primary production experiments.

DIEL PRIMARY PRODUCTION OF SEVERAL IMPORTANT MACROALGAE

Diel primary production was determined *in situ* for two species of *Dictyota* and a cyanobacterial mat at East Flower Garden Bank (EFGB). Algae were incubated in 500 ml seawater spiked with $H^{13}CO_3$ for about 7 h. Throughout incubation, algae received a total light dose of 9.15 moles photon/m^2 with a maximum of 529 μmoles photons/m^2 s at 1315 h. (Figure 1). Carbon fixation by the two brown seaweeds was exceeded two times that of the cyanobacterial mat (Figure 2). The greater production rate of eukaryotic macroalgae suggests that they may contribute substantially more carbon to higher trophic levels in the Flower Garden community than cyanobacteria.

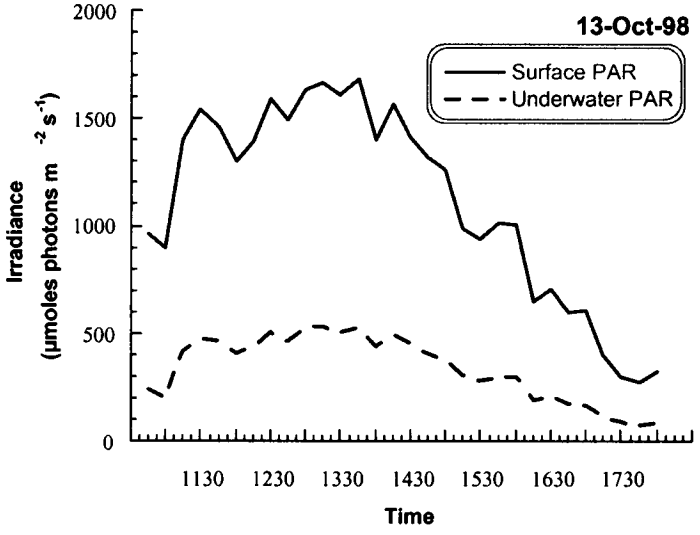


Figure 1. Incident surface and underwater PAR available for photosynthesis in the 13 October 1998 primary production experiment (East Bank). Production experiments and concurrent underwater light measurements were conducted on the East Flower Garden seafloor (20 m). Ambient underwater light levels represented 32% of surface intensity at the daily solar maximum.

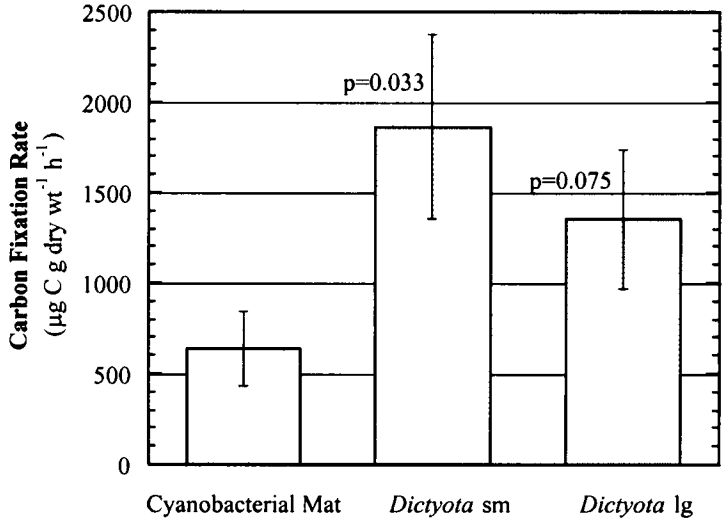


Figure 2. Carbon production comparison for three macroalgae over a diel *in situ* incubation at East Flower Garden Bank. Both *Dictyota* species assimilated more carbon over the incubation period than the cyanobacterial mat (assuming significance $p < 0.1$). T-test P values between both *Dictyota* species and the cyanobacterial mat are shown (mean ± S.E., n=4). *Dictyota* sm = *D. divaricata Dictyota* lg = *D. dichotoma*

BOTTOM-UP CONTROL OF ALGAL PRIMARY PRODUCTION

LaPointe's (1987) hypothesis that phase shifts from corals to macroalgae, an indication of coral reef demise, are controlled by bottom-up nutrient enrichment of the ecosystem is dependent on whether primary producers are nutrient or light limited. Light and nutrient concentrations were measured just above the reef at both banks. Typical of oligotrophic environments, ammonium concentrations were below analytical detection limits and phosphate concentrations were extremely low at both sites (Table 1). DIN (nitrate + nitrite) levels were slightly greater (0.1–0.2 μM) than oceanic blue water implying either nitrate advection or nitrate production within the reef community. Nitrate values agree with values reported from nearshore waters of southwestern Florida Bay (Delgado and Lapointe, 1994).

Table 1

Nutrient concentrations 3 m above the East and West Flower Garden Banks in October 1998. Values are mean ± standard error (n=3)

Station	**Ammonium (μM)**	**Ortho-phosphate (μM)**	**Silicate (μM)**	**Nitrate+Nitrite (μM)**
EFGB	0	0.08 ±0.03	3.47 ±0.37	0.46 ±0.13
WFGB	0	0.05 ±0.00	2.22 ±0.64	0.22 ±0.05

Productivity (net photosynthesis) was compared for algae enriched in six different nutrient regimes. *Dictyota* thalli were incubated overnight in seawater enriched with NH_4^+, NO_3^-, PO_4^{-3}, NO_3^- + PO_4^{-3}, and a natural seawater control. Productivity was measured as ^{13}C uptake at *in situ* incident light and temperature. Underwater PAR was measured adjacent to the underwater experiment (Figure 3). Carbon fixation was greater at all nutrient enrichments (except phosphate only treatment) compared to the control (Figure 4). In particular, algal productivity increased by 21–22% in response to ammonium and to nitrate plus phosphate additions. Although ammonium concentrations were undetectable in the environment, these algae must possess efficient mechanisms of uptake and assimilation. Since light levels were similar in all treatments, results substantiate that nutrient availability regulates algal productivity at the FGB. If light treatments are standardized, Flower Garden productivity values are congruent with *Dictyota divaricata* carbon uptake reported from coral reefs in Belize (Lapointe *et al.*, 1987).

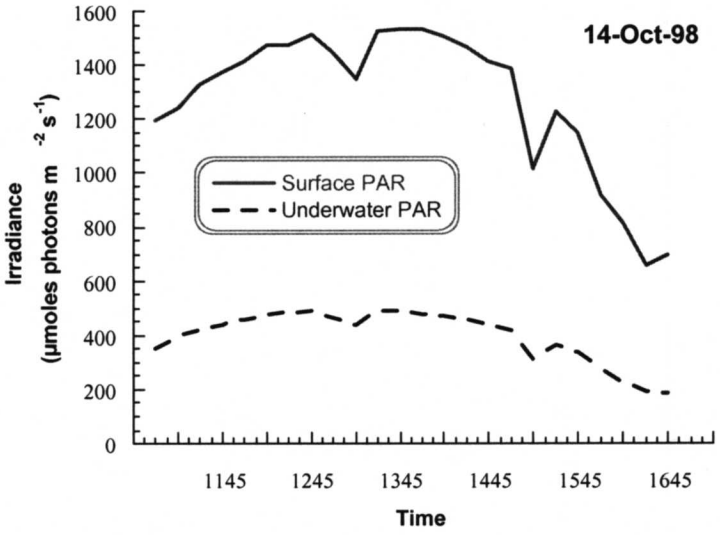


Figure 3. Incident surface and underwater PAR available for photosynthesis in the 14 October 1998 nutrient enrichment experiment (West Bank). Production experiments and concurrent underwater light measurements were conducted on the West Flower Garden seafloor (24 m). Ambient underwater light levels represented 32% of surface intensity at daily solar maximum.

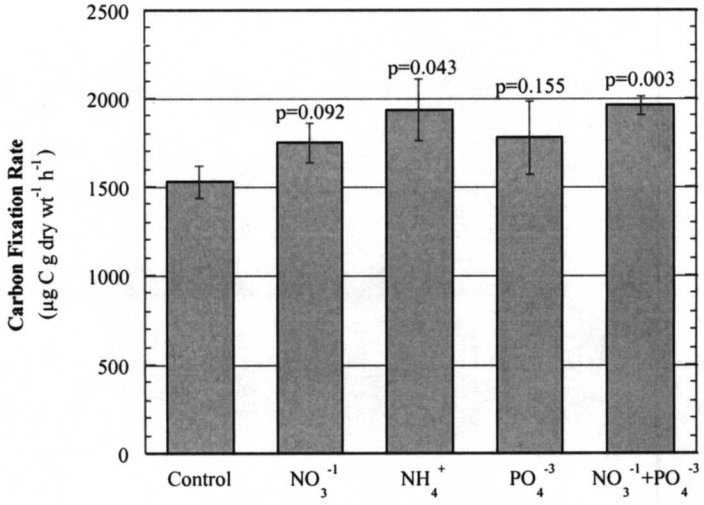


Figure 4. *Dictyota* diel carbon production after pretreatment with various nutrient enriched seawater. Algae were incubated under ambient *in situ* light regimes on the West Flower Garden Bank. Nutrient enrichment enhanced carbon uptake compared to the untreated control in all nutrient treatments except addition of phosphate (assuming significance of $p < 0.1$). T-test P values are shown comparing each treatment to control (mean ± S.E., n=4).

CORAL REEF FOOD WEB STRUCTURE

Distinctive ^{13}C and ^{15}N isotopic signatures of the primary producers of the FGB community permit the evaluation of trophic relationships. The purpose of this investigation is to construct a food web based on the stable nitrogen and carbon isotopic composition of producers and consumers. Tissue stable carbon and nitrogen isotopic values of organisms collected from the FGB are reported in Table 2. The assumptions used in interpretation of $\delta^{13}C$ and $\delta^{15}N$ data in the evaluation of trophic interrelationships (DeNiro and Epstein, 1981; Fry *et al.*, 1984; Owens, 1987) are: (1) algae fractionate nitrogen by about 1‰ during assimilation, (2) as respiration discriminates against ^{13}C, carbon enrichments also increase by about 1‰ per trophic level, and (3) light nitrogen (^{14}N) is preferentially excreted such that $\delta^{15}N$ values increase 3 to 5‰ per trophic level. Based on this knowledge and a preliminary analysis of the data, we can conclude the following:

The three primary producers of the community, i.e., corals, POM, and macroalgae (including Cyanobacteria), are well separated by $\delta^{13}C$ values resulting from differential fractionation by RUBISCO during carbon fixation.

- Cyanobacteria are unique to this ecosystem based on a elevated $\delta^{13}C$ signature (-10‰) and low $\delta^{15}N$ values, near 0‰ (= atmospheric N_2). Respectively, these values imply (1) that cyanobacterial production is not preferentially consumed by herbivores, and (2) that these organisms may by an important source of nitrogen to the ecosystem via nitrogen fixation (Shearer and Kohl, 1988).

- $\delta^{13}C$ values of macroalgae (Chlorophyta, Phaeophyta, and Rhodophyta) range 4‰, but $\delta^{15}N$ values vary narrowly between 1 and 2‰. The ^{15}N depleted algae are expected if nitrogen fixing cyanobacteria release a majority of the available nitrogen into the community.

- POM nitrogen signatures are more ^{15}N enriched than macroalgae, probably a result of both phytoplankton and zooplankton in the filtered sample. Similarly, corals are more ^{15}N enriched (3‰) heavier than macroalgae – congruent with partial heterotrophic consumption by coral polyps.

- Suspension feeders (i.e., sponges, christmas tree worms) and filter feeders (i.e., oysters) are approximately 2‰ ($\delta^{13}C$) and 2–3‰ ($\delta^{15}N$) greater than their likely POM food source. Benthic snails conceivably consume macroalgae.

- Sea urchins, (i.e., *Diadema antillarium*), have predictable $\delta^{15}N$ values for a diet of algae, but their $\delta^{13}C$ values were variable and are difficult to interpret. Error may have resulted from analyzing dried ova instead of dried muscle tissue. For future collections of urchins, we plan to dissect and separate tissue in the field.

- Analysis of tissue isotopes of herbivorous fish (i.e., blue tang and brown chromis) is enigmatic. Nitrogen analysis agrees well with observed consumption of coral polyps;

however, the $\delta^{13}C$ values (-17.9‰) do not suggest a strict diet of corals ($\delta^{13}C$ = -14.3‰). The only primary producers capable of supplying ^{13}C depleted carbon are water column POM, an argument which is counterintuitive to known feeding behavior. Interestingly, nitrogen isotopic analysis of blue tang gut contents ($\delta^{15}N$ = 3.4‰) was consistent with tissue composition plus metabolic enrichment ($\delta^{15}N$ = 8.3‰). Subsequent collection opportunities should resolve this confusion.

CONCLUSIONS

Coral reef communities are especially susceptible to nutrient excess since these organisms are highly adapted to nutrient-deficient, oligotrophic conditions. The stability of the FGB coral reef ecosystem could possibly be linked to nutrient inputs from the Mississippi River. The characteristically higher $\delta^{15}N$ signatures of riverine derived nitrogen (McClelland et al., 1997; McClelland and Valiela, 1998) indicate that it is a valuable tracer of anthropogenic nutrient sources. However, both low ambient nutrient concentrations and depleted ^{15}N in tissues of primary producers at the FGB suggest new nutrients are produced autochthonously by benthic cyanobacterial mats rather than transported onto the reef by advection from coastal zones. Understanding community response to increased nitrogen inputs at the FGB remains a priority since (1) baseline data is needed to understand possible nutrient stresses in the future, and (2) a coral community removed from coastal influences is useful comparatively with other Caribbean reef systems. Research into the extent of Mississippi River eutrophication into Gulf of Mexico benthic ecosystems should be initiated by sampling primary producers at open ocean banks near river plume influence.

Table 2

Stable carbon and nitrogen isotope values (‰) of tissue sampled from in the Flower Garden Banks. Values are algebraic means ± S.E. (n). Sample number reported only for replicates greater than one

Taxon	**Species**	**$\delta^{13}C$**	**$\delta^{15}N$**
Cyanophyta		-9.62	0.56
	unidentified mat	-9.62	0.56 ±0.11 (5)
Phaeophyta		-16.17 ±0.10 (2)	1.34 ±0.06 (2)
	Dictyota (large)	-16.08 ±0.24 (8)	1.44 ±0.17 (5)
	Dictyota (small)	-16.27	1.33 ±0.26 (5)
Rhodophyta		-14.40	0.78
	Red algal mat	-14.40 ±0.38 (2)	0.78 ±0.17 (2)
Chlorophyta		-17.91	2.00
	Cladophora sp.	-17.91	2.00
Anthozoa		-14.34 ±0.29 (3)	4.00 ±0.25 (3)
	Scolymia sp.	-14.76	3.74
	Diploria strigosa	-14.50 ±0.18 (2)	4.50 ±0.37 (2)
	Montastraea faveolata	-13.87 ±0.15 (2)	3.76 ±0.04 (2)
POM	Phytoplankton/Zooplankton	-20.15 ±0.65 (5)	2.61 ±0.26 (3)
Porifera		-17.89 ±0.25 (8)	4.85 ±0.47 (8)
	Xestospongia sp.	-18.58 ±0.27 (2)	6.76 ±0.22 (2)
	Neofibularia sp.	-17.80	2.73
	Pseudoceratina sp.	-18.21 ±0.05 (2)	3.69 ±0.53 (2)
	Agelas sp.	-17.26	5.74
	unidentified species #1	-18.49	3.99
	unidentified species #2	-17.14	4.98
	unidentified species #3	-16.90	6.03
	unidentified species #4	-18.66	4.85
Polychaeta		-17.99 ±0.14 (2)	4.61±1.0
	Hermodice carunculata	-18.12	5.57
	Spirobranchus giganteus	-17.85	3.64
Gastropoda		-15.65	2.85
	Cerithium litteratum	-15.65	2.85

Table 2

Stable carbon and nitrogen isotope values (‰) of tissue sampled from in the Flower Garden Banks. Values are algebraic means ± S.E. (n). Sample number reported only for replicates greater than one (continued)

Taxon	**Species**	**$\delta^{13}C$**	**$\delta^{15}N$**
Echinoidea		-8.16	4.12
	Diadema antillarum	-8.16 ±1.73 (2)	4.12 ±0.16 (2)
Osteichthyes		-17.94 ±0.27 (2)	8.30 ±0.39 (2)
	Chromis multilineatus	-17.67	8.70
	Acanthurus coeruleus	-18.21	7.93
Blue Tang gut contents		-19.40	3.41

LITERATURE CITED

Delgado, O. and B.E. Lapointe. 1994. Nutrient-limited productivity of calcareous versus fleshy macroalgae in a eutrophic, carbonate-rich tropical marine environment. Coral Reefs 13:151–159.

DeNiro, M. J. and S. Epstein. 1981. Influence of diet on the distribution of nitrogen isotopes in animals. Geochim. Cosmochim. Acta. 45: 341–351.

Fry, B., R.K. Anderson, L. Entzeroth, J.L. Bird, and P. Parker. 1984. ^{13}C enrichment and oceanic food web structure in the northwestern Gulf of Mexico. Contrib. Mar. Sci. 27:49–63.

Lapointe, B. E., M.M. Littler, and D.S. Littler. 1987. A comparison of nutrient-limited productivity in macroalgae from a Caribbean barrier reef and from a mangrove ecosystem. Aquat. Bot. 28: 243–255.

McClelland, J. W. and I. Valiela. 1998. Linking nitrogen in estuarine producers to land-derived sources. Limnol. Oceangr. 43: 577–585.

McClelland, J. W., I. Valiela, and R.H. Michener. 1997. Nitrogen-stable isotope signatures in esuarine food webs: a record of increasing urbanization in coastal watersheds. Limnol. Oceangr. 42: 930–937.

Owens, N. J. P. 1987. Natural variations in ^{15}N in the marine environment. Advances in Marine Biology, Vol. 24. Academic Press Inc., London. p. 389–451.

Rabalais, N. N., R.E. Turner, W.J. Wiseman, Jr., and Q. Dortch. 1998. Consequences of the 1993 Mississippi River flood in the Gulf of Mexico. Regul. Rivers: Res. Mgmt. 14:161–177.

Shearer, G. and D.H. Kohl. 1988. Estimates of N_2 fixation in ecosystems: the need for and basis of the ^{15}N natural abundance method. *In* (eds.) Rundel, P. W., Ehleringer, J. R. & Nagy, Stable Isotopes in Ecological Research, Vol. 68. Springer-Verlag, New York,NY. 342–374.

Turner, R. E. and N.N. Rabalais. 1991. Changes in Mississippi River water quality this century: implications for coastal food webs. Bioscience 41:140–147.

11.0 ATTACHMENT 4

MICROMOLLUSCAN FAUNAL SURVEY OF THE EAST AND WEST FLOWER GARDEN BANKS

Noe Barrera and John W. Tunnell, Jr.
Center for Coastal Studies, Texas A&M University-Corpus Christi
6300 Ocean Drive, Corpus Christi, TX 78412

INTRODUCTION

Studies now show the significance that benthic marine communities have in determining the asthetic, recreational, and economic aspects of coastal waters (Kay, 1980). Presently, a significant number of approaches are available for the assessment of benthic communities.

Studies utilizing small organisms such as foraminiferans (Bandy, 1953; Murray, 1973), have been useful in determining the effects of physical changes on benthic environments (Kay, 1980). In this report another group of small organisms common in marine environments and useful in benthic study is considered, micromolluscs, those molluscs whose greatest diameter is less than 10 mm (Moore, 1964; Tunnell, 1974; Kay, 1980; Vokes and Vokes, 1983).

Because micromolluscs remains persist in sediments for long periods of time and their numbers allow for statistical analysis, these organisms provide useful indices of benthic conditions (Kay, 1980). However, the need for baseline data points must be established in order for meaningful evaluations to be made on marine ecosystems (Kay, 1980). The purpose of this project is to determine micromolluscan faunal assemblages and to enhance the knowledge of biodiversity, which in turn would create baseline data useful in determining the condition of the Flower Garden Banks (FGB) and any fluctuations that might occur over time.

METHODS

In 1981, 1996, and 1997 researchers collected sediment samples from the East and West Flower Garden Banks for identification and enumeration of micromolluscan infaunal assemblages. Samples collected from depths of 21, 23, 24, 26, 36, 46, and 51 m were preserved in isopropyl alcohol for 72 hours. In the lab, samples were washed, dried and divided into 50 ml aliquots. Sediments were then sorted, and molluscs were identified to the lowest possible taxon and counted.

RESULTS

To date, a total of 4,294 individual micromolluscs have been identified from fifteen 300 ml sediment samples taken at the FGB, representing 131 species, 53 families, and three classes (Appendix a). For now, the micromolluscs are divided into three areas of study according to depth and location (Table 1). Area 1 is located at the EFGB at depths less than 26 m. Area 2 is located at the EFGB with depths greater than 26 m, and Area 3 is located at the WFGB at depths

≤ 26 m. The *Montastraea-Diploria-Porites* zone begins to merge with the *Madracis* zone at 26 m.

Within Area 1, a total of 613 individuals were identified representing 71 species, 35 families, and 2 classes. The most abundant gastropods were *Amphithalamus vallei* (102), *Alvania auberiana* (56), cf. *Vitrinella* sp. (40), *Odostomia dydima* (26), *Iniforis turristhomae* (20), and *Melanella intermedia* (19). The most abundant bivalves were *Arcopsis adamsi* (12), *Barbatia cancellaria* (11), *Carditopsis smithii* (10), and *Barbatia domingensis* (9). The most diverse gastropod families included Pyramidellidae, Certhiopsidae, and Triphoridae, which all had six different species each. The Fissurellidae and Caecidae had four species and Eulimidae three species. Most bivalve families were Arcidae (3 species), Limidae (2), and Veneridae (2).

Area 2 had a total of 2,325 individuals with 108 species, 46 families, and three classes. The most abundant gastropods were *Amphithalamus vallei* (375), *Acmaea pustulata* (129), *Alvania auberiana* (127), *Willimia krebsii* (84), *Atlanta peronii* (33), *Rissoella* cf. *galba* (24), *Odostomia dydima* (24), *Cerithiopsis* cf. *gemmulosa* (24), *Omalogyra sculpturata* (23), and *Orbitestella* cf. *bermudezi* (22). The most abundant bivalves were *Gregariella coralliophaga* (117), *Barbatia domingensis* (63), *Lima tenera* (59), and *Barbatia cancellaria* (50). One chiton, *Acanthochitona* sp. from the family Acanthochitonidae represented the class Polyplacophora. The most diverse gastropod families were Fissurellidae (11 species), Pyramidellidae (7), Cerithiopsidae (6), Caecidae (6), Rissoidae (5), Omalogyridae (5), and Vitrinellidae (4). The most diverse bivalve families included Arcidae (4), Veneridae (3) Limidae (2), and Pectinidae (2).

Area 3 had a total of 1,356 individuals with 73 species, 37 families, and three classes. The most abundant gastropods were cf. *Vitrinella* sp. (468), *Amphithalamus vallei* (195), *Persicula lavelleeana* (42), *Odostomia dydima* (38), *Alvania auberiana* (37), *Iniforis turristhomae* (24), *Omalogyra sculpturata* (23), and *Cerithiopsis* cf. *gemmulosa* (21). The most abundant bivalves were *Barbatia domingensis* (30) and *Gregariella coralliophaga* (22). The most diverse gastropod families were Cerithiopsidae (5 species), Pyramidellidae (4), Omalogyridae (4), Fissurellidae (3), Rissoidae (3), and Vitrinellidae (3). The most diverse bivalve family was the Arcidae (4), with all remaining families within this area having 1 species in each. Three species and two families represented the class Polyplacophora, with the most abundant chiton being *Acanthochitona* sp. (17), within the family Acanthochitonidae.

DISCUSSION

Studies of the FGB molluscan fauna have focused primarily on macromolluscs (Bright *et al.*, 1974). This portion of the report deals specifically with micromolluscs.

Of the three areas studied, Area 2 (EFGB deep reef) was the most diverse, with 108 species and 46 families, Area 1 (EFGB reef cap) had 71 species and 35 families, and Area 3 (WFGB reef cap) had 73 species and 37 families. Although Area 2 was most diverse, Moore (1964), noted that because of gravitational pull, water currents, and other disturbances, sediments shift and tend to "roll" downward. Micromolluscs are a component of coral sediment, so we

should assume a certain proportion of micromolluscs from the upper reef were displaced and found at greater depths, whereas others may be ubiquitous.

From the 15 sites studied, Station 5a (Area 2) was the most diverse and abundant. This site was located at the base of a three meter drop-off from the bottom of the coral cap, at a depth of ~ 46 m. Fifty-nine species of molluscs overlapped between Area 1 and Area 2, and 45 species were found in all three areas.

Of the 125 species of molluscs listed by Bright *et al.* (1974), 31 were found in common with the present study. Thus the combined efforts of Bright *et al.* (1974) and the current study bring the total number of molluscs collected from the FGB to more than 225, which significantly increases the reported invertebrate species of the FGB by more than 100 species.

Although the study of micromolluscs is relatively new, it has proven helpful on the Hawaiian islands as indicators as to the health of the environments being studied (Kay, 1979, 1980; Russo *et al.*, 1998; Swartz *et al.*, 1998). The monitoring of these organisms should provide a better understanding of the mollusc community of the FGBNMS.

Table 1

Collection sites for micromolluscan sediment samples from the East and West Flower Garden Banks

EFGB			
Site	**Location/Date/Depth**	**Description**	**Collectors**
1	EFGB: buoy 2, 11 June 1996, depth 21.02m	Base of *Montastraea cavernosa* coral head, with *Diploria strigosa* adjacent	Steve Gittings and Noe Barrera
2	EFGB: 11 June 1996, depth 24m	Base of *Montastraea annularis* coral ledge	Steve Gittings and Noe Barrera
3	EFGB: 21 October 1981, depth 24m	N/A	Larry Martin
4 & 4a	EFGB: buoy 2, 11 September 1997, depth 36.04m	Beneath "plate-like" protrusions of *Montastraea annularis*. Sand-patches are difficult to locate in this area	Wes Tunnell and Judy Ovard
5 & 5a	EFGB: 11 September 1997, depth 46.25m	Base of coral reef drop-off	Peter Vize
6	EFGB: 11 September 1997, depth 50.45m	Rubble-flat beyond base of coral reef	Peter Vize
WFGB			
1	WFGB: bouy 5, 10 June 1996, depth 23.12m	Small sand-flat between *Montastraea annularis* and *Diploria strigosa*	Steve Gittings and Noe Barrera
2	WFGB: 11 June 1996, depth 25.53m	*Montastraea-Madracis* convergence zone	Steve Gittings and Noe Barrera
3	WFGB: 10 June 1996, depth 24.02m	Base of *Porites asteroides* with *Agaricia* sp. growing upon it	Steve Gittings and Noe Barrera
4	WFGB: 10 June 1996, depth 21.02m	Sand-flat between *Montastraea annularis* and *Diploria strigosa*	Steve Gittings and Noe Barrera
5	WFGB: 10 June 1996, depth 21.02m	Beneath "umbrella" of *Montastraea annularis*	Steve Gittings and Noe Barrera
6 & 6a	WFGB: 28 August 1997, depth 23.72m	Base of small *Montastraea annularis* with *M. franksi* adjacent	Terry Riggs

LITERATURE CITED

Bandy, O.L. 1953. Ecology and paleocology of some California Foraminifera, Part I; the frequency distribution of recent Foraminifera off California. J. Paleont. 27:161-174.

Bright, T.J., J.W. Tunnell, L.H., Pequegnat, T.E. Burke, C.W. Cashman, D.A. Cropper, J.P. Ray, R.C. Tresslar, J. Teerling, and J.B. Willis. 1974. Biotic Zonation on the West Flower Garden Banks. p. 4-54, *in* T.J. Bright and L.H. Peguegnat (eds.) Biota of the West Flower Garden Bank. Gulf Publ. Co., Houston, Texas.

Kay, E.A. 1979. Hawaiian marine shells: reef and shore fauna of Hawaii, sec. 4: Mollusca. Bishop Mus. Spec. Publ. 64(4). Honolulu: Bishop Museum Press. 653 p.

Kay, E.A. 1980. Micromollusks: Techniques and patterns in benthic marine communities. p. 93-112, *in* Environmental Survey Techniques for Coastal Water Conference proceedings. Water Resources Research Center, University of Hawaii at Manoa, Honolulu, and Hawaii Water Pollution Control Association.

Russo, A.R., E.A. Kay, J.H. Baily-Brock, and W.J. Cooke. 1998. Benthic sampling adjacent to the Waianae ocean outfall, Oahu, Hawaii. City and County of Honolulu PR-98-11, Water Resources Research Center, Univ. of Hawaii at Manoa, Honolulu.

Swartz, R.C., J.H. Baily-Brock, W.J. Cooke, and E.A. Kay. 1998. Benthic faunal sampling adjacent to Sand Island ocean outfall, Oahu, Hawaii. City and County of Honolulu PR-98-08, Water Resources Research Center, Univ. of Hawaii at Manoa, Honolulu.

Moore, D.R. 1964. The family Vitrinellidae in south Florida and the Gulf of Mexico. Ph. D. Dissertation, Univ. of Miami, Florida.

Murray, J.W. 1973. Distribution and ecology of living benthic foraminiferids. Crane-Russak, New York, NY.

Tunnell, J.W. Jr. 1974. Ecological and geographical distribution of Mollusca of Lobos and Enmedio coral reefs, southwestern Gulf of Mexico. Ph. D. dissertation, Texas A&M University, College Station, Texas.

Vokes, H. E. and E. H. Vokes. 1983. Distribution of shallow water marine Mollusca, Yucatan Peninsula, Mexico. Middle American Research Institute, Publication 54. 183 p.

Appendix a. Species checklist of the micromolluscs (or juvenile molluscs) collected in sediment samples taken during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks.

	EFGB < 26 m				EFGB > 26 m						WFGB < 26 m							
STATION	**1**	**2**	**3**	**Total**	**4**	**4a**	**5**	**5a**	**6**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**6a**	**Total**
DEPTH (m)	21	21	24		36	36	46	46	51		23	26	24	21	21	24	24	
PHYLUM MOLLUSCA																		
CLASS POLYPLACOPHORA																		
ISCHNOCHITONIDAE																		
Ischnochitona sp.											2							**2**
Lepidochitona sp.											2							**2**
ACANTHOCHITONIDAE																		
Acanthochitona sp.									1	**1**	6	2		6	3			**17**
CLASS GASTROPODA																		
SCISSURELLIDAE																		
Scissurella cingulata						2				**2**								
Scissurella cf. *tabulata*			1	**1**	5	14		2	7	**28**								
FISSURELLIDAE																		
Emarginula phrixoides			5	**5**	3	9		2	1	**15**				2	1			**3**
Emarginula tuberculosa						1			1	**2**	1							**1**
Emarginula pumila						1	1	1	3	**6**								
Puncturella sp.					4	5				**9**								
Rimula frenulata			3	**3**			5	1	1	**7**		1						**1**
Rimula aequisculpta			1	**1**														
Diodora listeri					1					**1**								
Zeidora bigelowii									2	**2**								
Lucapinna sowerbii						1				**1**								
Lucapinna aegis						1				**1**								
Lucapinella limatula			1	**1**														
ACMAEIDAE																		
Acmaea pustulata							27	29	73	**129**								
TROCHIDAE																		
Calliostoma fascinans							2		2	**4**								
SKENEIDAE																		
Cyclostremiscus ornatus		2	7	**9**	1	2				**3**						2		**2**
CYCLOSTREMATIDAE																		
Cyclostrema cf *tortuganum*								3	6	**9**								
Cyclostrema sp.								2	2	**4**								
TURBINIIDAE																		
Arene cruentata								11	7	**18**						1		**1**
Arene tricarinata							5	5	10	**20**				1				**1**
Astraea phoebia									1	**1**								
RISSOIDAE																		
Alvania auberiana	3	5	48	**56**	19	9	23	34	42	**127**	5	2	6	3	12	4	5	**37**
Zebina browniana							5	1	1	**7**								

Appendix a. Species checklist of the micromolluscs (or juvenile molluscs) collected in sediment samples taken during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. (continued).

	EFGB < 26 m				EFGB > 26 m						WFGB < 26 m							
STATION	**1**	**2**	**3**	**Total**	**4**	**4a**	**5**	**5a**	**6**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**6a**	**Total**
DEPTH (m)	21	21	24		36	36	46	46	51		23	26	24	21	21	24	24	
Rissoina sagriana			1	**1**		2		3	12	**17**	1				2			**3**
Rissoina cf. *multicostata*		1		**1**				2		**2**	2		2					**4**
Rissoina cf. *striatocostata*									1	**1**								
BARLEEIDAE																		
Amphithalamus vallei	17	37	48	**102**	89	105	56	80	45	**375**	21	11	20	13	31	71	28	**195**
CAECIDAE																		
Caecum cooperi							1		6	**7**								
Caecum cornucopiae			1	**1**					1	**1**				1				**1**
Caecum floridanum			11	**11**			1			**1**	1		1		1	3	2	**8**
Caecum johnsoni			1	**1**				2	10	**12**	1		5				1	**7**
Caecum pulchellum	3	1	10	**14**	1	2	8	2	10	**23**	3	1	2	2	4		1	**13**
Caecum vestitum								2	6	**8**					2			**2**
ORBITESTELLIDAE																		
Orbitestella cf. *bermudezi*						3	4	6	9	**22**					2		4	**6**
VITRINELLIDAE																		
cf. *Vitrinella* sp.	2	4	34	**40**	7		8	8	3	**26**	165	9	211	26	18	34	5	**468**
Parviturboides interruptus									1	**1**								
Sansonia tuberculata					1	2	1	3	3	**10**	1							**1**
Teinostoma incertum															1			**1**
Teinostoma sp.									1	**1**								
MODULIDAE																		
Modulus modulus					1					**1**								
CERTHIIDAE																		
Cerithium litteratum	6	5		**11**	6	26		61	45	**138**	19	11	6	4	8	6	5	**59**
Cerithium guinaicum											3							**3**
LITIOPIDAE																		
Alaba incerta									1	**1**								
DIASTOMATIDAE																		
Obtortio dubia							2			**2**								
SILIQUARIDAE																		
Siliquaria squamata	1		9	**10**	3	6	21	51	65	**146**	2	4	1		5	1	1	**14**
VERMETIDAE																		
Petaloconchus erectus	6	12	11	**29**	3	91		64		**158**	4	10			29		7	**50**
Petaloconchus cf. *mcgintyi*													3					**3**
Spiroglyphus cf. *annulatus*					2	35	5	24		**66**	7	1						**8**
Spiroglyphus cf. *irregularis*			2	**2**		2				**2**								
CREPIDULIDAE																		
Crepidula plana								2		**2**								
ATLANTIDAE																		
Atlanta peronii	1		7	**8**	4	16	3	5	5	**33**		1	3	4	7			**15**

Appendix a. Species checklist of the micromolluscs (or juvenile molluscs) collected in sediment samples taken during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. (continued).

	EFGB < 26 m				EFGB > 26 m						WFGB < 26 m							
STATION	**1**	**2**	**3**	**Total**	**4**	**4a**	**5**	**5a**	**6**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**6a**	**Total**
DEPTH (m)	21	21	24		36	36	46	46	51		23	26	24	21	21	24	24	
NATICIDAE																		
Haliotenella patinaria			1	**1**														
CERITHIOPSIDAE																		
Cerithiopsis cf. *hero*			1	**1**					1	**1**	1							**1**
Cerithiopsis cf. *emersoni*							1			**1**								
Cerithiopsis cf. *fusiforme*			2	**2**				2		**2**	3	3					1	**7**
Cerithiopsis cf. *gemmulosa*	1		8	**9**	2	5		11	6	**24**	9	4	2	4		2	21	**21**
Cerithiopsis latum			6	**6**			1	6	3	**10**	2	1	2		2			**7**
Cerithiopsis cf. *rugulosum*			2	**2**					2	**2**	1	2		1	1	1		**6**
Seila adamsi			2	**2**		1		2	1	**4**								
TRIPHORIDAE																		
Cosmotriphora melaneura			7	**7**	1	2	7	5		**15**	8		2	2		3		**15**
Iniforis turristhomae	2	4	14	**20**	1	2	6	21		**30**	12	4	3	1			4	**24**
Triphora cf. *novem*		1	6	**7**	1					**1**			1				1	**2**
Triphora cf. *decorata*												1						**1**
Triphora sp. A	2			**2**														
Triphora sp. B			1	**1**				2		**2**								
Triphora sp. C			1	**1**														
EULIMIDAE																		
Melanella arcuata			1	**1**		4	1	1		**6**	1	2	1	1				**5**
Melanella intermedia	2		17	**19**		1		1		**2**	2	1		3	5			**11**
Strombiformis auricinctus	1		1	**2**	2	3		2	2	**9**								
ACLIDIDAE																		
Bermudaclis bermudensis			3	**3**				1		**1**								
Graphis underwoodae									1	**1**			2					**2**
CORALLIOPHILIDAE																		
Coralliophila sp.		1		**1**				6	1	**7**	1	1					1	**3**
NASSARIIDAE																		
Nassarius albus		2		**2**														
MARGINELLIDAE																		
Persicula lavelleeana											12	5	5	5	15			**42**
MITRIDAE																		
Mitra nodulosa	2	3	12	**17**		6	1	10	10	**27**	3		3	2	3	1	3	**15**
VEXILLIDAE																		
Vexillum sp. A						2				**2**								
Vexillum sp. B																	1	**1**
CONIDAE																		
Conus sp. A			1	**1**														
Conus sp. B							2			**2**								
Conus sp. C		1		**1**														

Appendix a. Species checklist of the micromolluscs (or juvenile molluscs) collected in sediment samples taken during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. (continued).

	EFGB < 26 m				EFGB > 26 m						WFGB < 26 m							
STATION	**1**	**2**	**3**	**Total**	**4**	**4a**	**5**	**5a**	**6**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**6a**	**Total**
DEPTH (m)	21	21	24		36	36	46	46	51		23	26	24	21	21	24	24	
OMALOGYRIDAE																		
Omalogyra albospeciosa						2		1		**3**			1					**1**
Omalogyra familiaris						3				**3**								
Omalogyra minortalis	3	5		**8**		9	1	5		**15**	5			9				**14**
Omalogyra sculpturata	6			**6**		10			13	**23**			2		21			**23**
Omalogyra zebrina					3	8		6		**17**				1				**1**
RISSOELLIDAE																		
Rissoella caribaea						8		7	2	**17**		1						**1**
Rissoella cf. *galba*						20		3	1	**24**	3	3		7				**13**
PYRAMIDELLIDAE																		
Odostomia dydima	2	9	15	**26**	4	6		24	40	**74**	7	15	3	3	8	2	38	**38**
Odostomia babylonia		1	11	**12**	2					**2**	1		1		1			**3**
Odostomia impressa			6	**6**		3		18		**21**		3		1				**4**
Cyclostremella humilis								1		**1**								
Turbonilla cf. *fonteini*			4	**4**			3	3		**6**		1		1				**2**
Turbonilla sp. A									4	**4**								
Turbonilla sp. B								1		**1**								
Turbonilla sp. C		1		**1**														
Turbonilla sp. D			1	**1**														
HAMINEIDAE																		
Atys sandersoni								1		**1**								
Haminoea cf. *glabra*													1					**1**
Haminoea succinea								1		**1**								
RETUSIDAE																		
Retusa caelatus			1	**1**		1		3		**4**			3	1				**4**
CAVOLINIDAE																		
Cavolinia tridentata	3			**3**		9		2	7	**18**	1	1			4		3	**9**
Cavolinia longirostris	3	1	24	**28**		13	3	2	2	**20**	6	1	16	6	12			**41**
Cavolinia unicinata	1		6	**7**		2		1		**3**	1	1	8					**10**
Creseis acicula			8	**8**		6				**6**	2		3		5	1		**11**
Diacria quadridentata			2	**2**				1		**1**								
Diacria trispinosa			1	**1**								1						**1**
SIPHONARIIDAE																		
Willimia krebsii		1	8	**9**	9	25	8	2	40	**84**	3		1	3	1			**8**
CLASS BIVALVIA																		
ARCIDAE																		
Arca zebra						1	1		2	**4**							1	**1**
Barbatia cancellaria	1		10	**11**	11	11	12	16		**50**		3	1	2	1			**7**
Barbatia domingensis		3	6	**9**	17	27	4	8	7	**63**	4	7	2	4	12		1	**30**

Appendix a. Species checklist of the micromolluscs (or juvenile molluscs) collected in sediment samples taken during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. (continued).

	EFGB < 26 m				EFGB > 26 m						WFGB < 26 m							
STATION	**1**	**2**	**3**	**Total**	**4**	**4a**	**5**	**5a**	**6**	**Total**	**1**	**2**	**3**	**4**	**5**	**6**	**6a**	**Total**
DEPTH (m)	21	21	24		36	36	46	46	51		23	26	24	21	21	24	24	
Arcopsis adamsi			12	**12**	5	2				**7**		1						**1**
GLYCEMERIDAE																		
Glycemeris pectinata												2	1					**3**
MYTILIDAE																		
Gregariella coralliophaga		1	5	**6**	23	53	1	19	21	**117**	3	1	2	6	9		1	**22**
LIMIDAE																		
Lima scabra			1	**1**	4			2		**6**								
Lima tenera			3	**3**	20	37		1	1	**59**	1				2			**3**
PECTINIDAE																		
Chlamys benedicti			1	**1**		1				**1**								
Argopectin gibbus					1					**1**								
ANOMIIDAE																		
Anomia simplex								9		**9**								
LUCINIDAE																		
Codakia orbiculata	3		5	**8**			2			**2**		2	2		1			**5**
UNGULINIDAE																		
Diplodonta punctata			1	**1**														
CONDYLOCARDIIDAE																		
Carditopsis smithii			10	**10**	3	5	2	3	1	**14**					1	1	1	**3**
CHAMIDAE																		
Chama sp.	1		6	**7**		11		4	6	**21**	1	1	1					**3**
CRASSITELLIDAE																		
Crassinella martinicensis			2	**2**			2	3	1	**6**								
MESODESMATIDAE																		
Ervilia concentrica											1							**1**
VENERIDAE																		
Gouldia cerina			2	**2**					2	**2**								
Ventracolaria rugitina			2	**2**														
Pitar cf. *munde*							6	4	1	**11**				1				**1**
Chione sp.					1					**1**								
TOTAL	72	101	440	**613**	260	634	242	627	562	**2325**	340	121	329	126	230	133	77	**1356**

12.0 ATTACHMENT 5

TOXICITY TESTING OF SEDIMENT PORE WATER FROM THE FLOWER GARDEN BANKS, GULF OF MEXICO

Marion Nipper[1] and R. Scott Carr[2], Co-principal Investigators
[1]Center for Coastal Studies and [2]U.S. Geological Survey-Biological Resources Division
Marine Ecotoxicology Research Station, Texas A & M University–Corpus Christi
6300 Ocean Drive, Corpus Christi, TX 78412

INTRODUCTION

As part of an ongoing monitoring program of the coral reefs and associated community of the Flower Garden Banks (FGB), Gulf of Mexico, the deployment of semi-permeable membrane devices (SPMD) showed the presence of low levels of organochlorinated chemicals, including PCB's, DDT's, and other pesticides, as well as polycyclic aromatic hydrocarbons (PAH's) (Dokken *et al.*, 1999). This generated concern with potential adverse biological effects of these chemicals on the coral reef and associated biota. Throughout the country, sediment porewater toxicity tests are a standard technique for assessing the presence of bioavailable contaminants in toxic amounts in marine sediments (National Biological Survey, 1993, 1994; Carr *et al.*, 1996a, b, c, 2000; U.S. Geological Survey, 1997, 1998, 1999). Most of these surveys have been done in sediments with fine grain size, i.e., with high content of silt and clay. However, a recent survey in Hawaii and Mexico showed that the application of this approach could pick up contamination signals in pore water extracted from coarse sand from the vicinity of coral reefs (Nipper and Carr, 2000). Therefore, sediment pore water was extracted *in situ* from 6 stations at the East Flower Garden Bank (EFGB) (Figure 1) and 7 stations at the West Flower Garden Bank (WFGB) (Figure 2), and taken to the laboratory for further processing and toxicity testing. Porewater extraction was performed by vacuum. Two different filtration media were used at 5 of the 13 stations, to assess effects of filtration medium on porewater quality.

The specific objectives of this study were to:

- Assess toxicity of sediment porewater samples from the EFGB and WFGB, through the analysis of adverse effects on fertilization rate and embryological development of the sea urchin, *Arbacia punctulata*.
- Assess if there were differences in the quality and toxicity of porewater collected *in situ*, by vacuum, using two different filtration media.
- Measure water quality parameters (salinity, dissolved oxygen, pH, and ammonia) of porewater samples prior to toxicity testing.

METHODS

POREWATER SAMPLING, STORAGE, AND HANDLING

Porewater samples were collected from 13 stations in the EFGB and WFGB in September 1999. Sampling was conducted by divers through insertion of the extraction device into the sand in the vicinity of the coral reef. Station 6 was located right by the SPMD of the EFGB. The

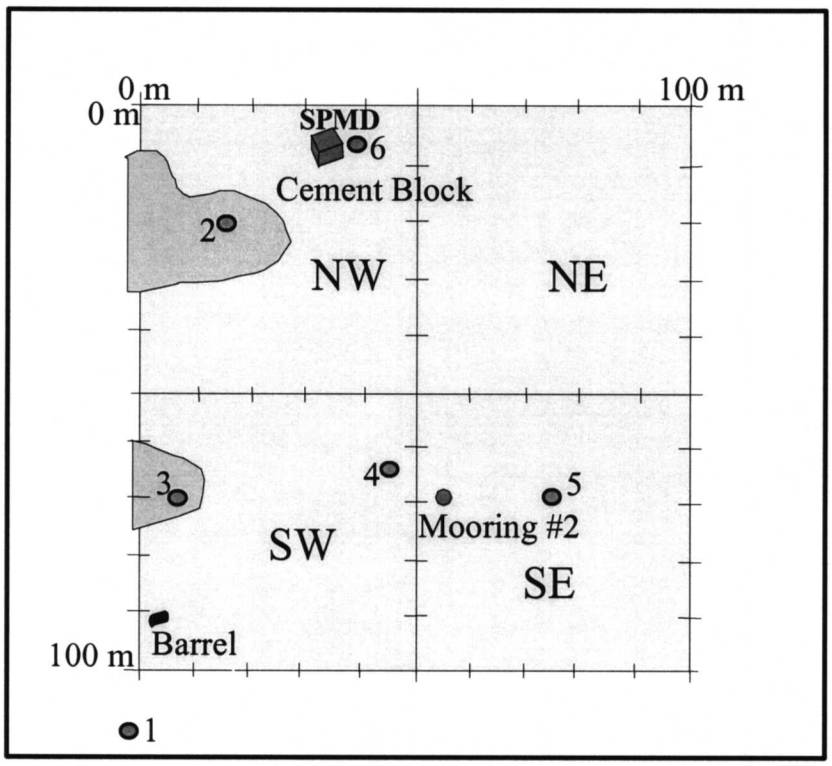


Figure 1. Map of porewater sampling stations at the East Flower Gardens Bank.

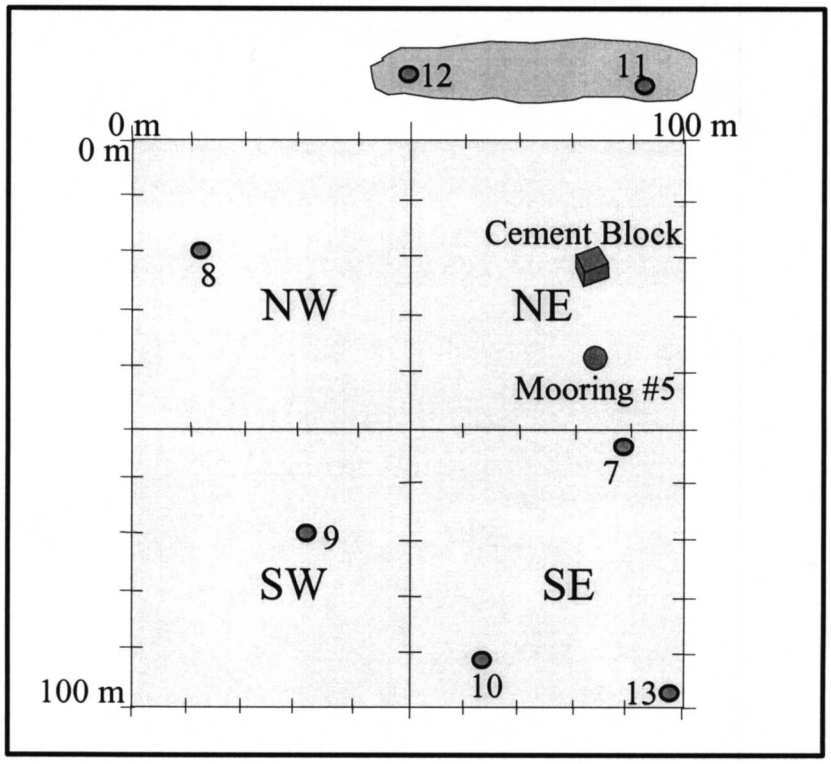


Figure 2. Map of porewater sampling stations atthe West Flower Gardens Bank.

sampling devices consisted of a filtration medium attached to a disposable syringe. Two different filtration media, consisting of a ground glass aquarium air stone, or a stainless steel cone-shaped filter with 250 μm mesh (Figure 3), were used for means of comparison at 5 of the 13 sampling stations. The stainless steel filter was placed inside a 100 and 200 μl disposable pipette tips in order to prevent breakage when inserted into the sediment. All sampling material was pre-soaked in distilled water for a minimum of 24 hours prior to use in the field.

Samples were removed from syringes, placed in pre-cleaned 120 ml amber glass jars with Teflon lined screw caps, and kept in coolers on ice for up to 3 days, including the duration of the cruise to the FGB and transportation back to the Marine Ecotoxicology Research Station in Corpus Christi, TX. Samples were accompanied by sample tracking sheets and were logged into laboratory sample tracking systems. Upon arrival at the laboratory the samples were centrifuged in polycarbonate bottles at 1200 x *g* for 20 min to remove any suspended particulate material. The supernatant was placed in clean amber glass jars and frozen at -20°C.

POREWATER QUALITY MEASUREMENT AND ADJUSTMENT

Two days before conducting the toxicity tests, the samples were moved from the freezer to a refrigerator at 4°C. One day prior to testing samples were thawed in a tepid (20°C) water bath. Temperature of the samples was maintained at 20 ± 1°C. Sample salinity was measured and adjusted to 30 ± 1 ppt using purified deionized water (Corpus Christi SOP F10.12, 1994). Other water quality measurements (dissolved oxygen, pH, and ammonia concentration) were made. Dissolved oxygen (DO) was measured with an YSI® meter, salinity was measured with a Reichert® refractometer, and pH and total ammonia (expressed as nitrogen; NH_4) were measured with an Orion® meter and the respective probes. Unionized ammonia (expressed as nitrogen; NH_3) concentrations were calculated for each sample using the respective salinity, temperature, pH, and NH_4 values. Following water quality measurements and adjustments, the samples were stored overnight at 4°C but returned to 20 ± 1°C before the start of the toxicity tests.

TOXICITY TESTING WITH SEA URCHIN GAMETES AND EMBRYOS

Toxicity of the porewater was determined using the fertilization and embryological development tests with the sea urchin *Arbacia punctulata* following the procedures outlined in Corpus Christi SOP F10.6 and F10.7 (1995 a & b).

Arbacia punctulata urchins used in this study were obtained from Gulf Specimen Company, Inc. (Panacea, Florida). A reference porewater sample collected from Redfish Bay, Texas, which had been extracted by pneumatic pressure and thereafter handled identically to the test samples, was included with each toxicity test as a negative control. This site is far removed from any known sources of contamination and has been used extensively as a reference site (Carr and Chapman, 1992; National Biological Survey, 1993, 1994; National Biological Service 1995a, b; Carr *et al.*, 1996a, c, 2000; U.S. Geological Survey 1997, 1998, 1999; Nipper and Carr, 2000). In addition, dilution blanks of filtered seawater were also included. A dilution series test with a

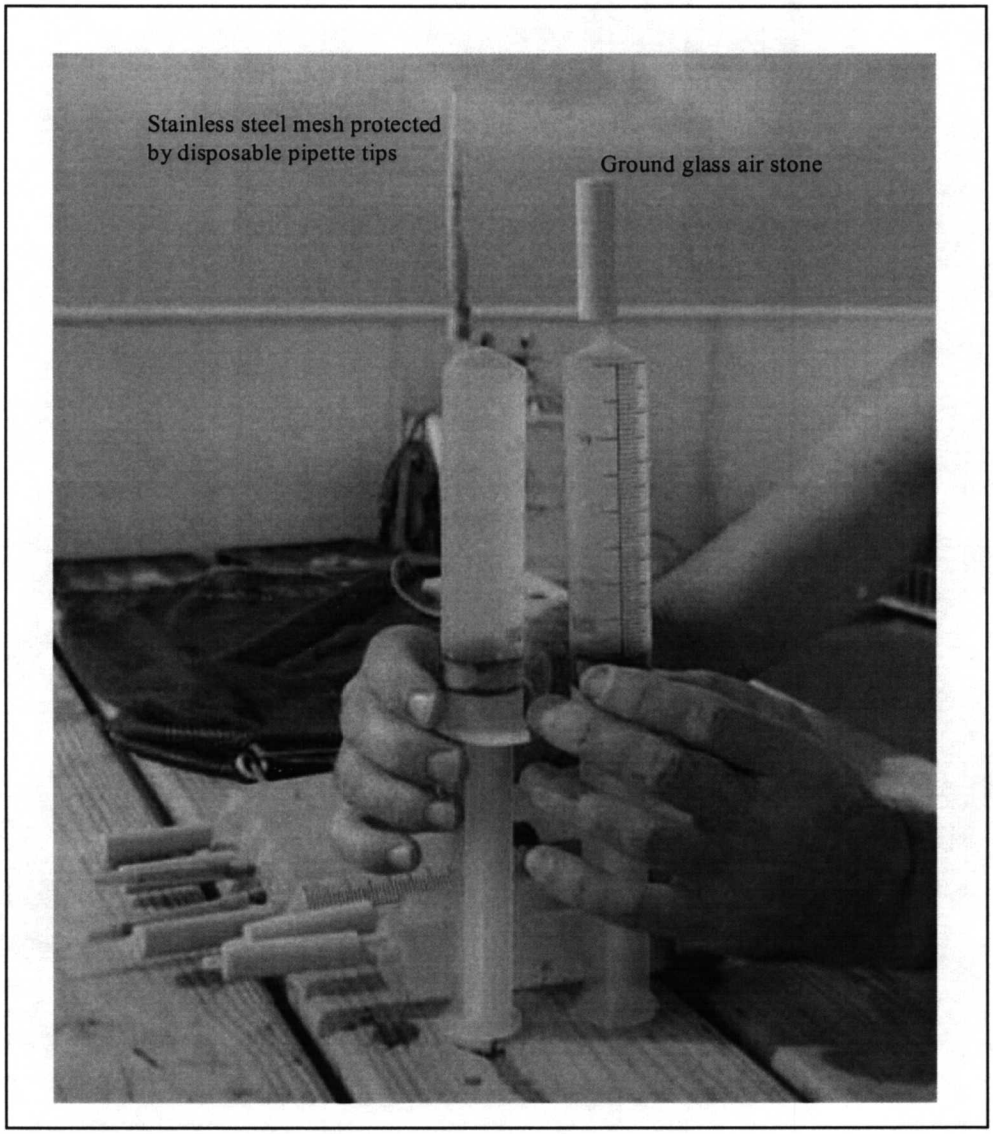


Figure 3. Photo of porewater sampling devices with different filtration media.

reference toxicant, sodium dodecyl sulfate (SDS), was included as a positive control. Reference toxicant test results were compared to a control chart with the results of the previous tests with this reference toxicant, in order to ensure that the sensitivity of the test organisms was within the standard range (Environment Canada, 1990).

TOXICITY TEST DATA ANALYSIS

The regular kind of statistical analyses for these toxicity tests involves comparisons among treatments using ANOVA and Dunnett's test. A second criterion is also used to compare test means to reference means. Detectable significance criteria (DSC) were developed to determine the 95% confidence value based on power analysis of all similar tests performed by our

laboratory (Carr and Biedenbach, 1999). This value is the percent minimum significant difference from the reference that is necessary to accurately detect a difference from the reference. The DSC value for the sea urchin fertilization assay is 15.5% at $\alpha = 0.05$, and 19% at $\alpha = 0.01$. For the embryological development test the DSC values at $\alpha = 0.05$ and $\alpha = 0.01$ are 16.4 and 20.6%, respectively. Since none of the results were below DSC, no statistical analyses were applied.

Reference toxicant test results were analyzed by the trimmed Spearman-Karber method (Hamilton *et al.*, 1977) with Abbott's correction (Morgan, 1992) to calculate EC_{50} (effective concentration to 50% of the test organisms) values. Prior to statistical analysis, the transformed data sets were screened for outliers (SAS Institute Inc., 1992). Outliers were detected by comparing the studentized residuals to a critical value from a *t*-distribution chosen using a Bonferroni-type adjustment. The adjustment is based on the number of observations, *n*, so that the overall probability of a Type I error is at most 5%. The critical value, *cv*, is given by the following equation: $cv = t\ (df_{Error}\ ,\ .05/(2 \times n))$. After omitting outliers but prior to further analysis, the transformed data sets were tested for normality and for homogeneity of variance using SAS/LAB® Software (SAS Institute Inc., 1992).

RESULTS AND DISCUSSION

POREWATER QUALITY MEASUREMENTS

Water quality measurements for all samples, including the reference pore water from Redfish Bay, Texas, and the 0.45 µm filtered seawater control, are presented on Table 3.1.0.1. The water quality of the pore water samples was very stable. All samples from the FGB had salinity between 37 and 38 ppt and required adjustment prior to toxicity testing in order to satisfy the test salinity requirement of 30 ± 1 ppt. The percentage of porewater in the test samples after salinity adjustment (%OS – Table 1) ranged from 78 to 81%. Dissolved oxygen was above 90% saturation in all samples, except the reference pore water, which had 85% DO, and pH values were between 8.01 and 8.34. Unionized ammonia levels varied slightly, ranging from 0.44 to 24.92 µg/liter. The reference pore water had a somewhat higher NH_3 concentration of 47.36 µg/liter, which is still below toxic levels to *A. punctulata* fertilization and embryological development (Carr *et al.*, 1996c).

Table 1

Water quality parameters after salinity adjustment, and original salinity of sediment porewater samples from the East and West Flower Garden Banks

Station	Filtration Medium	Salinity (ppt)	DO[1] (mg/L)	DO (% sat.)	pH	Total NH_4 (mg/L)	NH_3 (µg/L)	% OS[2]
Control[3]	-	33	6.85	91.1	8.11	0.003	0.124	91
REF[4]	-	32.5	6.52	84.9	8.1	1.210	47.364	92
1	AS[5]	37	7.62	98.2	8.26	0.054	3.014	81
1	SSF[6]	37.5	7.13	93.4	8.04	0.160	5.482	80
2	AS	38	7.29	95.6	8.22	0.489	24.922	79
2	SSF	37	7.33	94.8	8.26	0.143	7.952	81
3	AS	38	7.42	97.3	8.34	0.051	3.352	79
4	AS	37	7.41	98.2	8.27	0.042	2.381	81
4	SSF	38	7.02	92.8	8.29	0.074	4.386	79
5	AS	38	7.37	97.7	8.21	0.014	0.718	79
6	AS	37	7.27	95.8	8.14	0.035	1.497	81
7	AS	38	7.14	94.6	8.31	0.025	1.525	79
7	SSF	38	7.41	98.9	8.30	0.036	2.196	79
8	AS	38	6.9	91.7	8.2	0.009	0.439	79
9	AS	38	7.12	94.1	8.31	0.031	1.940	79
10	AS	38	7.56	99.6	8.22	0.152	7.747	79
11	AS	38	7.58	100.3	8.13	0.067	2.811	79
11	SSF	38	7.24	95.9	8.01	0.018	0.590	79
12	AS	38	7.14	94.9	8.34	0.007	0.456	79
13	AS	38	7.02	93.3	8.14	0.020	0.864	78

[1] DO = Dissolved oxygen
[2] %OS = % original porewater in sample after salinity adjustment
[3] Control = 0.45 mm filtered seawater
[4] REF = Reference pore water from Redfish Bay, Texas
[5] AS = Air stone used as filtration medium for pore water sampling
[6] SSF = Stainless steel filter used as filtration medium for pore water sampling

SEA URCHIN TOXICITY TESTS

Raw data and means from the fertilization test are given in Table 2, and for the embryological development test, in Table 3.2.0.2. None of the porewater samples were significantly toxic to *A. punctulata* early-life stages, regardless of the filtration medium used for porewater sampling. Fertilization rates were similar to those in control seawater and higher than in the reference porewater. Normal embryological development rates were similar to those in both control seawater and reference porewater. The EC_{50} values for the SDS tests were within the normal range based on the control chart with the results of previous tests performed in our laboratory with this reference toxicant, indicating that the sensitivity of the test organisms was within the acceptable standard.

In a previous survey, porewater from sandy sediment collected in the vicinity of coral reefs in southeastern Mexico and in Honolulu, Hawaii, exhibited toxicity, showing that these kinds of tests are useful indicators of contaminant accumulation in toxic amounts around coral reefs, and could serve as early warning signals of potential biological impact to the reef itself (Nipper and Carr, 2000). The results obtained in the current study suggest that although small amounts of organic contaminants were captured in SPMDs (Dokken *et al.*, 1999), they are currently not accumulated in toxic amounts in the sediments around the FGB and are not expected to cause biological impacts at least in the short-term, provided that there is not an increase in contaminants input into the system.

ACKNOWLEDGMENTS

We are grateful for being allowed to participate on a regular trip of the Flower Gardens long-term monitoring team, which allowed us to do the porewater sampling. We are indebted to the expert technical assistance of Jim Biedenbach, Russell Hooten, and Linda May who processed the samples in the laboratory and conducted the toxicity tests.

Table 2

Sea urchin (*Arbacia punctulata*) fertilization test raw data, means and standard deviations for sediment porewater samples from the East and West Flower Garden Banks, and for the reference toxicant, SDS, with EC_{50} value (95% confidence limits in parenthesis)

Station	Filtration Medium	% Fertilization Replicate No.					Mean % Fert	Standard Dev.	
		1	2	3	4	5			
Control[1]	-	98	96	97	97	95	95.0	2.21	
		92	95	95	94	91			
REF[2]	-	96	94	93	94	93	89.7	4.92	
		85	83	87	83	89			
1	AS5	96	96	94	97	-	95.8	1.26	
1	SSF6	97	97	96	97	97	96.8	0.45	
2	AS	99	96	98	96	98	97.4	1.34	
2	SSF	96	99	98	97	95	97.0	1.58	
3	AS	98	98	94	96	95	96.2	1.79	
4	AS	95	96	98	98	97	96.8	1.30	
4	SSF	89	96	92	91	95	92.6	2.88	
5	AS	96	96	97	97	96	96.4	0.55	
6	AS	94	97	91	95	95	94.4	2.19	
7	AS	97	98	96	95	99	97.0	1.58	
7	SSF	97	95	99	96	95	96.4	1.67	
8	AS	96	95	95	92	95	94.6	1.52	
9	AS	94	99	92	97	97	95.8	2.77	
10	AS	98	95	97	96	97	96.6	1.14	
11	AS	97	94	96	93	98	95.6	2.07	
11	SSF	97	99	95	95	100	97.2	2.28	
12	AS	88	95	94	94	95	93.2	2.95	
13	AS	94	95	96	98	99	96.4	2.07	
	Conc. (mg/L)								
SDS	20.5	0	3	0	0	0	0.6	1.34	
SDS	10.25	0	2	0	5	3	2.0	2.12	**EC50**
SDS	5.12	38	45	31	35	22	34.2	8.53	4.65
SDS	2.56	92	93	94	92	96	93.4	1.67	(4.32-5.00)
SDS	1.28	98	98	96	99	96	97.4	1.34	

[1] Control = 0.45 mm filtered seawater

[2] REF = Reference pore water from Redfish Bay, Texas

Table 2

Sea urchin (*Arbacia punctulata*) embryological development test raw data, means and standard deviations for sediment porewater samples from the East and West Flower Garden Banks, and for the reference toxicant, SDS, with EC_{50} value (95% confidence limits in parenthesis)

Station	Filtration Medium	% Normal Larvae Replicate No. 1	2	3	4	5	Mean % Normal	Stand. Dev.	
Control[1]	-	97	96	94	92	97	96.2	2.04	
		99	95	98	97	97			
REF[2]	-	91	94	97	89	88	93.5	3.54	
		95	91	97	98	95			
1	AS5	95	96	100	97	93	96.2	2.59	
1	SSF6	97	97	91	94	94	94.6	2.51	
2	AS	98	97	94	97	98	96.8	1.64	
2	SSF	99	95	96	92	95	95.4	2.51	
3	AS	98	92	93	91	96	94	2.92	
4	AS	90	92	94	94	96	93.2	2.28	
4	SSF	91	98	92	92	89	92.4	3.36	
5	AS	93	95	96	94	97	95	1.58	
6	AS	90	98	93	95	95	94.2	2.95	
7	AS	95	96	96	95	92	94.8	1.64	
7	SSF	98	98	99	93	94	96.4	2.70	
8	AS	90	97	97	94	95	94.6	2.88	
9	AS	97	95	88	97	97	94.8	3.90	
10	AS	98	94	95	92	95	94.8	2.17	
11	AS	98	94	97	100	92	96.2	3.19	
11	SSF	95	91	95	94	97	94.4	2.19	
12	AS	94	97	95	97	93	95.2	1.79	
13	AS	95	97	91	95	91	93.8	2.68	
	Conc. (mg/L)								
SDS	20.5	0	0	0	0	0	0	0.00	
SDS	10.25	0	0	0	0	0	0	0.00	**EC_{50}**
SDS	5.12	24	21	22	30	32	25.8	4.92	4.10
SDS	2.56	89	93	79	83	84	85.6	5.46	(3.81-4.41)
SDS	1.28	96	96	96	98	93	95.8	1.79	

[1] Control = 0.45 mm filtered seawater

[2] REF = Reference pore water from Redfish Bay, Texas

LITERATURE CITED

Carr, R.S. and J.M. Biedenbach. 1999. Use of power analysis to develop detectable significance criteria for sea urchin toxicity tests. Aquat. Ecol. Health and Management 2(4):413-418.

Carr, R.S. and D.C. Chapman. 1992. Comparison of solid-phase and pore-water approaches for assessing the quality of marine and estuarine sediments. Chem. Ecol. 7:19-30.

Carr, R.S., D.S. Chapman, C.L. Howard, and J.M. Biedenbach. 1996a. Sediment quality triad assessment survey of the Galveston Bay, Texas system. Ecotox. 5(1):341-364.

Carr, R.S., D.C. Chapman, B.J. Presley, J.M. Biedenbach, L. Robertson, P. Boothe, R. Kilada, T. Wade, and P. Montagna. 1996b. Sediment porewater toxicity assessment studies in the vicinity of offshore oil and gas production platforms in the Gulf of Mexico. Can. J. of Fish. Aquat. Sci. 53:2618-2628.

Carr, R.S., E.R. Long, H.L. Windom, D.C. Thursby, G. Sloane, G.M. Wolfe, and D.A. Chapman. 1996c. Sediment quality assessment studies of Tampa Bay, Florida. Env. Toxicol. Chem. 15(7):1218-1231.

Carr, R.S., P.A. Montagna, J.M. Biedenbach, R. Kalke, M.C. Kennicutt, R. Hooten, and G. Cripe. 2000. Impact of storm water outfalls on sediment quality in Corpus Christi Bay, Texas. Env. Toxicol. Chem. (in press).

Corpus Christi SOP F10.6. 1995a. Sea urchin fertilization toxicity test. Center for Coastal Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX. (unpublished) 16 p.

Corpus Christi SOP F10.7. 1995b. Sea urchin embryological development toxicity test. Center for Coastal Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX. (unpublished) 19 p.

Corpus Christi SOP F10.12. 1994. Water quality adjustment samples. Center for Coastal Studies, Texas A&M University-Corpus Christi, Corpus Christi, TX. (unpublished) 6 p.

Dokken, Q.R., I.R. MacDonald, J.W. Tunnell Jr, C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long-term monitoring at the East and West Flower Garden Banks, 1996-1997. OCS Study MMS 99-0005. Texas A&M University-Corpus Christi, Corpus Christi, TX. 101 p.

Environment Canada. 1990. Guidance document on control of toxicity test precision using reference toxicants. EPS 1/RM/12. Environment Canada, Ottawa, Ontario, Canada.

Hamilton, M.A., R.C. Russo, and R.V. Thurston. 1977. Trimmed Spearman-Karber method for estimating median lethal concentrations on toxicity bioassays. Env. Sci. Tech. 11(7):714-719; correction 12(4):417.

Morgan, B.J.T. 1992. Analysis of Quantal Response Data. Chapman and Hall, London, England.

National Biological Service. 1995a. Toxicity testing of sediments from Biscayne Bay and Surrounding Areas. Submitted to the National Oceanic and Atmospheric Administration, Coastal Monitoring and Bioeffects Division, Seattle, WA. National Biological Service, Corpus Christi, TX. 11p. + 17 tables, 11 figures, and 4 attachments.

National Biological Service. 1995b. Toxicity testing of sediments from western Florida and coastal South Carolina and Georgia. Submitted to the National Oceanic and Atmospheric Administration, Coastal Monitoring and Bioeffects Division, Seattle, WA. National Biological Service, Corpus Christi, TX. 14p. + 35 tables, 10 figures, and 4 attachments.

National Biological Survey. 1993. Toxicity testing of sediments from Charleston Harbor, South Carolina and vicinity. Submitted to the National Oceanic and Atmospheric Administration, Ocean Assessment Division, Seattle, WA. National Biological Survey, Corpus Christi, TX. 7p. + 16 tables, and 4 attachments.

National Biological Survey. 1994. Survey of sediment toxicity in Pensacola Bay and St. Andrew Bay, Florida. Submitted to the National Oceanic and Atmospheric Administration, Ocean Assessment Division, Seattle, WA. National Biological Survey, Corpus Christi, TX. 12 pp. + 24 tables, and 5 attachments.

Nipper, M. and R.S. Carr. 2000. Porewater toxicity testing: a novel approach for assessing contaminant impacts in the vicinity of coral reefs. Bull. Mar. Sci. (in press).

SAS Institute Inc. 1992. SAS/LAB Software: User's Guide, Version 6, First Edition. SAS Institute Inc., Cary, NC, USA.

U.S. Geological Survey. 1997. Toxicity testing of sediments from Biscayne Bay, Florida and surrounding areas - Phase II. Submitted to the National Oceanic and Atmospheric Administration, Coastal Monitoring and Biological Assessment Division, Seattle, WA. U.S. Geological Survey, Corpus Christi, TX. 10 pages + 8 tables, 10 figures, and 4 attachments.

U.S. Geological Survey. 1998. Toxicity testing of sediment from Delaware Bay and surrounding areas. Submitted to National Oceanic and Atmospheric Administration, Office of Ocean Resources Conservation Assessment, Bioeffects Assessment Branch, Silver Springs, MD. U.S. Geological Survey, Corpus Christi, TX. 9 pages, 8 tables, 5 figures, + 4 attachments.

U.S. Geological Survey. 1999. Toxicity testing of sediment from the New York Bight, U.S. Geological Survey. Submitted to U.S. Geological Survey, Coastal and Marine Geological Team, Woods Hole Field Center, Woods Hole, MA. U.S. Geological Survey, Corpus Christi, TX. 7 pages, 7 tables, 1 figure, + 4 attachments.

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.