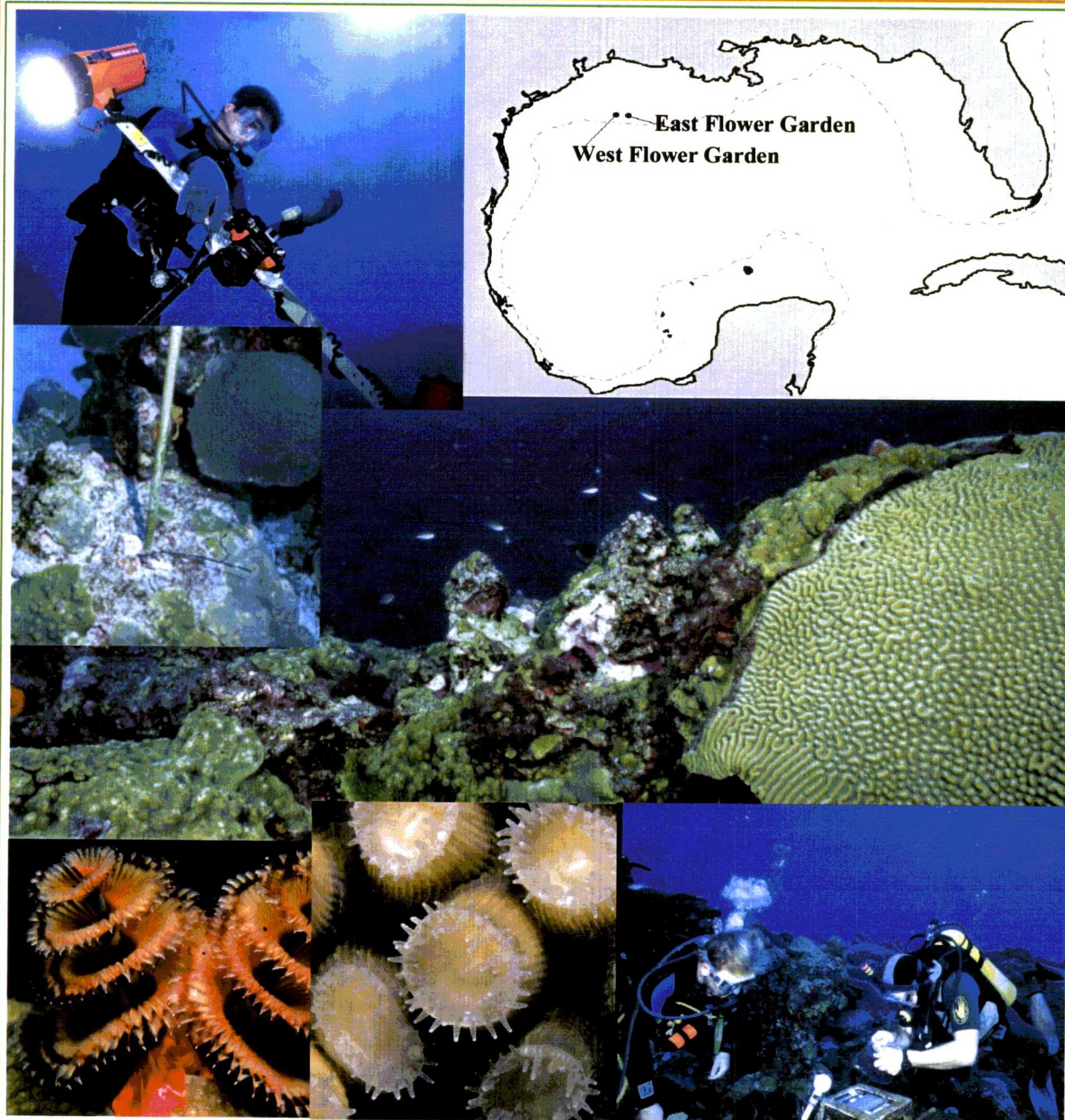
OCS Study
MMS 99-0005

Long-Term Monitoring at the East and West Flower Garden Banks, 1996-1997



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

OCS Study
MMS 99-0005

Long-Term Monitoring at the East and West Flower Garden Banks, 1996-1997

Authors

Quenton R. Dokken
Ian R. MacDonald
John W. Tunnell, Jr.
Carl R. Beaver
Gregory S. Boland
Derek K. Hagman

Prepared under MMS Contract
1435-01-96-CT-30822
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
February 1999

DISCLAIMER

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., C.R. Beaver, G.S. Boland, and D.K. Hagman. 1999. Long-term Monitoring of the East and West Flower Garden Banks, 1996-1997. OCS Study MMS 99-0005, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 101 pp.

ACKNOWLEDGMENTS

The project personnel would like to thank the many individuals who contributed their time and expertise toward the completion of this project. They are listed below. We gratefully acknowledge their efforts. We would also like to thank Rinn Boats Inc., Captains Phil Combs and Judy Ovard as well as the crew and divemasters aboard the *M.V. Fling*. A special thank you goes to Dr. Niall Slowey for assistance in preparation and interpretation of the coral cores for the sclerochronological analysis. We also thank . Susan Childs for her help with the development of report graphics and Dr. Kenneth Deslarzes for his invaluable advice and for his analysis of past temperature data.

Project personnel and their major responsibilities:

1.	Quenton Dokken	Project Manager, Co-Principal Investigator
2.	Ian MacDonald	Data Management, Co-Principal Investigator
3.	Wes Tunnell	Scientist, Co-Principal Investigator
4.	Norman Guinasso	Scientist/Data Analysis
5.	Carl Beaver	Scientist/Logistics/Data Analysis/Field Management
6.	Derek Hagman	Scientist/Logistics/Data Analysis/Field Management
7.	Greg Boland	Scientist/Data Analysis

The Principal Investigators would like to recognize individual authorship or contribution for certain sections of this report. Numerous individuals contributed time effort and expertise to increase the value of this document as a management tool. Individual authors / contributors and the tasks they performed are listed below.

Task/Analysis	**Author/Contributor**
Random Photographic Transects	Carl Beaver
Encrusting Growth Stations	Carl Beaver and Terry Riggs
Repetitive Quadrats	Derek Hagman
Accretionary Growth	Greg Boland
Sclerochronology	Greg Boland and Niall Slowey
Accretionary Growth Pins	Greg Boland
Water Chemistry	Terry Wade
Insolation	Ian MacDonald and Norman Guinasso
Temperature	Carl Beaver
Sea Urchin Surveys	Carl Beaver
Micromollusc Identification	Noe Barrera/Wes Tunnell
Zooxanthellae Identification	Jay Reichman
Document Layout & Preparation	Susan Childs
Editors	Quenton Dokken and Wes Tunnell

Project Divers

Ed Andrews
Lisa Barko
Noe Barrera
Carl Beaver
Greg Boland
Robert Borut
Dana Buchanan
Jeff Childs
Susan Childs
Ralph Daniels
Suzanne Dilworth
Quenton Dokken
Tannika Englehard
Mike Flynn
Mike Fredricks
Steve Gittings
Norman Guinasso
James Guisen
Derek Hagman
Emma Hickerson
Joel Hickerson
Brian Huff
Jay Jones
Kenneth Kenlee
Eric Lader
Judy Lang
Angela Lohse
Ian MacDonald
Tom Maher
Mark Militello
Harley Moody
Chris Ostrum
Jay Reichman
Terry Riggs
Tony Sebastian
Andy Shepard
Wes Tunnell
Lisa Vitale
Peter Vize

EXECUTIVE SUMMARY

This report was produced by the Texas A&M University-Corpus Christi Center for Coastal Studies and the Texas A&M University-College Station Geochemical and Environmental Research Group through contract to the Minerals Management Service and the National Oceanic Atmospheric Administration. This study represents an ongoing effort to understand the reef dynamics of the Flower Garden Banks coral reefs, and to protect this unique and valuable natural resource. Increased human activity (i.e. shipping, oil/gas exploration/production, recreational diving, fishing) in the vicinity of the Flower Garden Banks National Marine Sanctuary, makes research/monitoring efforts critical to preserving the long-term health and sustainability of the Flower Gardens Banks ecosystem.

The Flower Garden Banks comprise a unique coral reef ecosystem located approximately 200-km (110 nmi) southeast of Galveston, Texas, on the outer continental shelf of the northwestern Gulf of Mexico. Designated as a National Marine Sanctuary in 1992, the Flower Garden Banks represents the northernmost coral reef on the continental shelf of North America. The banks are topographic highs of bedrock displaced upward by the intrusion of two salt diapirs. The bedrock is capped with the calcium carbonate deposition of reef-building corals and calcareous algae. The living coral reef is comprised of 20 species of corals, and supports 120 species of fishes and more than 250 species of invertebrates.

This ecological monitoring effort is the continuation of monitoring efforts begun in 1989 and first reported in 1992. Study purposes are:

1) to provide relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and production in the vicinity of sensitive ecosystems,
2) to document 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) to document long-term natural variation in reef growth and associated communities on the Flower Garden Banks and,
4) to stimulate ancillary research efforts and coordinate monitoring activities with agencies and institutions conducting water quality assessments and other studies in the vicinity of the Flower Gardens in order to better evaluate causes of environmental change.

Photographic techniques (i.e., random transects, encrusting growth, repetitive quadrats, and video transects) were used to measure/assess the growth, diversity, percent cover, and incidence of bleaching and disease of scleractinian hermatypic corals at the Flower Garden Banks. Accretionary growth of corals was assessed using both direct measurement and sclerochronology methodology. Visual assessments of the population density of large-bodied fishes and sea urchins were made. Long-term temperature and

insolation (light attenuation) were measured on the reef. The water column was sampled for contaminants using semi-permeable membrane devices (SPMD). Additionally, surveys of sea urchin populations, micromolluscan fauna, and habitats were conducted below the coral cap.

As in past studies, the *Montastraea annularis* complex (*M. annularis, M. franksi, M. faveolata*) was the dominant coral, providing 29.2% and 28.3% cover on the East and West Bank, respectively. *Diploria strigosa* was the second most common species of hermatypic coral with 13.1% and 10.0% cover on the East and West Bank, respectively. Total percent coral cover did not vary significantly between the East (54.4%) and West (49.8%) bank or between years. Analysis of species diversity and evenness showed no significant difference among studies, banks, or 1996 -1997.

In 1997, 45% of East Bank colonies and 67% of the West Bank colonies of *Montastraea cavernosa* showed substantial bleaching. Bleached colonies of *M. annularis* and *Millepora alcicornis* were also observed in 1997. This was believed to be a response to unusual water temperature fluctuations in 1997. Water temperatures ranged from 20.1 to 30.1 °C at the East Bank and 20.2 to 30.0 °C at the West Bank. Temperatures at the East Bank (mid-April through mid-June) were lower than the seven year average (1990-1997). Another apparent deviation from the seven year average occurred from late July until mid-August, 1997 at the East Bank when daily temperatures were higher than average. Daily water temperatures at the West Bank were higher than average from March through the first week of April and from mid-June through early September, 1997.

Mean accretionary growth at the East Bank was 5.7mm/year and 7.3mm/year at the West Bank. The encrusting growth rate was 0.37 and 0.40cm/year at the East and West Bank, respectively. Average net encrusting growth rates were 0.06 and 0.14 cm/year at the East and West Bank, respectively.

Coral disease was minimal, occurring in 0.006% of the 3,700 coral colonies examined. *Diploria strigosa* and *Montastraea* spp. were the most commonly afflicted corals. The overall loss of coral cover due to disease was less than 0.03%.

Analysis of fish counts did not indicate any trends, but some significant differences did occur. Creole fish (*Paranthias furcifer*) were significantly more abundant in 1996 than 1997. Compared to 1991, density of all large bodied fish combined on the West Bank was significantly greater in 1996/1997, as was the density of the creole fish and creole wrasse (*Clepticus parrai*). 1996/1997 density of the queen parrotfish (*Scarus vetula*) was significantly greater on the East Bank than in 1991.

Water chemistry indicated the presence of polycyclic-aromatic hydrocarbons (PAH) at the West (273 ng/l) and East Banks (290 ng/l) from February to September 1997. From September 1996 to February 1997, 1,023 ng/l of PAH was recorded at the East Bank. The source of PAH was likely natural hydrocarbon seepage, condensate oil seepage, and/or combusted ship fuels. The reader is cautioned that: 1) the concentrations measured (ng/liter = parts per trillion) are infinitesimal, and 2) the application of the semi-permeable membrane devices to record these contaminants was done under less than ideal conditions. Conclusions from this information are not warrented. Further study is required.

Pesticides and PCBs were also recorded. The amount of 4,4'-DDE (West Bank = 49.5 ng/l; East Bank = 43.5 ng/l) and 4,4'-DDT (West Bank = 23.6 ng/l; East Bank = 21.6 ng/l) were similar from the two sites collected from February to September 1997. The 4,4'-DDE (93.2 ng/l) and 4,4'-DDT (39.4 ng/l) were almost twice as high September 1996 to February 1997. The concentration of DDT relative to its derivative DDE suggests recently used DDT. The source and impact of these pesticides is not known. As with the application of semi-permeable devices to record PAH data, further study is warranted before drawing conclusions.

Other contaminants were detected, including:

- chlordane and its metabolites
- dieldrin
- hexachlorobenzene and its metabolites
- lindane
- PCB congeners

Analysis of attenuation coefficients (k) indicate that the water column at the Flower Garden Banks falls between the published values for the clearest coastal water (k=0.15) and the clearest oceanic waters (k=0.033). Analysis of trends in k values suggested that at least two attenuation regimes related to plankton blooms occurred that reduced water column transmissivity. It appeared that blooms were periodically flushed by the infiltration of oceanic water.

Surveys and habitat characterizations of deep (30 to 50 m) reef zones further substantiate the biogenic zonation correlated to depths previously described. More investigation is required to describe the interactive dynamics of the coral cap with the deeper adjacent habitats.

Transect surveys of sea urchins, a primary herbivore, were conducted at each bank during both sampling periods. Based on the data, it was concluded that the sea urchin population continues to be depressed, and that it did not vary significantly between sampling years or banks. During the 1996 transect surveys, one sea urchin was counted, and during the 1997 survey, three urchins were counted.

Micromolluscs from sand samples are currently being identified and counted. To date, 114 species representing 50 families have been identified, increasing by one-third the previously known invertebrate fauna of these reefs.

CONCLUSIONS

- The dominant corals of the Flower Garden coral reef ecosystem continue to grow at rates consistent with past measurements.

- The incidence of coral diseases is minimal and inconsequential at this time.
- The corals responded to elevated temperatures by exhibiting bleaching in 1997.
- Fish numbers showed limited variation, but no trends were apparent.
- Polycyclic-aromatic hydrocarbons and pesticides were present in the water column, but at minute levels (i.e. parts per trillion). Impact is not known.
- The sea urchin population was depressed.
- The molluscan fauna has only been partially described in past studies, and it is likely that more intensive sampling of other groups of organisms would substantially increase the recorded biodiversity at the Flower Garden Banks.
- The strength of the monitoring strategy as has been applied since 1989 is that is provides a long-term database of repeatable measures of growth and condition of the scleractinian corals forming the habitats of the Flower Garden coral reefs.
- The weakness of the monitoring strategy as has been applied since 1989 is that it does not adequately assess the interactive dynamics of the Flower Garden coral reef ecosystem to describe the ecosystem dynamics. More measures need to be taken to assess cause and effect relationships.

RECOMMENDATIONS

1) Eliminate growth spikes as a method for measuring accretionary growth. Use sclerochronology measurements to measure accretionary growth exclusively.
2) Continue and expand water chemistry analysis using SPMD technology. Record data no less than quarterly.
3) Expand water chemistry analysis to include nutrients (nitrogen and phosphorous) on a schedule no less than quarterly.
4) The protocol and technology applied to the measurement of light characteristics should be enhanced to allow diurnal collections, particularly during the late summer months before and after the annual spawning event.
5) Use random photographic transects outside the boundaries of the $100m^2$ study sites to test the representativeness of the designated study sites.
6) Continue analysis of sea urchin population densities on a quarterly basis.
7) Add qualitative and quantitative analysis of macroalgae.
8) Add fish census (stationary visual and/or roving diver census) to suite of measurements.
9) Add seasonal photographic transects to assess temporal occurrences, such as disease and bleaching.
10) Continue and expand monitoring and studies of the biogenic zones below the coral cap. Trophic structure analysis should be undertaken to describe biological energy linkages between the biogenic zones.
11) Measure seasonal and annual current patterns around and above the Flower Garden Banks.
12) Develop and apply dynamic ecosystem models to research and management decision making.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

Figure **Page**

LIST OF TABLES

LIST OF TABLES (Continued)

1.0 INTRODUCTION

1.1 OVERVIEW

This document was produced by the Texas A&M University-Corpus Christi (TAMUCC) Center for Coastal Studies (CCS) and the Texas A&M University-College Station Geochemical and Environmental Research Group (GERG) under contract to the Minerals Management Service (MMS) and the National Oceanic and Atmospheric Administration (NOAA). The study reported herein represents an ongoing effort to monitor the resources of the Flower Garden Banks coral reefs, and to protect this unique and valuable natural resource. Increased human activity, within and near the Flower Garden Banks, and the potential threat posed by this activity on the environments of the outer continental shelf of the northwestern Gulf of Mexico make research and monitoring efforts critical to preserving the long-term health and sustainability of the Flower Gardens Banks coral reef system.

This monitoring and research effort is the continuation of efforts begun in 1989 (Gittings *et al.*, 1992) for the purposes of:

1) to provide relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and production in the vicinity of sensitive ecosystems,
2) to document 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) to document long-term natural variation in reef growth and associated communities on the Flower Garden Banks and,
4) to stimulate ancillary research efforts and coordinate monitoring activities with agencies and institutions conducting water quality assessments and other studies in the vicinity of the Flower Gardens in order to better evaluate causes of environmental change.

1.1.1 Habitat Description

The Flower Garden Banks are located on the edge of the outer continental shelf of the Gulf of Mexico. The East Flower Garden Bank located at 27°54.5' North latitude and 93°36.0' West longitude is approximately 193 km southeast of Galveston, Texas, and the West Flower Garden Bank is located approximately 172 km southeast of Galveston at 27°52.4' North latitude and 93°48.8' West longitude (Figure 1.1.1). Both banks are topographic highs created by the uplift of underlying salt domes of Jurassic, Louann origin (Rezak, 1981). These domes of bedrock overlying the uplifted salt domes and capped by an overgrowth of calcareous marine organisms 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 varies in depth from approximately 18 to 36 m. (Rezak *et al.*, 1985).

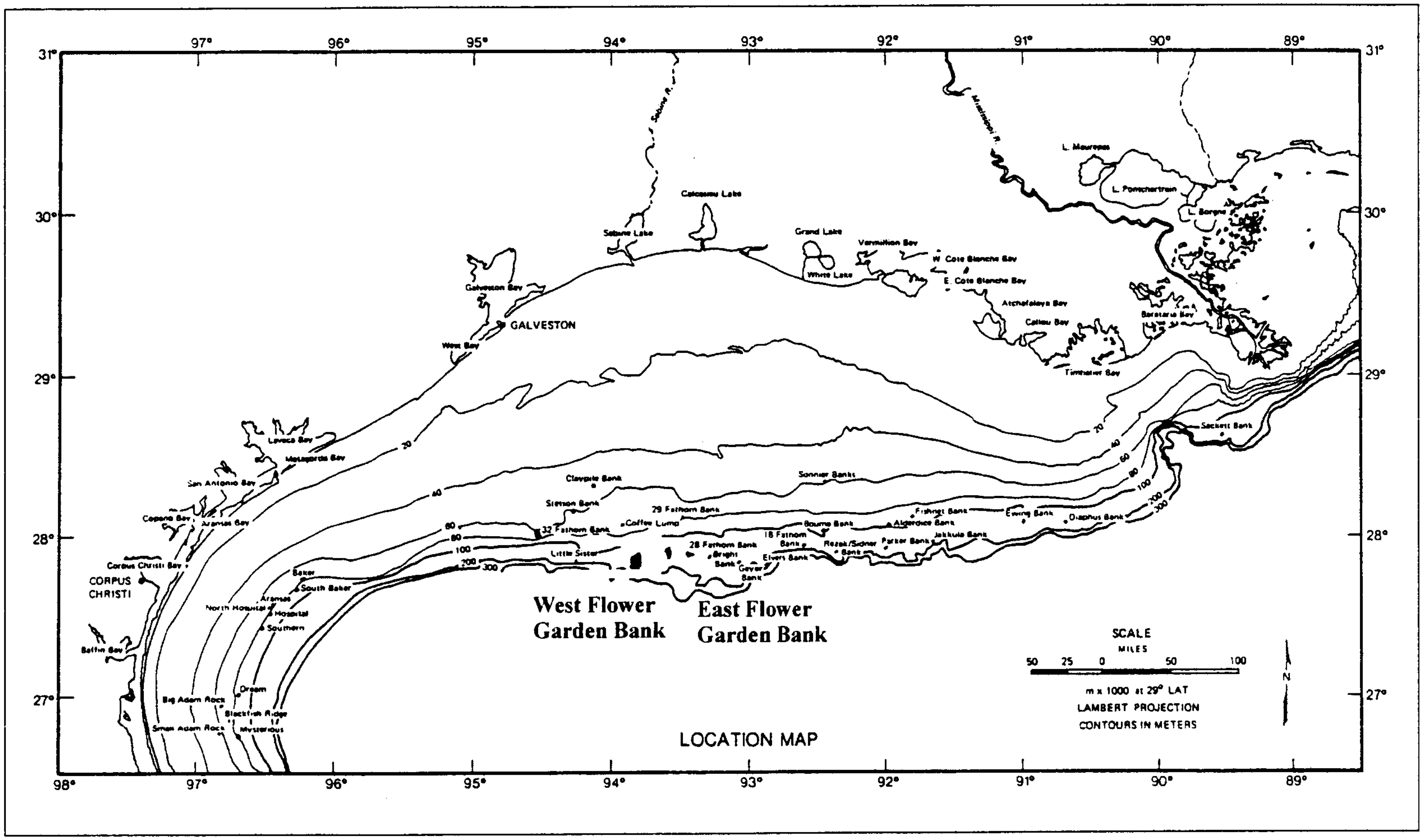


Figure 1.1.1. Location map of the East and West Flower Garden Banks in relation to the continental shelf and other topographic features of the northwestern Gulf of Mexico (from Gittings *et al.*, 1992).

The pear shaped East Flower Garden Bank, which covers an area of approximately 67km^2 (Rezak *et al.*, 1985) slopes from the crest at approximately 20m to a plane of terrigenous muds surrounding the banks at a depth of 100-120m. The eastern and southern edges of the bank slope steeply while the area to the north and west of the high diversity coral cap exhibits a more gentle slope (Figure 1.1.2).

The major features of the 137km^2 West Flower Garden Bank are three crests aligned along an east-west axis (Figure 1.1.3). The middle crest rises from a depth of 100 -150m to within 18m of the surface and supports a coral reef habitat (Rezak *et al.*, 1985).

The Flower Garden Banks 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 100km south of Tampico, Mexico, are the closest extensively developed coral community in the Gulf of Mexico.

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

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

The biological zonation of the coral reefs is dominated by the higher diversity in the *Montastraea-Diploria-Porites* Zone, which is depth limited to less than 36m (Figure 1.1.4), and the lower diversity *Stephanocoenia-Millepora* Zone extending from 36-52m. (Rezak *et al.*, 1985). A lower diversity reef environment is found in the Algal-Sponge Zone from ~ 46-88m. Lower portions of this depth range are characterized by antipatharians which grade into a soft bottom environment composed of coarse carbonate sands below ~88m.

***Montastraea-Diploria-Porites* Zone**

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*. Crustose coralline and calcareous green algae are also common in this zone. Total live coral cover is ~45-52% The high coral cover is interupted by areas of bare reef rock and patches of biogenic sands. The calcium carbonate substrate in this zone was formed and is maintained primarily 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

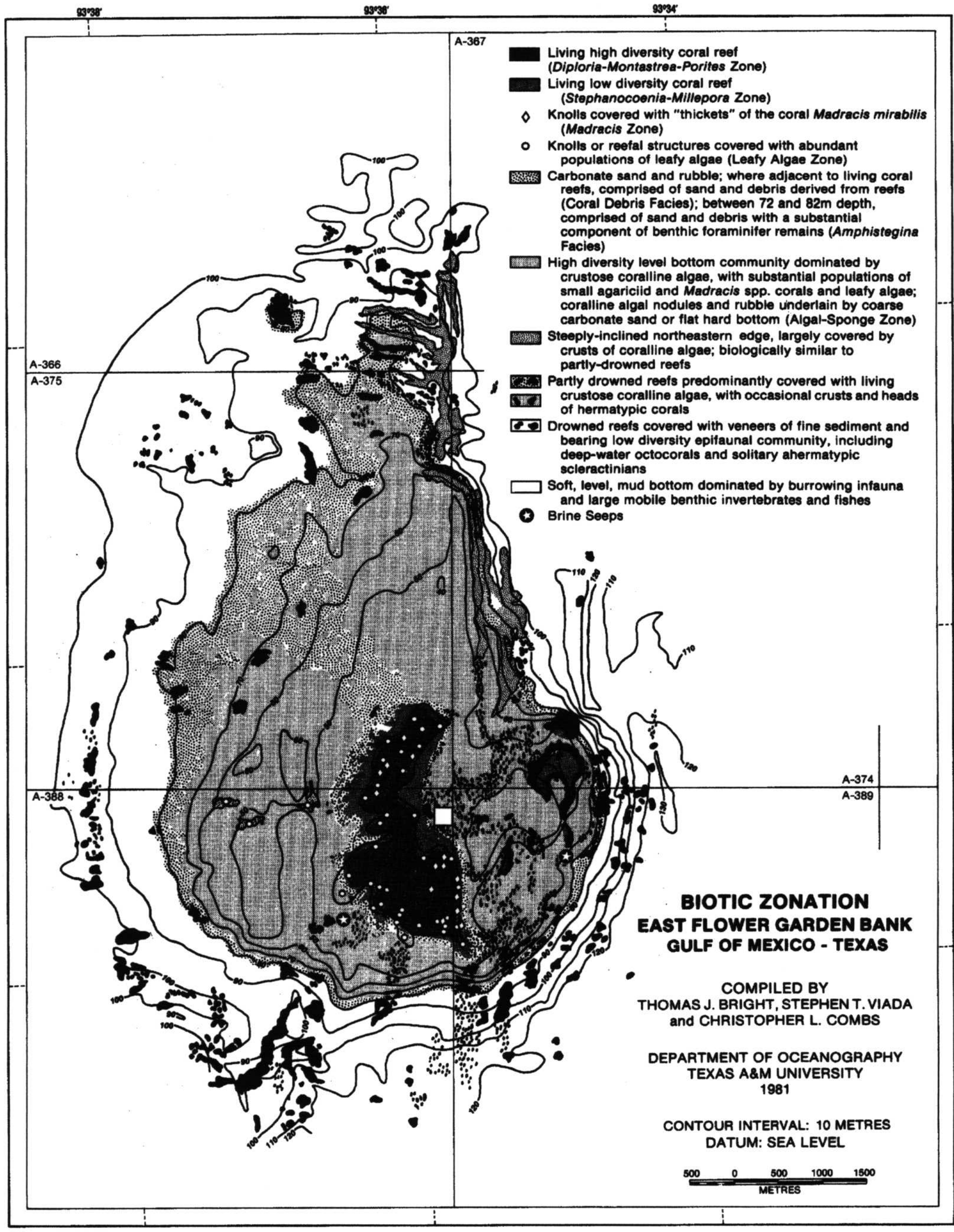


Figure 1.1.2. Biotic zonation and topography of East Flower Garden Bank. The dark area depicts the high diversity coral reef zone and the white square denotes the study site (from Rezak *et al.* 1985, permission granted for use by John Wiley and Sons publishing).

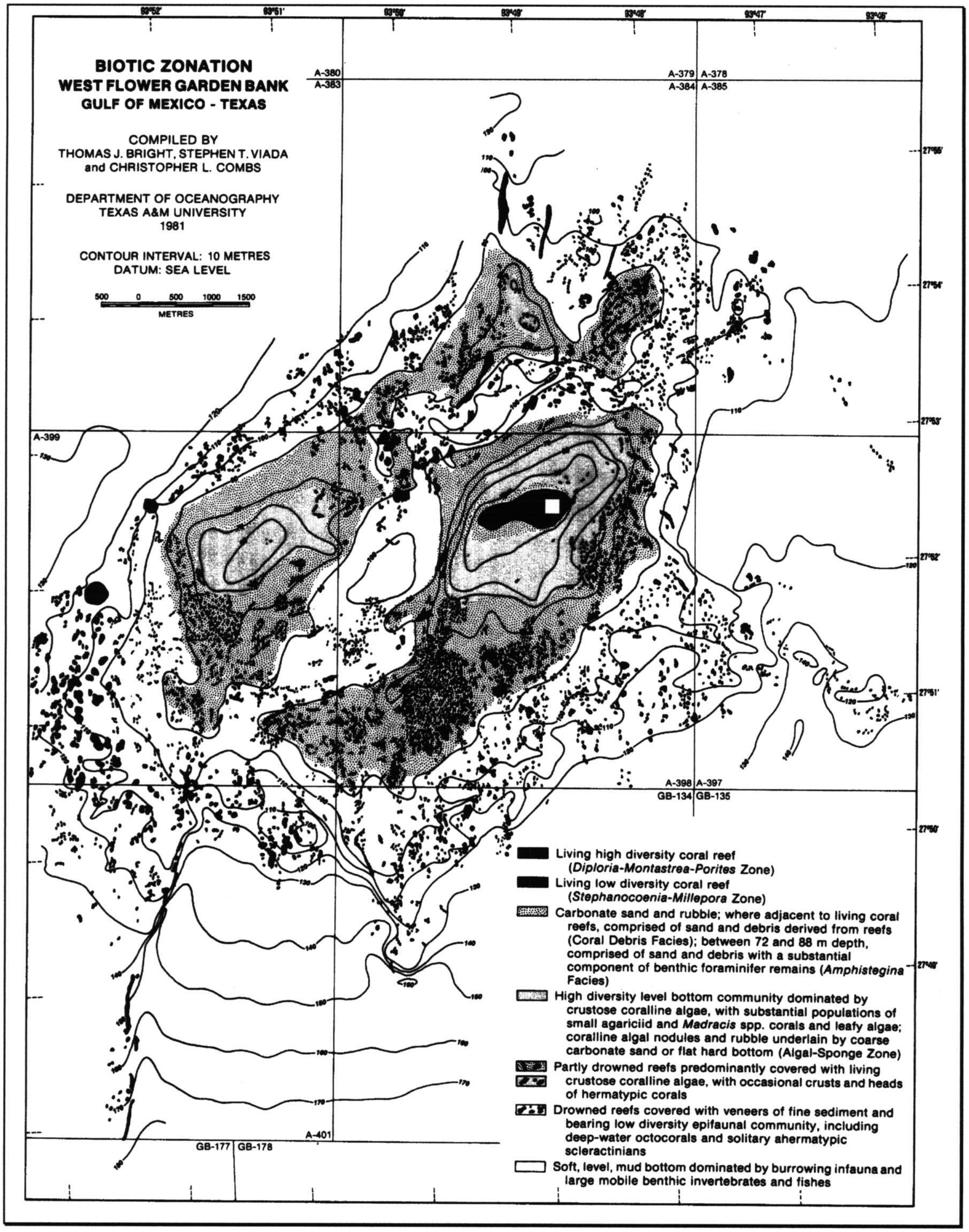


Figure 1.1.3. Biotic zonation and topography of West Flower Garden Bank. The dark area depicts the high diversity coral reef zone and the white square denotes the study site (from Rezak *et al.* 1985, permission granted for use by John Wiley and Sons publishing).

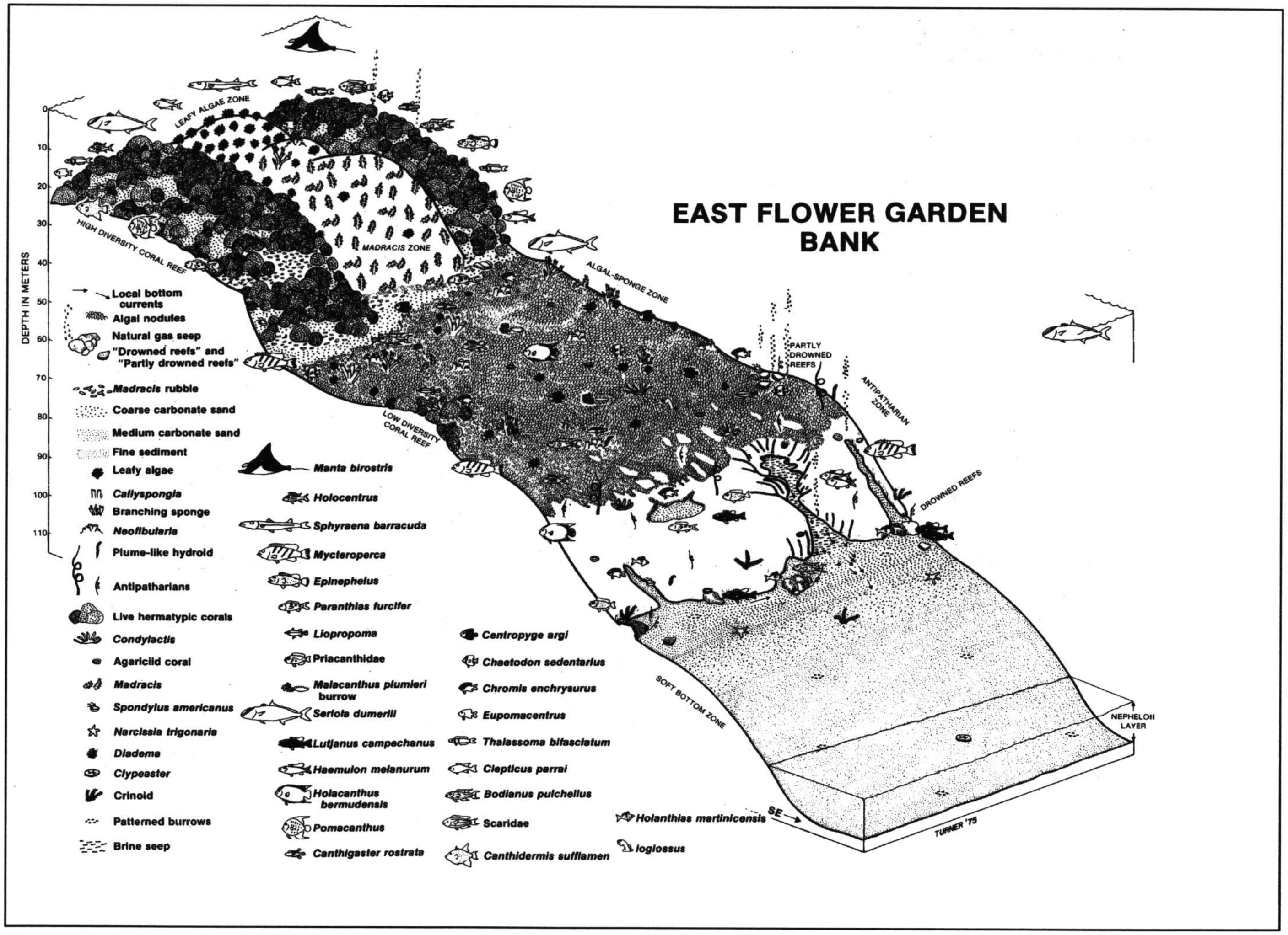


Figure 1.1.4. Cross-section of East Flower Garden Bank showing zonation and distribution of common species (from Rezak *et al.* 1985, permission granted for use by John Wiley and Sons publishing).

and Pequenat, 1974) and 120 species of fishes (Pattengill *et al.,* 1997) also inhabit this high diversity community.

***Stephanocoenia-Millepora* Zone**

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

2.0 METHODS

2.1 FIELD LOGISTICS

Sampling cruises were conducted aboard the *M.V. Fling* during 14 - 18 October 1996 and 9 - 12 September 1997. Poor weather conditions during the October 1996 cruise made sampling difficult and caused the cancellation of some ancillary studies. Conditions during the September 1997 cruise were optimal, facilitating the completion of several ancillary studies in addition to all contracted work.

2.2 STUDY SITES

During both cruises sampling was conducted within previously established 100 x 100 m study sites on both East and West Banks. The East Flower Garden Bank site was initially established in 1989 by Texas A&M University during early MMS-funded monitoring efforts (Gittings *et al*., 1992). The West Flower Garden Bank site was originally established by Continental Shelf Associates (CSA) in 1988 and incorporated into the monitoring efforts by Texas A&M University for MMS (Gittings *et al*., 1992). Subsurface buoys attached to stainless steel eye-bolts cemented into the reef rock marked the four corners of each study site. During each field effort, graduated, color coded polypropylene lines were extended between each corner eye-bolt 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 1m above the reef substrate to increase visibility for the divers and to reduce contact with the living reef. Boundary lines were installed prior to sampling and were removed at the end of sampling. Each dive team was supplied with detailed underwater maps (Figures 2.2.1 and 2.2.2) depicting the relative position of each repetitive station in relation to boundary lines and major topographical features. A master map on the surface was constantly updated with the relative positions of new or re-numbered stations added during each cruise. During spring, summer and fall months a large surface buoy is attached to a mooring line attached to a stainless steel u-bolt permanently cemented into the reef rock within each site. The buoys are owned by the 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

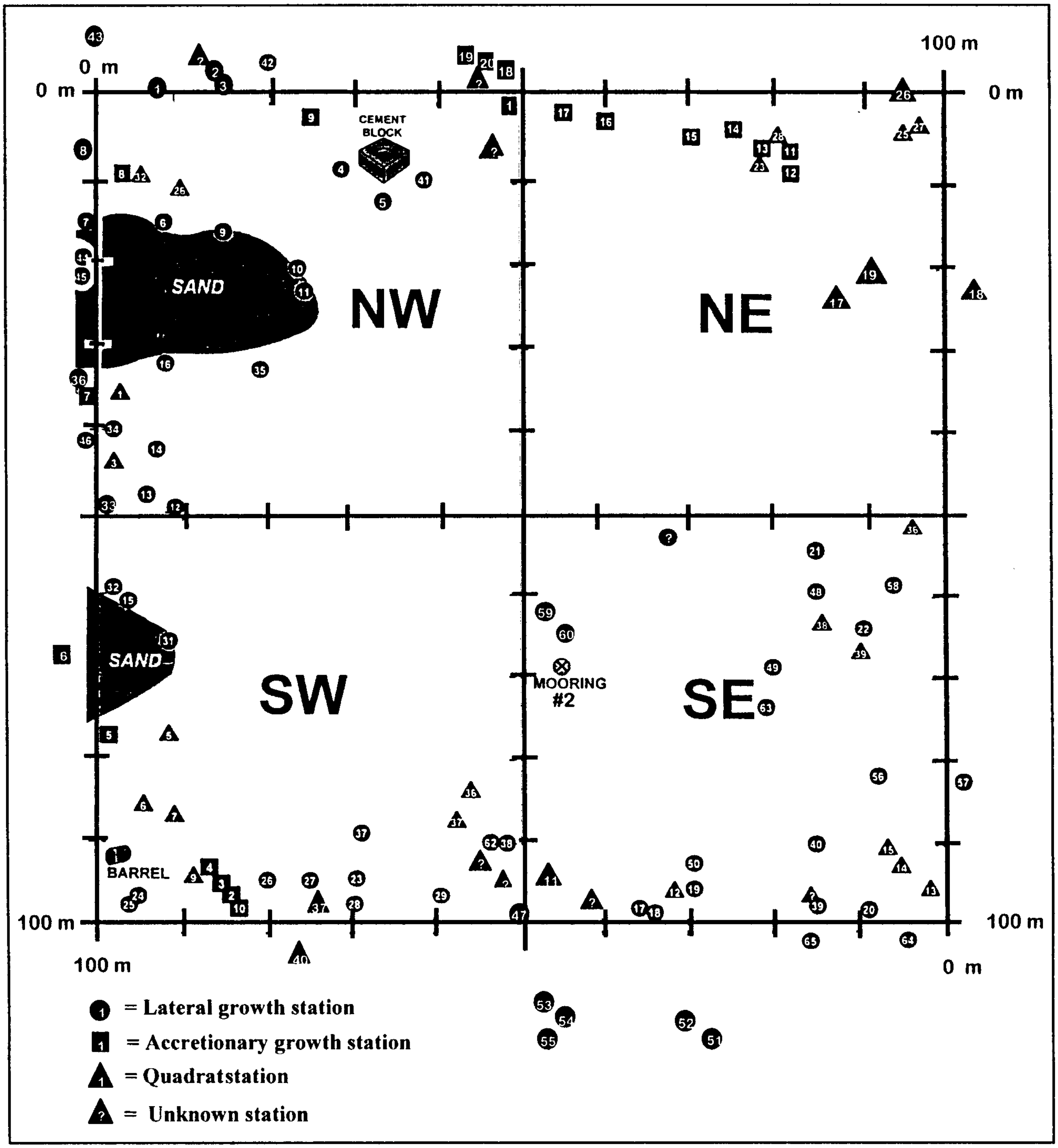


Figure 2.2.1. Map of East Flower Garden Bank 100 m x 100 m study site showing relative positions of permanent stations, mooring bolt and other conspicuous features.

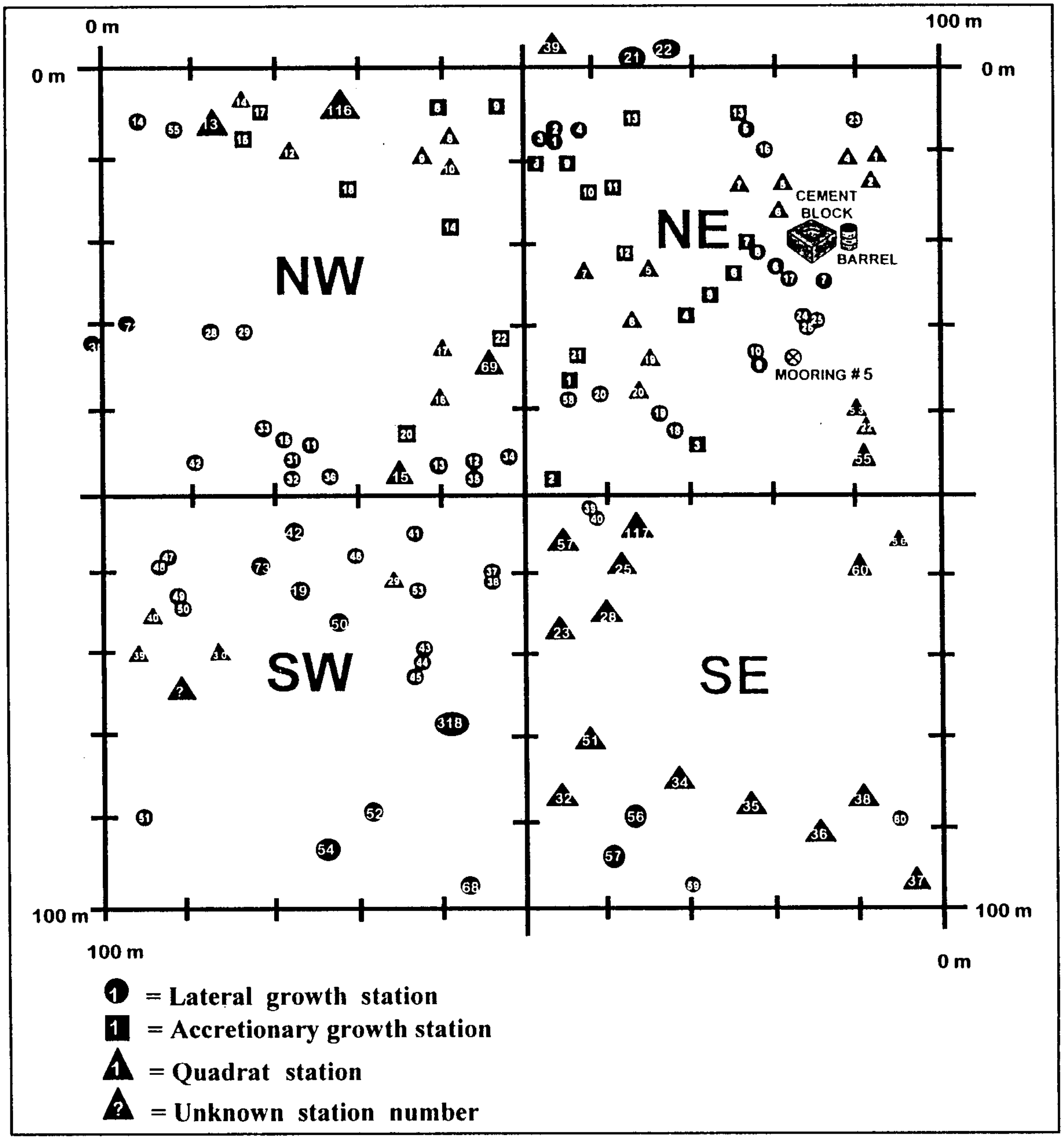


Figure 2.2.2. Map of West Flower Garden Bank 100 m x 100 m study site showing relative positions of permanent stations, mooring bolt and other conspicuous features.

2.3 RANDOM TRANSECTS

Random photographic transects conducted within the boundaries of each study site provided data on coral community population diversity and cover. Fourteen 10m transects, each containing seventeen non-overlapping photographs, were taken on each site during each cruise (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, 28mm lens and dual Nikonos strobes mounted on a rectangular aluminum or stainless steel camera frame (Figure 2.3.1). The bottom of each frame was wrapped in closed cell foam to protect the corals from damage. This system produced color positive images of approximately 44 x 63cm of the seafloor.

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

Incidents of obvious coral bleaching were quantified on random transects. The number of bleached colonies of a species divided by the total number of colonies of that species in a transect provided the percent of bleached colonies per transect. A colony was considered significantly bleached when greater than 50% of the colonies' areal coverage showed a definitive lack of pigmentation.

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. Data were acquired using a Wacom serial graphics tablet and Jandel Scientific Sigma-Scan Pro 4.0 software. Colonies were calibrated and outlined using the serial graphics pen and cover automatically calculated. Cover data were calculated for corals, sponges, leafy algae and exposed reef rock. Species diversity (Eq.1), evenness (Eq.2), and relative dominance (Eq.3) were calculated as follows:

$$H' = -\sum \frac{Ni}{N} \log \frac{Ni}{N} \qquad \text{(Eq.1)}$$

$$J' = H' / \ln S \qquad \text{(Eq.2)}$$

$$Dn = 1 - \sum p_i^2 \qquad \text{(Eq.3)}$$

Kruskal-Wallis analysis of variance tests were employed 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 a posteriori to define differences.

Figure 2.3.1. Diver with random transect camera framer.

2.4 ACCRETIONARY GROWTH

The dominant coral species at the Flower Gardens, *Montastraea annularis* (Gittings *et al.*, 1992; Continental Shelf Associates (CSA), 1996: relative dominance> 50%) has recently been divided into three separate species (Weil and Knowlton, 1994). Two of these sibling species are common at the Flower Gardens, *M. franksi* and *M. faveolata*. Of these two, only *M. faveolata* produces massive colonies appropriate for determining accretionary growth rates.

Two methods were used for determining *M. faveolata* growth rates during the 1996-1997 contract period. The older technique using growth spike measurements from Gittings *et al.*, (1992) and CSA (1996) was continued. A more accurate sclerochronology method (Hudson, 1981; Hudson *et al.,* 1976) was also used, consisting of measurements of multiple coral cores collected during each sampling effort. This technique involves the measurement of growth band widths on radiographic images of coral core slabs.

2.4.1 Growth Spike Stations

Thirty stainless steel spikes were originally implanted in the tops of *Montastraea faveolata* colonies (Figure 2.4.1) on both the East and West Flower Garden Banks during the 1989-1991 TAMU study (Gittings *et al.,* 1992). At the end of the project, accretionary growth measurements were derived from 26 of 30 on the West Bank and 23 of 30 stations on the East Bank. During the 1994-1995 CSA study (CSA, 1996) an entirely new set of accretionary growth stations was established because most station pins remaining from the previous study were deemed unusable. Twenty, 0.25 inch masonry expansion bolts were then installed on both banks. Estimates of accretionary growth rates were determined from two or more length measurements of the same spike over time; suspicious or aberrant data were eliminated. Inherent problems with accretionary growth spike measurements have been described in both previous reports (Gittings *et al.*, 1992; CSA, 1996).

The most significant of these has been the alteration of coral growth patterns at the site of spike placement. Observed effects include the death of coral tissue around the spike, apparently caused by installation of the spike itself. More commonly, healthy coral tissue tends to grow upward on the spike resulting in inaccurate subsequent measurements (smaller measurements suggesting higher growth rates). Field data were therefore evaluated for reasonableness and extreme variations in collected data must be discarded. In general, data were evaluated for:

- Negative growth rates: i.e., a longer spike measurement after some period of time (e. g., one year) with no sign of mortality or abrasion. This is the typical result of a loose growth spike.

- Growth rates exceeding 12 mm/year. This figure is somewhat arbitrary but is nearly a factor of two more than the mean growth rates obtained from any particular location over many years and usually results from coral tissue growing upward along the spike at a faster rate than the rest of the colony.

- Zero growth: Though it may be possible for a coral to exhibit no growth over 12 months (continuously bleached for example), this has never been observed at the Flower Gardens.

Figure 2.4.1. Diver measuring growth spike installed in a colony of *Montastraea faveolata*. Note numbered tag to the right of growth spike.

If two different spike measurements separated by a year or more are identical, it is suspected that there has been some type of measuring error or spike movement.

A total of 15 measurements for the West and 18 from the East were used to derive final growth data reported in CSA (1996). The majority of these pins were utilized for 1996-97 measurements. During this study, six new pins were installed on the East Bank in 1996. In 1997, eight pins were replaced on the West Bank and ten on the East Bank, primarily due to overgrowth.

2.5 SCLEROCHRONOLOGY

Sclerochronology in this monitoring effort involved the determination of annual coral growth rates through the measurement of accretionary growth band widths. Cores were obtained from live coral colonies using a pneumatic drill attached to a compressed air scuba cylinder. Resulting cores were 60mm in diameter and were drilled to a minimum depth of 100mm representing more than ten years of growth. It was also essential to drill the core sample perpendicular to the surface of the coral colony to obtain the most accurate and continuous growth information. Two coral samples were obtained from two colonies on both the East and West banks. It should be noted that these cores were not taken from the apex of the selected *M. faveolata* colonies and the resulting growth band measurements may not represent maximum growth rates. Resulting holes left behind after core removals were plugged with tapered concrete plugs. The plugs prevent accumulation of detritus in the core holes and allow coral growth on the concrete substrate.

Cores were sectioned in the laboratory using a dual-blade diamond impregnated rock saw providing 3-4mm thick slabs. Coral slabs were arranged on a piece of Kodak brand Industrix 400 x-ray film and exposed to x-rays (4 mA, 40 KV for 1 minute) to reveal annual density bands. A machined metal scale was included in each image to insure precise measurement of growth bands. Resulting film negatives were scanned directly into a computer so they could be expanded in size for analysis purposes and report illustration.

One annual growth increment was defined as the combination of both one low density band and its adjacent high density band (Knutson *et al.*, 1972). The area between the upper boundary of two sequential high density growth bands was considered as an annual growth increment. Scanned images were expanded by a factor of about ten for measurement of growth band widths. An object-oriented drawing program was used to place measurement lines parallel to growth axis. Object information (line length) was automatically displayed. Measurements were taken at three separate locations for each annual growth band when possible. Measurement data was then corrected using the x-rayed precision metal scale included in each x-ray.

2.6 ENCRUSTING GROWTH

During the previous study (CSA, 1996), 60 colonies of *Diploria strigosa* were established as permanent encrusting growth stations on each bank. Growth stations were installed along the margin of live coral growth adjacent to bare reef rock. These stations were established by placement of two permanently installed pins imbedded 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. Each station was identified by a uniquely numbered plastic tag secured to one of the pins. Net growth rate was defined as the mean rate of change of coral margins observed to advance or retreat using pooled measurements from all stations.

A Nikonos V camera equipped with a 28mm lens, Nikonos close-up kit, Nikonos strobe and Kodak Ektachrome 100, 36 exposure slide film was used to produce 13.3 x 19.7cm photographic images of each station. By placing the inside lower edge of the camera framer against the two pins, a repeatable image of the station was produced (Figure 2.6.1). Each station was photographed and the station number and frame number recorded on an underwater slate. This information was transferred to the permanent data log.

All resulting images were digitized and stored on CD-ROM digital media. Identical images taken on different cruises were matched by ridge position of the corals. Consecutive images were traced using a Wacom serial graphics tablet and Jandel Scientific Sigma-Scan Pro 4.0 software. This software calculated the area coverage (cm^2) relative to growth and retreat of live coral for each photograph. Growth and/or retreat rates for each station (cm/yr) were determined by dividing areal measurements (cm^2) by the total border length of the station. Net growth was determined by pooling growth and retreat measurements from all stations. Each station provided a single measurement of growth, retreat and net growth and net retreat.

2.7 REPETITIVE QUADRATS

During an initial baseline monitoring survey in 1988, CSA established 40 permanent repetitive photographic stations on the West Flower Garden Bank. The following year, 40 additional stations were established on the East Flower Garden Bank by Texas A&M University during the initial stages of a three year monitoring study of both banks. During the 1994-1995 study conducted by CSA most of these "original" 80 stations were used, although a few new ones were established to replace lost stations. During the 1996 survey, several stations were found to be in need of repair. These stations were refurbished and reestablished when necessary. The most recent 1996-1997 monitoring survey utilized the new stations as well as those previously established by CSA in 1994.

Repetitive post stations were established by vertically implanting a brass or stainless steel rod into the reef rock. Individual stations were then identified by affixing a numbered plastic tag to each post (Figure 2.7.1). During the annual cruises, each station was photographed using a T-shaped camera frame bearing a downward facing Nikonos V camera with a 15mm lens synched to two Ikelite 225 watt-second strobes mounted on the ends of the horizontal bar (Gittings *et al.*, 1992). Distance was set at 2m and f-stop at 8. The repetitiveness of the photographs was assessed by orientating 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 individual station photographs was conducted by projecting the images onto a flat surface, generating an 25.2cm by 37.9cm image. For each station, the margins of individual coral colonies were traced from 1996 photographs. The 1997 photographs were then superimposed on the 1996 templates for temporal comparisons. Differences between current and pre-existing

Figure 2.6.1. Diver photographing a permanent encrusting growth station.

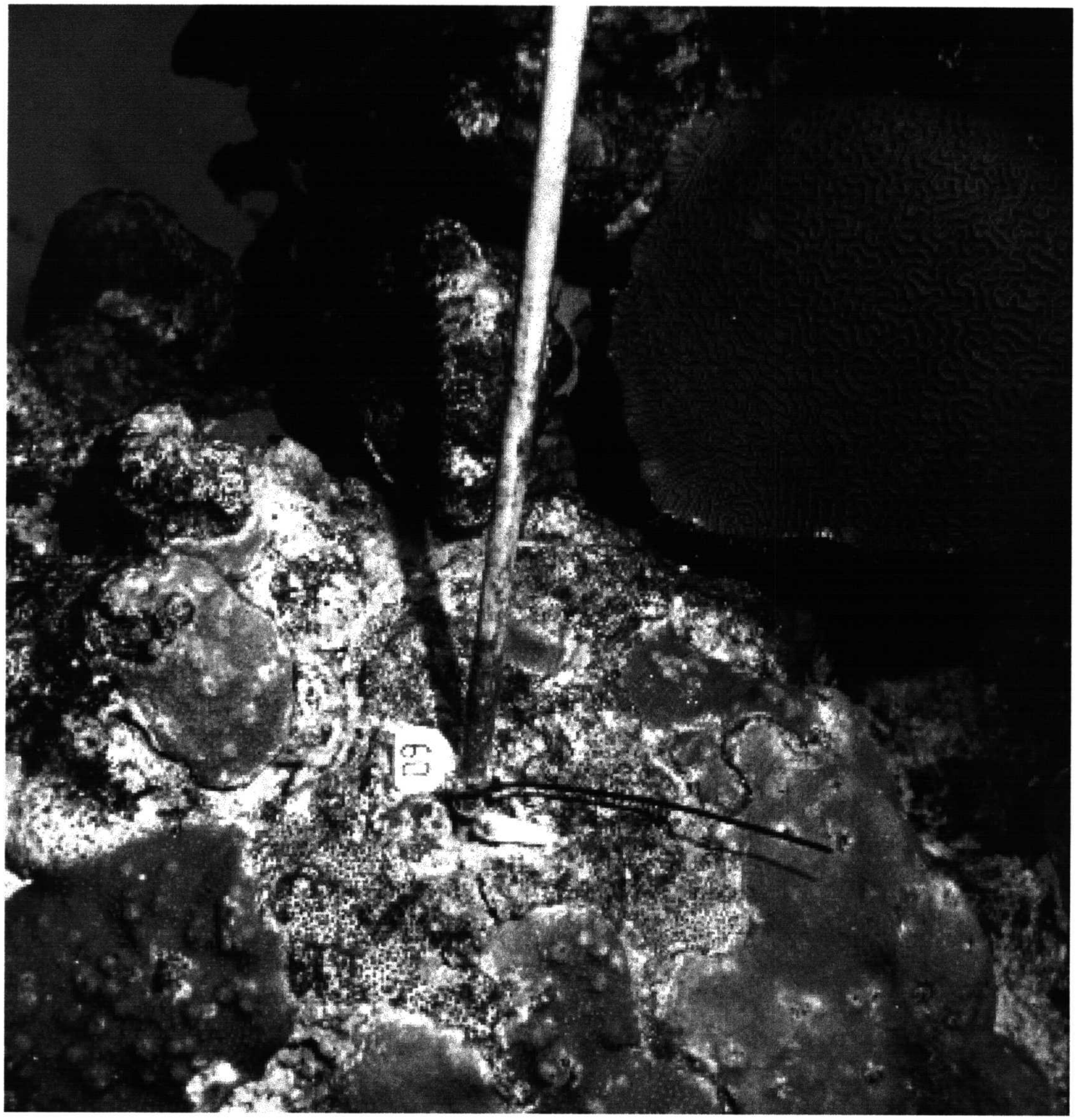


Figure 2.7.1. Permanent repetitive photographic station. Each station was identified by a numbered plastic tag.

margins were identified and characterized in one of the following categories: growth, (marginal or in-filling), loss of tissue (retreat), whether by algae, sediment, disease, competition, fish biting or other factors, and the incidence of bleaching and disease. In addition, coral cover was determined for each station using 24 transparent overlays containing 100 randomly positioned crosses. Cover estimates were made by counting the total number of crosses intersecting live coral tissue. For each station, three randomly selected overlays were used to provide an estimate of actual coral cover. This same procedure was used to estimate bleached cover or tissue loss resulting from disease at stations in which these observations were made.

2.8 VIDEO TRANSECTS

Similar to the two previous studies (Gittings *et al.*, 1992; CSA, 1996), diver-held video transects were utilized. Though of limited quantitative value, the general objective of documenting a relatively large area of coral habitat is quickly and easily accomplished using this technique. Two transects were performed on each bank using the same techniques as 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, 2m guideline attached to the camera housing. This camera height-above-bottom results in a 3.5m transect width on the videotape when viewed at the center of the television monitor. Each 100m transect represents a total area of $350m^2$.

Prior to performing the video transects, it was critical to stretch the transect lines very tight as well as check that their path followed a straight line between corner markers. This was to insure the best chance to obtain transect data matching previous efforts as closely as possible. Typically, one entire dive per bank was necessary to conduct these transects. Using these precautions, at least portions of major coral colonies and other features were observed on repeated transects.

In addition to the four 100m boundary line transects, 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 is useful for observing detail and minor changes to the areas or reef around each corner marker.

Resulting transect video tapes were analyzed in the laboratory using one or two video tape players (VCR or camcorder) and one or two monitors. The second tape player and monitor were valuable for playing video transects from two different time periods simultaneously. This was the only method that proved reliable for detecting all varieties of change in the coral community, both major and minor, including bleaching, physical damage and various types of mortality.

Coral bleaching and areas of recent mortality were best detected while simultaneously viewing the same transect from two different time periods. Coral area apparently affected by bleaching was estimated using known dimensions of the video transect image in cases when the area was small. If a larger area appeared to be affected, a random dot pattern technique similar to that used for coral percent cover (Gittings *et al.*, 1992) was used on a still frame image.

Descriptions of mortality and bleaching observations will be separated. The distance location of each observation along the boundary marker line was determined using the elapsed time along the swimming transect. Distance markers in the line as well as the mid-point of the line where cross quadrat lines were joined (at 50m mark) were used to verify these distances. The time measurement technique proved to be accurate to within 2m.

Similar to Gittings *et al.* (1992), large bodied-fish were censused. This analysis was not performed in the CSA (1996) project. This limited data is certainly not robust, but does provide continuing data for the most prominent fish species at the Flower Garden Banks.

Large-bodied fish (approximately 15cm length) were counted within the 3.5m transect width at approximately the mid-point of the video monitor to avoid exaggerated counts from observations in the upper (distant) portion of the field of view. Data from each transect were divided into one-minute increments and data from each minute were considered a separate sample. Reef fish numbers were converted into density as number/100 m^2. Statistical comparisons between banks, years and previous studies were performed using standard t tests. With the same number of samples during all transects (5), the t test is particularly robust. With regard to trophic groups from the Flower Gardens specifically, Pattengill *et al.* (1997) identified the following groups: carnivores (piscivore) such as groupers and snappers, planktivores such as creolefish, grazers such as parrotfish and butterfly fish, and invertebrate feeders such as wrasses and angelfish.

2.9 WATER QUALITY/INSOLATION/TEMPERATURE

2.9.1 Water Quality

Semi-permeable membrane devices (SPMDs) were deployed at the East and West Flower Garden Banks from September 1996 to February 1997 and from February 1997 to September 1997. The SPMDs were dialyzed by Environmental Sampling Technologies (EST) and the dialysates returned to Geochemical and Environmental Research Group (GERG) for contaminant analyses. The dialysates were processed by GERG with analytical protocols used for tissue samples. Silica gel/alumina column chromatography and HPLC Phenogel columns were used to separate the contaminants of interest from any lipid materials absorbed by or contained within the SPMDs. The purified dialysates were then analyzed by gas chromatography with a mass selective detector (GC/MSD) for polycyclic aromatic hydrocarbons (PAH) and gas chromatography with an electron capture detector (GC/ECD) for pesticides and PCBs.

2.9.2 Insolation

Two underwater Li Cor spherical light sensors and Li-1000 data loggers were used to monitor total insolation at the East and West Flower Garden Banks. Both sensors were deployed at a 24m depth. The light sensors were secured to a projecting vertical bar on the cages using heavy-duty nylon cable ties. Commercially available "ziplock" plastic bags were secured over the sensors to prevent biofouling and subsequent scoring of sensor surfaces during cleaning. These protective covers will be replaced as needed by divemasters aboard the vessels *M/V Fling* or *M/V Spree* during scheduled sport diving trips. A reference sensor was also deployed on the Mobil HI389 platform to monitor light intensity at sea level. All instruments were configured to record hourly averages in units of $\mu M\ s^{-1}\ m^{-2}$. Data were recovered from the data loggers during the spring 1997 and fall 1997 monitoring cruises. On these occasions, batteries were replaced in the data loggers. The sensor at the West Bank was replaced with a newly calibrated sensor during the spring 1997 cruise.

2.9.3 Temperature

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. Thermographs were retrieved, downloaded and replaced during each monitoring cruise.

2.10 DEEP REEF SURVEY

Diver surveys, including macrophotography, sample collections and diver-held video transects, were conducted on both banks in deep water during the 1997 cruise. Transect lines were laid out beginning well off the edge of the coral community into the *Stephanocoenia/Millepora* zone. The maximum depth of the surveys was 51m (168 ft) at the East Bank and at 44m (144 ft) at the West Bank.

2.10.1 Deep Reef Video Survey

Using video transect techniques described in section 2.8, diver-held video was also obtained in the *Stephanocoenia/Millepora* Zone along a survey line placed on the bottom beginning in water beyond the edge of the coral reef habitat and extending toward the reef to a depth of about 30m. These transects were intended to be 100m in length but extended farther on the East Bank due to a longer than expected distance to reach the coral reef habitat. The video camera was held as close to vertical as possible while swimming along the transect line at a height of 2m off the bottom as determined by a suspended weight. Vertical orientation allows more accurate estimates of percent cover and permits density calculations derived from the camera lens angle of view together with the height above bottom. Because the vertical perspective makes it difficult to judge the relief of objects and makes some species identifications difficult, the diver periodically stopped swimming and moved the video camera closer to the bottom and into a nearly horizontal orientation. A slow 360° circular pan allowed detailed observations and close-ups at various points along the transect. Depths were indicated on video using hand signals. On the East Bank, the video transect began at a depth of 51m (168 ft) and continued up onto the coral reef to a depth of 31m (100 ft). The transect on the West Bank began at 44m (144 ft) and ended on top of the high diversity coral reef at a depth of 27m (90 ft).

Each video transect was reviewed and analyzed both qualitatively and quantitatively. Habitat composition was described qualitatively along the entire East Bank and West Bank transect lines and percent cover was determined from image analyses from a selected set of video frame images. Estimated percent cover and densities of some organisms were determined along vertically oriented transects. At several locations along the deep coral reef habitat, video frames were captured using a PC computer and Snappy brand video capture device. Images were enhanced and printed to enable point intercept analyses resulting in percent cover of various habitat elements. The captured images were analyzed using the standard 100 point intercept analysis for percent cover (three replicates for each estimate). Percent cover was determined for the vertical images only.

2.10.2 Deep Reef Photographic Survey

Still photographic surveys (35mm slide) were undertaken with partial success. Nikonos V cameras were used to take both $0.5m^2$ random photographic images and random 28mm lens close-up images. Due to camera malfunction, the $0.5m^2$ random photographic images were unusable. Eighteen random 28mm lens close-up images suitable for laboratory analysis were obtained. These images were analyzed using a standard point intercept method. An overlay containing 100 points was superimposed on each image and the organism or substrate lying under each point was identified. Three replicates for each image were analyzed.

2.11 SEA URCHIN SURVEYS

The long-spined sea urchin, *Diadema antillarum,* once common at the Flower Garden Banks suffered a region-wide die-off in 1983/84 (Lessios *et al.*, 1984). During recent years, observations suggest this species is rare at the Flower Gardens. In an effort to monitor changes in *Diadema* population levels, night time transects were conducted to establish current population levels as a basis for comparison with future observations. Transects were conducted approximately 1.5 hours after sunset. Site boundary lines were used as transect lines. Divers swam the length of the 100m long transect line recording the number of sea urchins observed within one meter of the line.

2.12 MICROMOLLUSCAN FAUNAL SURVEY

During the 1996 and 1997 monitoring cruise, researchers collected sediment samples from the East and West Flower Garden Banks for identification and enumeration of micromolluscan infauna. Samples collected from depths of 23, 34, 43, and 49m were preserved in isopropyl alcohol for 72 hours. In the lab, samples were washed, dried and divided into 50ml aliquots. Sediments were then sorted, and molluscs were identified to the lowest possible taxon and enumerated.

3.0 RESULTS

3.1 RANDOM TRANSECTS

3.1.1 Coral Cover and Relative Dominance

During the 1996 and 1997 cruises the *Montastraea annularis* complex was the dominant coral taxon in both percent cover (Table 3.1.1) and relative dominance (Table 3.1.2).

On the East Flower Garden Bank, the *M. annularis* complex had a mean percent cover and relative dominance of 29.2% and 60.0%, respectively, while on the West Flower Garden Bank the *M. annularis* complex displayed a mean 28.3% cover and relative dominance of 55.5%. *Diploria strigosa* was second in percent cover at both study sites comprising 13.0% and 10.0% mean cover on the East and West banks, respectively. Mean relative dominance for *D. strigosa* was 15.9% for the East Bank site and 19.7% for the West Bank site.

Table 3.1.1

Mean percent cover (%) of corals, reef rock, algae, sponge, and sand on random transects sampled during 1996 and 1997 survey cruises at the East and West Flower Garden Banks

	PERCENT COVER			
Analyzed Component	**East Flower Garden Bank**		**West Flower Garden Bank**	
	1996	**1997**	**1996**	**1997**
Montastraea "annularis"	30.49	28.00	33.98	22.63
Diploria strigosa	6.80	9.35	11.63	8.36
Porites astreoides	5.88	6.58	2.65	3.20
Montastraea cavernosa	6.00	3.73	4.69	3.26
Colpophyllia natans	0.95	3.11	1.73	1.20
Millepora alcicornis	2.31	0.79	1.50	0.89
Agaricia agaricites	0.97	0.20	0.26	0.38
Stephanocoenia intersepta	0.60	0.96	0.58	0.22
Madracis decactis	0.54	0.01	0.10	0.56
Siderastrea siderea	0.31	0.15	0.20	1.37
Mussa angulosa	0.01	0.01	0.01	0.19
Scolymia cubensis	0.01	0.02	0.01	0.01
Porites furcata	0.02	0	0	0.01
Madracis mirabilis	0	0.01	0	0.01
TOTAL CORAL	**54.79**	**52.92**	**57.39**	**42.29**
Reef Rock	41.82	48.59	39.80	51.54
Leafy Algae	0.01	5.20	0.87	4.80
Sponge	1.42	2.80	0.95	0.70
Sand	0	0	0	0.24

Table 3.1.2

Relative dominance (%), of all coral taxa on random transects sampled during 1996-1997 monitoring cruises at the East and West Flower Garden Banks study sites

Taxa	RELATIVE DOMINANCE			
	East Flower Garden Bank		West Flower Garden Bank	
	1996	1997	1996	1997
Montastraea annularis	55.60	64.50	58.20	52.90
Diploria strigosa	12.44	17.67	19.92	19.56
Porites astreoides	10.79	6.58	4.53	7.48
Montastraea cavernosa	10.97	3.73	8.02	7.63
Colpophyllia natans	1.74	3.11	2.90	2.80
Millepora alcicornis	4.20	1.82	2.56	2.08
Agaricia agaricites	0.97	0.46	0.44	0.89
Stephanocoenia intersepta	0.97	2.21	0.99	0.50
Madracis decactis	0.98	0.09	0.16	1.30
Siderastrea siderea	0.57	0.34	3.40	3.20
Mussa angulosa	0.10	0.18	0.16	0.44
Scolymia cubensis	0.06	0.46	0.01	0.01
Porites furcata	0.03	0	0	0.01
Madracis mirabilis	0.03	0.16	0	0.01

Percent cover for each species was compared between study sites by year, among years with sites pooled and between pooled data from all previous cruises. Total coral cover did not vary significantly ($p>0.05$) between study sites (54.4% for the East Bank and 49.8% for the West Bank) but total coral cover for the West Bank from 1996 was significantly greater than pooled data from all previous years. Only one species (*P. astreoides*) showed a significant variation in mean percent cover between study sites or between years for the 1996-1997 study (Table 3.1.3). This species showed a significantly higher mean percent coverage at the East Bank study site during both years of this study.

Colpophyllia natans was the single coral species determined to be significantly different in mean percent cover between the current study and previous studies. During the 1996 monitoring effort, the East Bank had a significantly lower percent cover for this species when compared to pooled data from all previous studies.

Comparisons of relative dominance for each species were made between study sites by year (Figure 3.1.1), between years with sites pooled and between pooled data from all previous cruises. Again, *P. astreoides* showed a significantly higher mean relative dominance at the East Bank site. *Colpophyllia natans* exhibited a significantly lower mean relative dominance compared to previous studies.

Table 3.1.3

Summary of analyses of percent cover for all corals, reef rock, leafy 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 (pooled)**	**Tukey* Groups**
Montastraea annularis	ns	ns	ns	ns
Diploria strigosa	ns	ns	ns	ns
Porites astreoides	EFG>WFG	EFG>WFG	ns	4 3 2 1
M. cavernosa	ns	ns	ns	ns
Colpophyllia natans	EFG<WFG	ns	EFG 96< previous EFG	1 2 3 4
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
Porites furcata	ns	ns	ns	ns
Madracis mirabilis	ns	ns	ns	ns
TOTAL COVER	**ns**	**ns**	**WFG 96 > previous WFG**	**1 2 3 4**
Reef Rock	ns	ns	ns	ns
Leafy Algae	ns	ns	ns	ns
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 96-97 study 4= East Bank 96-97 study

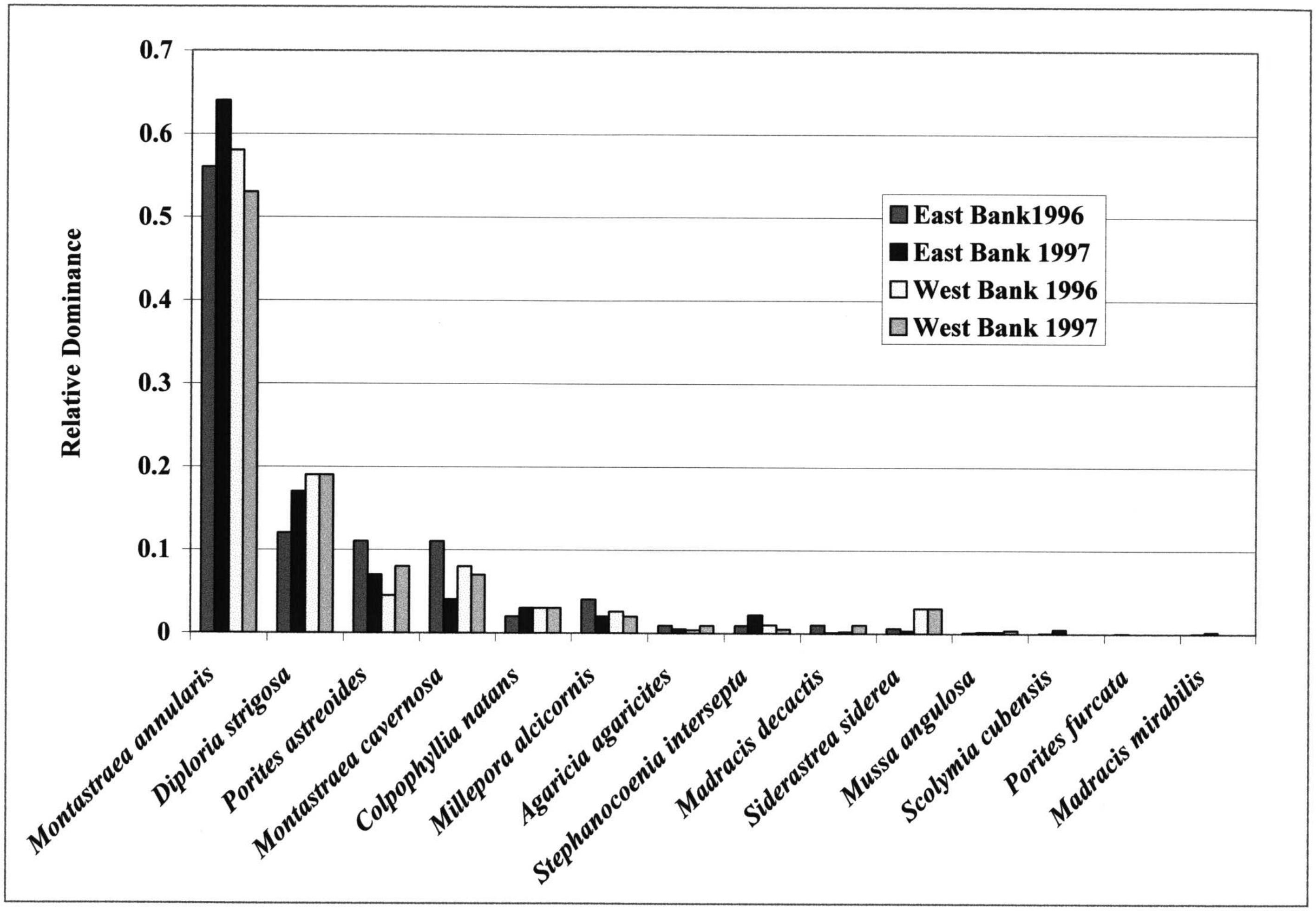


Figure 3.1.1. Comparison of relative dominance for all coral taxa by site for 1996-1997 cruises at the East and West Flower Garden Banks.

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 and coral colony counts. Comparisons of diversity and evenness were made between study sites by year, among years with sites pooled and between the 1996 and 1997 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 1996 and 1997 study compared to pooled data from all previous studies.

Table 3.1.2.1

Comparison of diversity (H') and evenness (E) by both count and percent cover for all cruises at the East and West Flower Garden Banks

Bank	Year	H'(count)	E(count)	H'(cover)	E(cover)
East	1992	1.835	0.861	1.21	0.56
West	1992	1.866	0.844	1.11	0.50
East	1994	1.841	0.839	1.34	0.60
West	1994	1.758	0.812	1.20	0.55
East	1995	1.672	0.815	1.11	0.53
West	1995	1.724	0.829	1.13	0.54
East	1996	1.704	0.892	1.56	0.43
West	1996	1.557	0.891	1.38	0.44
East	1997	1.751	0.866	1.54	0.46
West	1997	1.730	0.892	1.60	0.52
East	All	1.650	0.854	1.35	0.52
West	All	1.727	0.853	1.28	0.51

3.1.3 Incidence of Coral Bleaching

No species had greater than 5% bleached colonies at either bank during the 1996 cruise. During the 1997 cruise, bleaching was observed in colonies of *Montastraea cavernosa* with 45% of East Bank colonies and 67% of West Bank colonies showing substantial levels of bleaching. Limited numbers of bleached colonies of the *Montastraea annularis* complex as well as the hydrozoan *Millepora alcicornis* were also observed in the analysis of the 1997 random transects.

3.2 ACCRETIONARY GROWTH

3.2.1 Growth Spike Stations

A large number of accretionary growth spike measurements were aberrant due to a variety of problems, including spike overgrowth (causing apparent extreme growth rates), missing data from one of the two years of collection, and negative growth data (most likely due to loose growth spikes). In many cases, growth data were obtained from a single data point collected during this study and compared to a measurement obtained from the previous study (CSA, 1996).

In 1996, 25 measurements were obtained and six new stations were established on the West Bank. Twenty measurements were taken on the East Bank. In 1997, 17 measurements were obtained on the West Bank and 17 on the East Bank. Ten stations on the East Bank and eight on the West Bank were replaced in 1997.

At only 14 stations did sequential (i.e. 1996 & 1997) measurements meet the conditions outlined in section 2.4.1. This resulted in nine data points for the West Bank and only five for the East Bank (Table 3.2.1.1). The mean accretionary growth rate from this study for the East Bank was 5.7mm/yr (S.D.= 3.42) and the mean rate for the West Bank was 7.3mm/yr (S.D.= 3.45).

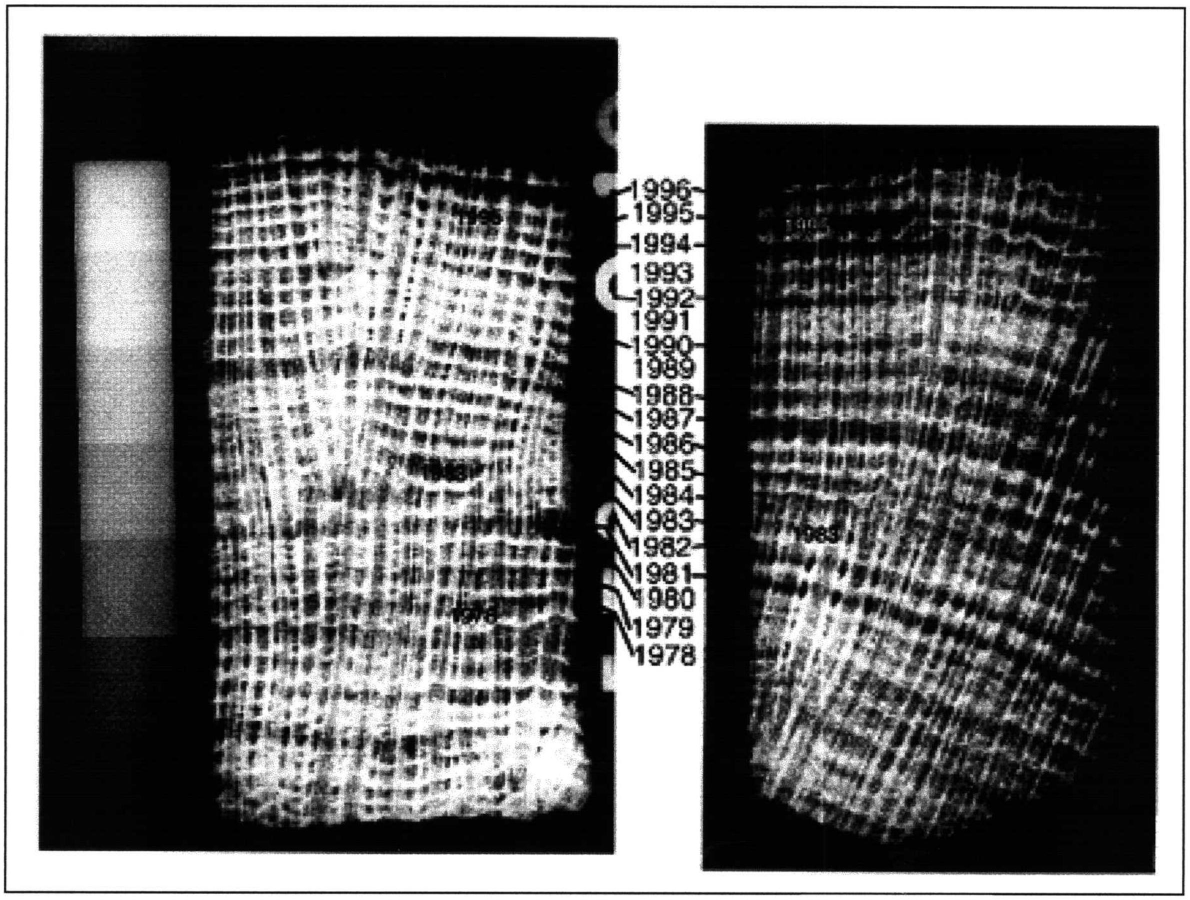
Table 3.2.1.1

Growth spike measurements (mm/yr) from colonies of *Montastraea faveolata* for 1996 and 1997 at the East and West Flower Garden Banks. The time span between sampling periods was 11 months. Annual growth = 1996 growth - 1997 growth x 1.1

East Flower Garden Bank				**West Flower Garden Bank**			
Tag#	**1996 Growth**	**1997 Growth**	**Annual Growth**	**Tag#**	**1996**	**1997**	**Annual Growth**
3	72	68	4.4	2	4	1	3.3
4	55	52	2.2	8	10	2	8.8
8	24	16	8.8	11	22	18	4.4
9	22	13	9.9	14	22	14	8.8
16	18	15	3.3	15	16	6	11.0
				17	16	5	12.1
				20	14	13	1.1
				21	22	14	8.8
				22	8	2	6.6
				63	150	140	7.7
n= 5, Std. Dev.=3.42		Mean	**5.7**	n=10, Std. Dev=3.45		Mean	**7.3**

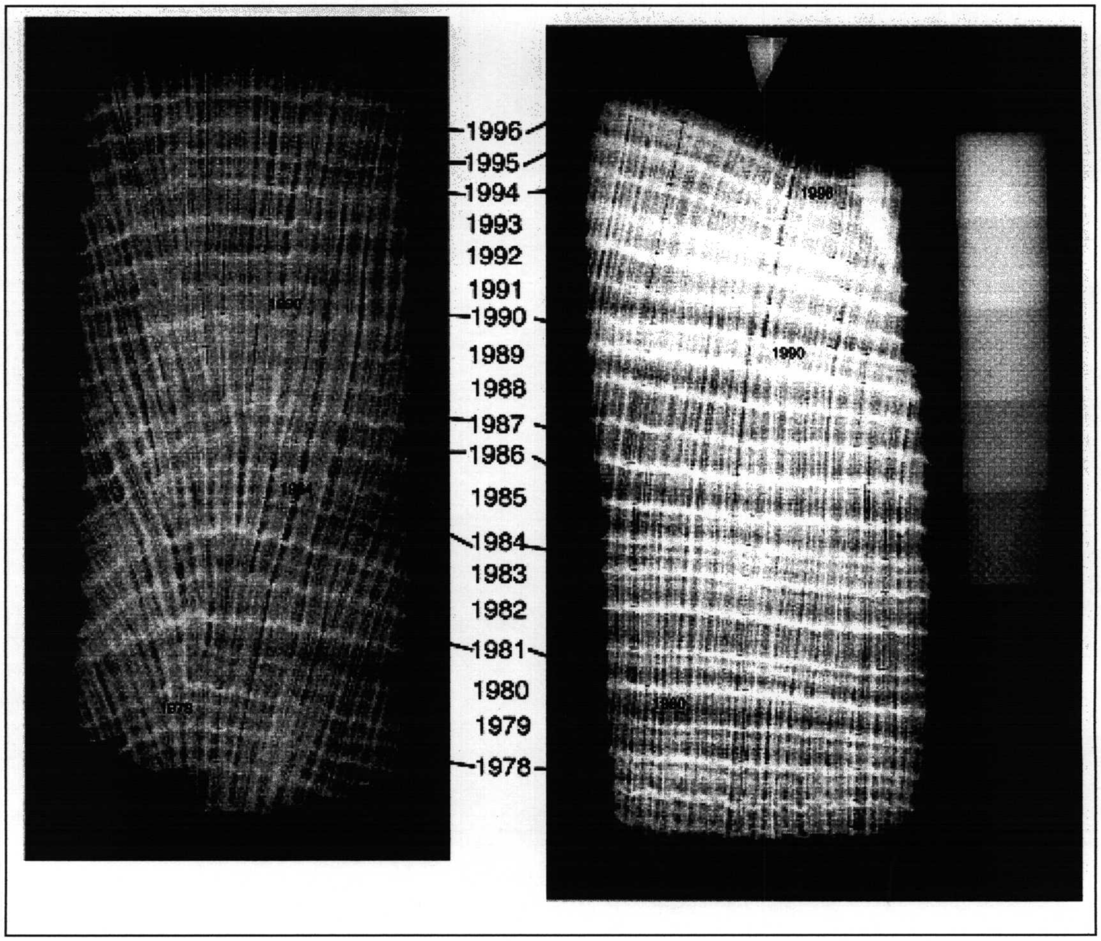
3.3 SCLEROCHRONOLOGY

Figure 3.3.1 and 3.3.2 are negative images of coral slab x-rays of *Montastraea faveolata* samples taken at the East and West Banks, respectively. Dark bands represent low density and 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. Sclerochronology results for 1996-1997 (Tables 3.3.1 and 3.3.2) were compromised through sampling error (i.e. sample taken from the side rather than crown of the colony).



Core A **Core B**

Figure 3.3.1. X-radiographs of *Montastraea faveolata* cores collected from the East Flower Garden Bank, 10 September 1997. Vertical scale divisions = 15.13 mm. 1997 growth undisturbed.



Core A **Core B**

Figure 3.3.2. X-radiographs of *Montastraea faveolata* cores collected from the West Flower Garden Bank 08 September 1997. Vertical scale divisions = 15.13 mm. 1997 growth undisturbed. Core A 1997 growth undisturbed. Core B 1997 growth scarred by drill.

Table 3.3.1

East Flower Garden Bank sclerochronology measurements; *Montastraea faveolata* sampled 10 September 1997. Measurements of annual growth taken at three different areas of core

Year	Rep. 1	Rep. 2	Rep. 3	Mean	Year	Rep. 1	Rep. 2	Rep. 3	Mean	Both Cores
1997*	2.92	3.80	3.44	**3.39**	**1997***	3.32	3.31	4.07	**3.57**	3.48
1996	3.71	3.37	3.95	**3.68**	**1996**	3.69	3.14	3.07	**3.30**	3.49
1995	3.98	4.25	3.95	**4.06**	**1995**	2.48	3.00	2.82	**2.77**	3.41
1994	3.98	4.16	4.09	**4.08**	**1994**	2.75	2.91	2.62	**2.76**	3.42
1993	4.16	3.89	4.08	**4.04**	**1993**	2.96	3.10	3.04	**3.03**	3.54
1992	3.10	3.27	4.17	**3.51**	**1992**	3.14	2.88	2.62	**2.88**	3.20
1991	3.45	3.65	4.70	**3.93**	**1991**	2.88	3.70	2.69	**3.09**	3.51
1990	3.75	3.68	5.06	**4.16**	**1990**	3.63	3.10	3.09	**3.27**	3.72
1989	4.35	3.73	4.95	**4.34**	**1989**	3.29	3.68	3.27	**3.41**	3.88
1988	3.73	4.43	5.03	**4.40**	**1988**	3.63	3.83	3.19	**3.55**	3.97
1987	4.60	5.13	5.17	**4.97**	**1987**	4.09	4.27		**4.18**	4.57
1986	3.54	3.54	4.31	**3.80**	**1986**	3.30	3.13		**3.22**	3.51
1985	3.36	3.99	3.61	**3.65**	**1985**	4.01	3.55		**3.78**	3.72
1984	4.56	4.71	4.55	**4.61**	**1984**	2.97	2.66		**2.82**	3.71
1983	3.47	4.68	4.44	**4.20**	**1983**	4.34	4.98		**4.66**	4.43
1982	5.20	4.51	4.87	**4.86**	**1982**	5.02	3.55		**4.29**	4.57
1981	4.20	4.51	4.53	**4.41**						
1980	3.69	3.33	3.25	**3.42**						
1979	2.88	3.66	3.42	**3.32**						
1978	4.46	4.48	4.51	**4.54**						

*Yearly growth band incomplete. High density bands indistinct below 1982, additional measurements unreliable

Table 3.3.2

West Flower Garden Bank sclerochronology measurements; *Montastraea faveolata* sampled 08 September 1997. Measurements of annual growth taken at three different areas of core

Year	Rep. 1	Rep. 2	Rep. 3	Mean	Year	Rep. 1	Rep. 2	Rep. 3	Mean	Both Cores
1997*	5.33	5.71	4.92	5.32	**1997****					
1996	5.12	4.65	5.22	5.00	**1996**	5.22	4.84	5.16	5.07	5.04
1995	4.79	4.66	5.21	4.89	**1995**	5.24	3.66	4.29	4.40	4.64
1994	5.29	4.48	5.03	4.93	**1994**	5.67	4.11	3.96	4.58	4.76
1993	6.07	6.33	5.74	6.05	**1993**	5.84	5.19	4.75	5.26	5.65
1992	5.36	5.89	5.66	5.64	**1992**	5.90	4.84	5.33	5.36	5.50
1991	5.42	6.01	5.19	5.54	**1991**	5.24	5.55	4.75	5.18	5.36
1990	5.26	4.93	4.83	5.01	**1990**	4.79	5.23	4.75	4.92	4.97
1989	5.20	4.68	4.86	4.91	**1989**	5.59	6.19	5.12	5.63	5.27
1988	4.62	4.55		4.59	**1988**	7.11	6.82	5.38	6.44	5.51
1987	5.31	5.69		5.50	**1987**	5.87	5.46	5.81	5.71	5.61
1986	5.19	3.89	5.88	4.99	**1986**	6.46	6.64	6.59	6.56	5.78
1985	4.67	4.65	5.38	4.90	**1985**	5.71	4.94	5.98	5.54	5.22
1984	4.48	4.91	4.99	4.79	**1984**	5.01	4.94	5.27	5.07	4.93
1983	5.67	6.31	6.22	6.07	**1983**	6.07	6.43	5.80	6.10	6.08
1982	6.79	7.19	6.38	6.79	**1982**	7.04	6.89	7.21	7.05	6.92
1981	6.62	5.71	5.81	6.05	**1981**	5.71	5.63	5.80	5.71	5.88
1980	6.02	6.79	7.27	6.69	**1980**	5.71	6.25	4.75	5.57	6.13
1979	6.14	6.17	6.05	6.12	**1979**	5.63	5.47	5.63	5.58	5.85
1978	6.62	6.19	6.87	6.56	**1978**	5.72	6.51	5.10	5.78	6.17
1977	5.31	5.67	5.50	5.49	**1977**	4.85	4.57	4.57	4.66	5.08

*Yearly growth band incomplete.
**Top of core damaged above 1996 growth boundary.

3.4 ENCRUSTING GROWTH

3.4.1 Encrusting Stations

Of the 60 permanent encrusting growth stations established during the 1994 and 1995 cruises, approximately 20 on each bank were found to be in suitable condition for continued use during the October 1996 cruise. During the 1996 cruise all damaged stations were replaced or re-established and photographed. All stations were photographed again during the 1997 cruise.

Of the 60 stations on the East Bank, 27 showed a net tissue gain, 11 showed net tissue loss, 15 showed no overall change (i.e. no overall change occurs when tissue increase matches tissue decrease), and 7 stations were undetermined due to improper camera angle or destruction of the station. On the West Bank, 29 stations showed a tissue gain, 14 stations showed tissue loss, 11 stations showed no change, and 4 stations were of undeterminable change due to improper camera angle or destruction of the station.

For the period October 1996-September 1997, East Bank advance rates were determined to be 0.37cm/year while West Bank advance rates were 0.40cm/year. Net growth rates for *Diploria strigosa* on both East (0.06cm/yr) and West Banks (0.14cm/yr) were positive for the period 1996-1997.

3.5 REPETITIVE QUADRATS

A total of 34 stations from the East Bank were photographed during both the 1996 and 1997 surveys. Mean coral cover was estimated at 58.2 ±1.6% and 57.0 ±1.6% for 1996 and 1997, respectively. Total observations of growth (903) exceeded the combined incidence of tissue loss (656) attributable to algae, sediment, disease, and other factors (Table 3.5.1).

At the East Bank, no bleaching was observed in the 1996 repetitive quadrates. In 1997 it was estimated that 1.9% of the total coral cover was bleached. During the 1996-97 study, seventeen incidents of disease were recorded in over 2,000 colonies observed resulting in an estimated total loss of tissue of 0.14%.

A total of 36 stations from the West Bank were photographed during both the 1996 and 1997 surveys. Mean coral cover was estimated at 56.6% and 56.5% for 1996 and 1997, respectively. Coral cover estimates at the various stations ranged from 21.2% to 77.2% in 1996, and from 30% to 76.3% in 1997. Total observations of growth (1602) exceeded the combined incidence of tissue loss (652) attributable to algae, sediment, disease, and other factors (Table 3.5.1). At the West Bank no bleaching was observed in 1996, but in 1997 it was estimated that 1.2% of the total coral cover was bleached. Only 6 incidents of disease were observed in over 1,700 (0.36%) colonies resulting in an estimated total loss of tissue of 0.12%.

Table 3.5.1

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

OBSERVATION	East Flower Garden Bank		West Flower Garden Bank	
	1995-1996	1996-1997	1995-1996	1996-1997
Paling		12		19
Bleaching followed by mortality				
Bleaching not followed by mortality		75		37
Disease followed by mortality	2	15	2	4
Disease not followed by mortality		3		2
Algae mediated retreat		321		65
Sediment mediated retreat		54		26
Algae/sediment mediated retreat				
Tissue loss due to competition	36			42
Fish biting resulting in tissue loss		3		
Unexplained tissue loss		227		313
Growth: infilling		109		203
Growth: marginal (encrusting or lateral)		794		1399
Estimated Coral Cover (%)	58%	57%	56%	57%
Approximate # of colonies	>2000		>1700	

3.6 VIDEO TRANSECTS

Two 100m video transects were obtained from each bank during the 1996 and 1997 cruises. Due to sampling error on the first cruise, one transect leg on the West Bank was done on the east side of the study site rather than the west, as had been done during previous studies. This new transect was repeated during 1997 to obtain consistent data within this study. Individual transect recording times were very consistent, ranging from 4 minutes 25 seconds to 4 minutes 58 seconds across the 100m transect lines (n=8, mean = 4.7 min, S.D. = 0.20) (Table 3.6.1).

There were no marine mammals, sea turtles or large motile invertebrates (including sea urchins) observed during the eight transects obtained during this study.

Table 3.6.1

Dates and elapsed time for video transects taken at the East and West Flower Garden Banks

Year	EFG North	EFG East	WFG South	WFG East
1996	16 October	16 October	14 October	14 October
	4:52	4:36	4:58	4:59
1997	10 September	10 September	8 September	8 September
	4:38	4:38	4:34	4:25

3.6.1 Gross Mortality and Bleaching

Utilizing both the normal 100m transects and circular video samples at the end of each boundary line there were virtually no detectable changes in the percent cover of live coral cover (Table 3.6.1.1). Generally, no new mortality was observed within the three video transects for which comparable data existed (Table 3.6.1.2).

The number of bleached areas detectable from video transects was greater in this study compared to the two previous studies (Gittings *et al.*, 1992; Continental Shelf Associates, 1996), though the total area remained small (Table 3.6.1.3). The largest total area (4.3m^2) occurred at the East Bank during 1997 representing only 1.2% of the total transect area.

Table 3.6.1.1

1996 and 1997 video observations of mortality and bleaching

East Flower Garden Bank	North Line	East Line
1996	27m: New mortality was observed on the top of a *M. faveolata* as compared to 9/91 video data, a small area of about 20cm in diameter ($0.3m^2$).	10m: Several patches ($50cm^2$) of apparent mortality observed in 9/91 video data are now grown over and appear as normal pigmented coral tissue.
	78m: Large sponge colony including 0.5m tall vase sponge (probably *Xestospongia* sp.) observed during 9/91 transect was missing in 1996.	57m: Small dead area of *M. franksi* observed in 9/91 data now larger, though still small, has expanded to about $0.02m^2$.
	100m: A small *D. strigosa* colony, measuring about 20 cm in diameter (0. $3m^2$), previously recorded on video immediately adjacent to the NE corner anchor post (9/91), was missing (not dead or eroded) in the 1996 video.	13m: Slight edge bleaching on a single *Montastraea franksi*, $20cm^2$ = $0.002m^2$.
	72m: A large *Montastraea franksi* colony ($2m^2$) had numerous small patches of apparent bleaching over its surface. The bleached area comprised only about 5% of the coral surface area or $0.1m^2$.	32m: Fully recovered (compared to 9/91) bleached area observed on top half of a small *Montastraea franksi* colony.
		80m: Area of extensive bleaching on a large *Montastraea franksi* (1.5m diameter) colony in 9/91 now normal with no observable mortality.
1997	No observable new mortality.	No observable new mortality.
	7m: Patch of *Millepora alcicornis* completely bleached, area of 0.7 X 0.5m = $0.35m^2$.	10m: Large colony of *Montastraea franksi* partly bleached. Estimated to be 8% of a $1.5m^2$ area colony = $0.12m^2$ that appeared normal in 1996.
		12m: Two colonies of *Montastraea franksi* 35% bleached. Top surfaces affected, representing $0.5m^2$.
		31m: Large area, 0.1m x 0.5m = $0.5m^2$ of a *Montastraea franksi* colony partially bleached
		38m: Patchy bleaching on $1m^2$ *Montastraea franksi* colony, total of 50% or $0.5m^2$.
		48m: Small area of *Millepora alcicornis* bleaching, 0.3 X 0.3m = $0.09m^2$.
		53m: Small *Montastraea cavernosa* totally bleached, total area = $0.05m^2$.
		64m: Patch of *Millepora alcicornis* bleached, 0.2 X 0.3m = $0.06m^2$.
		82m: Large area of encrusting *Montastraea franksi* bleached, 60% of total area of $2m^2$ colony = $1.2m^2$.
		89m: Patch of knobby *Montastraea annularis* bleached, 0.4 X 0.3m = $1.2m^2$.
		96m: Small colony of *Montastraea franksi* partially bleached, estimated area = 0. $2m^2$.

Table 3.6.1.1 continued

1996 and 1997 video observations of mortality and bleaching

West Flower Garden Bank	**South Line**	**East Line**
1996	100m: New area of mortality at SW corner post. *M. annularis*, showing new dead area, 40 X 25 cm ($0.1m^2$).	No observable new mortality.
	No bleaching observed	20m: Area of numerous bleached patches across two large *Montastraea franksi* colonies. Area estimated to be 15% of larger $3m^2$ colony and 5% of smaller $1m^2$ colony. Total area bleached = 0.45 + .05 = $0.5m^2$.
1997	No observable new mortality.	No observable new mortality.
	7m: Small *Montastraea cavernosa* colony bleached, 0.15m diameter = $0.52m^2$.	26m: Limited edge bleaching on *Montastraea franksi* colony, total colony only $0.02m^2 = 0.001m^2$ bleached area.
	10m: *Millepora alcicornis* patch with 50% bleaching = $0.01m^2$.	49m: *Millepora alcicornis* patch completely bleached. Area of irregular shape, about $0.75m^2$.
	41m: *Millepora alcicornis* patch 100% bleached = $0.06m^2$.	65m: *Colpophyllia natans* colony with a large bleached patch, 1.2 x 0.6 = $0.7m^2$.
	62m: Small *Montastraea cavernosa* bleached, total area of $0.2m^2$.	

Table 3.6.1.2

Total area (m^2) of new mortality by year and bank from video surveys at the East and West Flower Garden Banks

1996		**1997**	
EFG	WFG	EFG	WFG
0.62	0.1	0	0

Table 3.6.1.3

Total area (m^2) of bleaching by year and bank at the Flower Garden Banks. Number in parentheses represents portions from *Millepora alcicornis*

1996		**1997**	
EFG	**WFG**	**EFG**	**WFG**
0.1	0.5	4.3	2.3
(0)	(0)	(0)	(0.8)

3.6.2 Reef Fish Video Census Data

Counts of reef fish along all eight transects totaled 624 individuals (Table 3.6.3.1). Fish density data, determined for one-minute increments, were corrected for the last fractional minute division of each transect (Table 3.6.3.1). In general, counts were low. A total of 432 individuals were counted during the 1996 transects and 192 during the 1997 transects.

Statistical evaluations of these data are not definitive. Many natural variables, which were not controlled in this study, can affect the data and imply changes in fish densities that may not be real. For example, observations in 1996 were made a month later than in 1997 (ie. October 1996 and September 1997) and the time of day transects were performed varied.

Table 3.6.2.1

Summary of large-bodied reef fish density (number/100 m^2) observed during the 1996 and 1997 monitoring cruises at the East and West Flower Garden Banks

	1996 Data				1997 Data			
Species	**EFG North**	**EFG East**	**WFG South**	**WFG East**	**EFG North**	**EFG East**	**WFG South**	**WFG East**
Paranthias furcifer (Creolefish)	8.8	30.6	19.5	31.6	2.9	5.4	4.9	4.0
Clepticus parrae (Creole Wrasse)	0	0	10.5	7.2	0	13.7	5.4	0
Scarus vetula (Queen Parrot)	1.7	1.1	1.1	0.9	1.1	0.3	2.9	2.9
Sparisoma viride (Stoplight Parrot)	0.6	0.3	1.1	0.6	0.9	0	0.3	0.3
Sparisoma aurofrenatum (Red Band Parrot)	0	0	0	0	0	0	0	0
Scarus taeniopterus (Princess Parrot)	0	0	0	0	0.3	0	0	0
Melichthys niger (Black Durgon)	0	0	0.9	0.9	0	0	0.6	1.1
Holacanthus tricolor (Rock Beauty)	0.3	0.3	0	0	0	0	0	0
Chaetodon sedentarius (Reef Butterfly)	0.6	0.3	0.3	0	0.4	1.5	0	0
Acanthurus bahianus (Surgeon fish)	1.1	0.3	0	0	0.9	0	0.6	0
Acanthurus coeruleus (Blue Tang)	1.1	0.3	0	0	0.3	0.3	0.3	0.3
Mycteroperca tigris (Tiger grouper)	0	0	0	0	0.3	0	0	0
Bodianus rufus (Spanish Hogfish)	0	0	0.3	0	0	0.3	0	0
Bodianus pulchellus (Spotfin Hogfish)	0.6	0	0	0	0	0	0	0
Sphyraena barracuda (Barracuda)	0	0	0.3	0	0	0	0	0
Chaetodon ocellatus (Spotfin Butterfly)	0	0	0	0	1.9	0.3	0	0
Lutjanus jocu (Dog Snapper)	0	0	0	0	0.6	0	0	0
Caranx ruber (Bar Jack)	0	0	0	0	0	0.3	0	0
Cantherhines macrocerus (Whitespotted Filefish)	0.3	0	0	0	0	0	0	0
Total number of large bodied fish counted by year and bank (area=350m^2).	53	116	119	144	33	77	52	30
Total Density by Transect	15.1	33.2	34.0	41.2	9.6	22.1	15.0	8.6
Mean Density by Bank	EFG 24.2		WFG 37.6		EFG 15.9		WFG 11.8	
Mean Total by Cruise	1996 30.9				1997 13.8			

3.7 WATER QUALITY/INSOLATION/TEMPERATURE

3.7.1 Water Quality

The SPMD from West Bank for September 1996 to February 1997 was lost. The remaining three samples all indicate the presence of contaminants. The amounts of PAH (Polycyclic Aromatic Hydrocarbons) in the SPMDs from West Bank and East Bank from February to September 1997 were 273 and 290ng (parts/trillion), respectively. Differences between these values are within the uncertainty of the analytical method. PAH accumulation from September 1996 to February 1997 at the East Bank was 1,023ng, over three times higher than the SPMDs from February to September 1997. The PAH's accumulated by the SPMDs had distributions indicative of a petroleum source specifically from condensate oil seepage or ship fuels. Further studies would be required to establish which of these possible PAH sources is the most likely.

The SPMDs also accumulated pesticides and PCBs. The amount of 4,4'-DDE (West Bank = 49.5ng and East Bank = 43.5ng) and 4,4'-DDT (West Bank = 23.6ng and East Bank = 21.6ng) were similar from the two sites collected from February to September 1997. The 4,4'-DDE (93.2ng) and 4,4'- DDT (39.4ng) amounts were almost twice as high for the SPMD sample from the East Bank for September to February 1997.

Other pesticides accumulated in the SPMDs included chlordane (and metabolites), dieldrin, hexachlorobenzene (and metabolites) and lindane. These concentrations were more variable and will require additional studies to better understand. PCB congeners were also detected in the SPMD, but their distribution needs to be further explored by including field blanks with future sample processing.

3.7.2 Insolation

All light data from the fall 1996 to spring 1997 deployment interval were lost from the West Bank site during the spring 1997 recovery because the watertight housing containing the data logger leaked. Additional partial data were lost from the fall 1996 to spring 1997 deployment at the Mobil platform and the East Bank site because the sensor threshold values in the data logger were not set high enough by the previous contractor to prevent data logging during hours of darkness. This had the result of filling the storage capacity of the data-logger such that the values recorded early in the deployment intervals were overwritten. This problem was inadvertently repeated for the West Bank data logger during the spring to fall 1997 deployment interval with the result that additional partial data were lost.

The data-loggers collected their capacity of 2,727 light records during all deployments. The start and end times of the respective data sets (Table 3.7.1) show different recording lengths depending on the threshold values used to determine whether data were recorded during evening or night time hours. All data were converted from hourly means to accumulated total insolation in order to compare across the data sets (Figures 3.7.1, 3.7.3, 3.7.2, and 3.7.4).

Table 3.7.1

Recording intervals for data collected from Li Cor spherical light sensors at project monitoring stations

	Mobil Platform	East Bank	West Bank
Start	18:00 25-06-96	19:00 24-06-96	lost
End	08:00 18-10-96	09:00 16-10-96	lost
Start	17:00 14-02-97	16:00 05-03-97	19:00 17-05-97
End	13:00 09-09-97	17:00 09-09-97	09:00 08-09-97

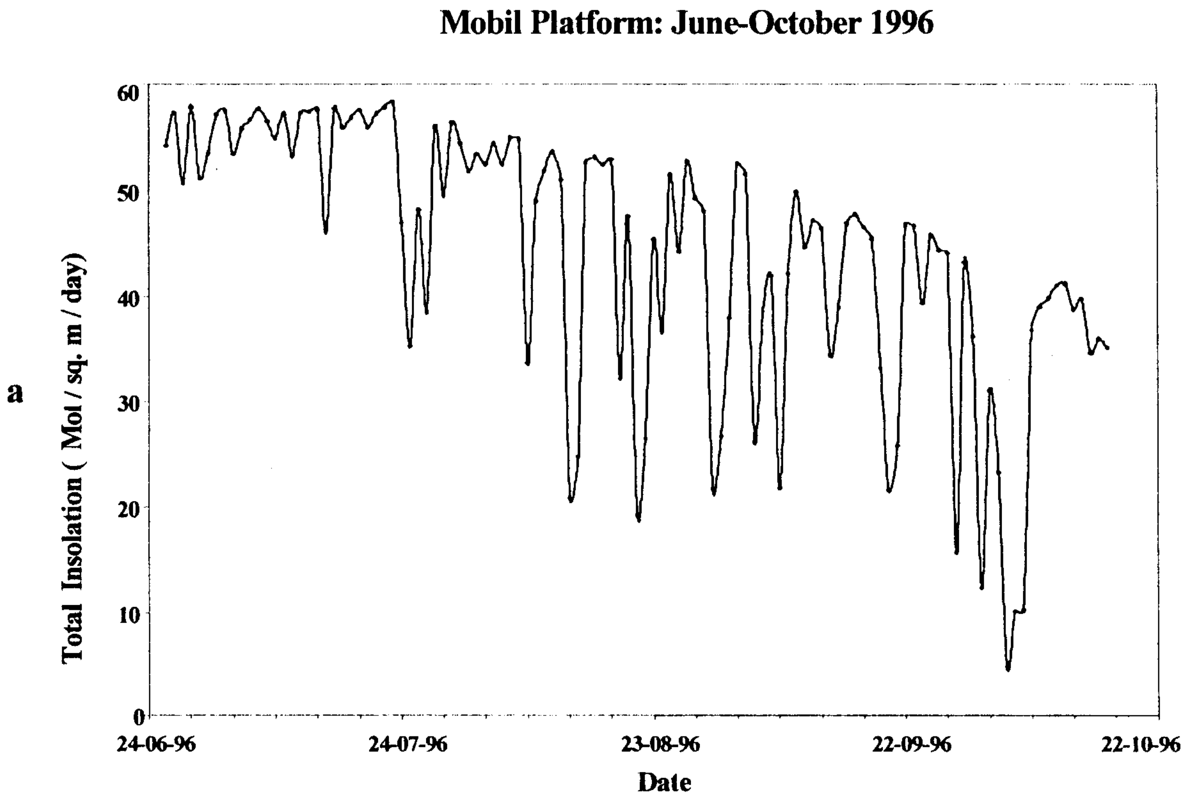
The attenuation coefficient for light transmission through water, *k*, is a parameter in the following equation,

$$I_d = I_0\, e^{-kd} \qquad \text{(Eq.1)}$$

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

$$k = ln(I_d/I_0)/-d \qquad \text{(Eq.2)}$$

it is possible to calculate the measured light attenuation in the water column at the two monitoring stations by comparing synoptic values to the reference sensor on the Mobil Platform (Figures 3.7.2 and 3.7.5). These estimates of *k* were calculated from the accumulated daily insolation at each sensor where full-day values were available for the reference and the underwater sensors.



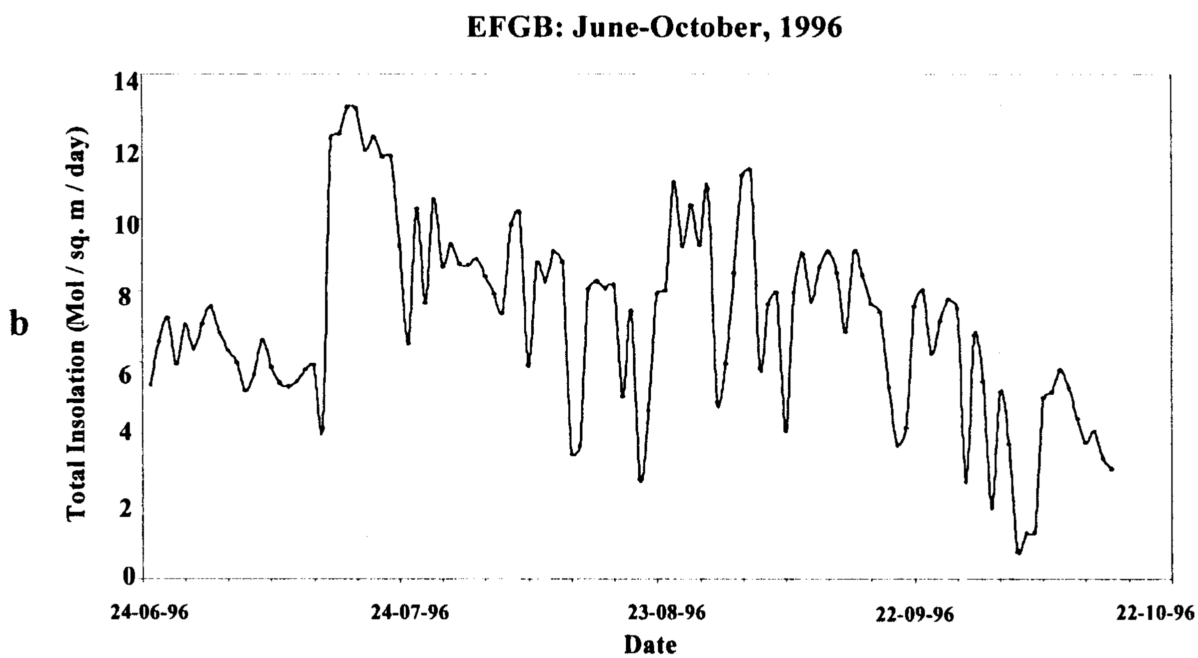


Figure 3.7.1. Total insolation at Mobil Platform (a) and at the East Flower Garden Bank (b) monitoring station (23.8m depth) during 24 June to 17 October 1996.

EFGB Attenuation June-October, 1996

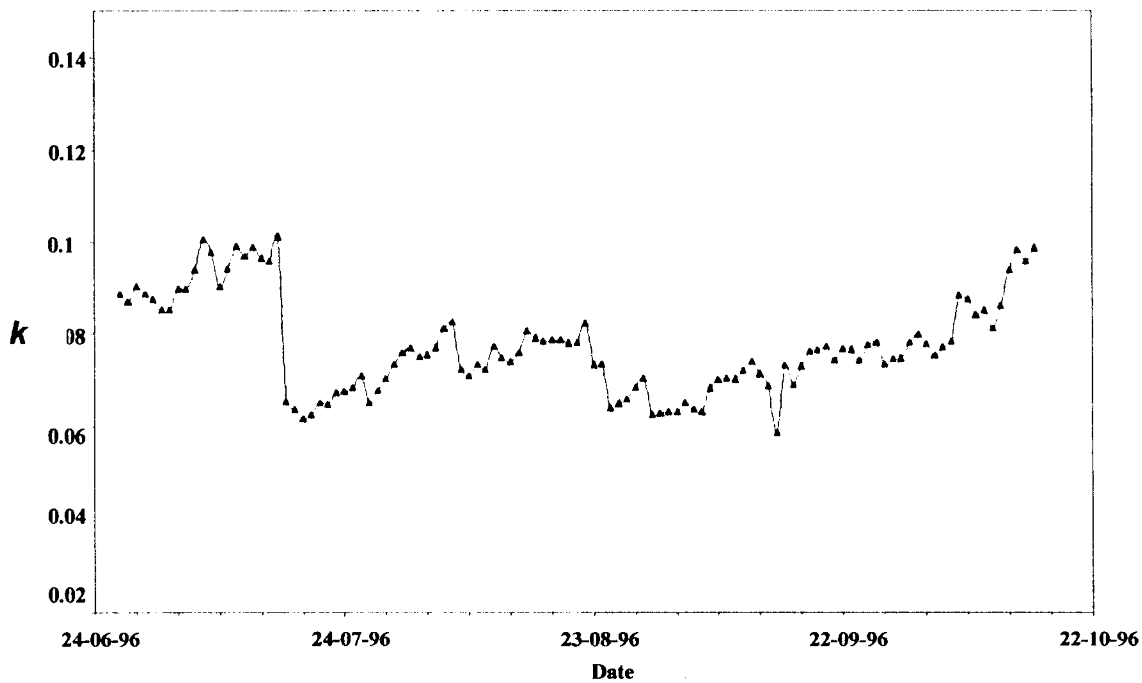
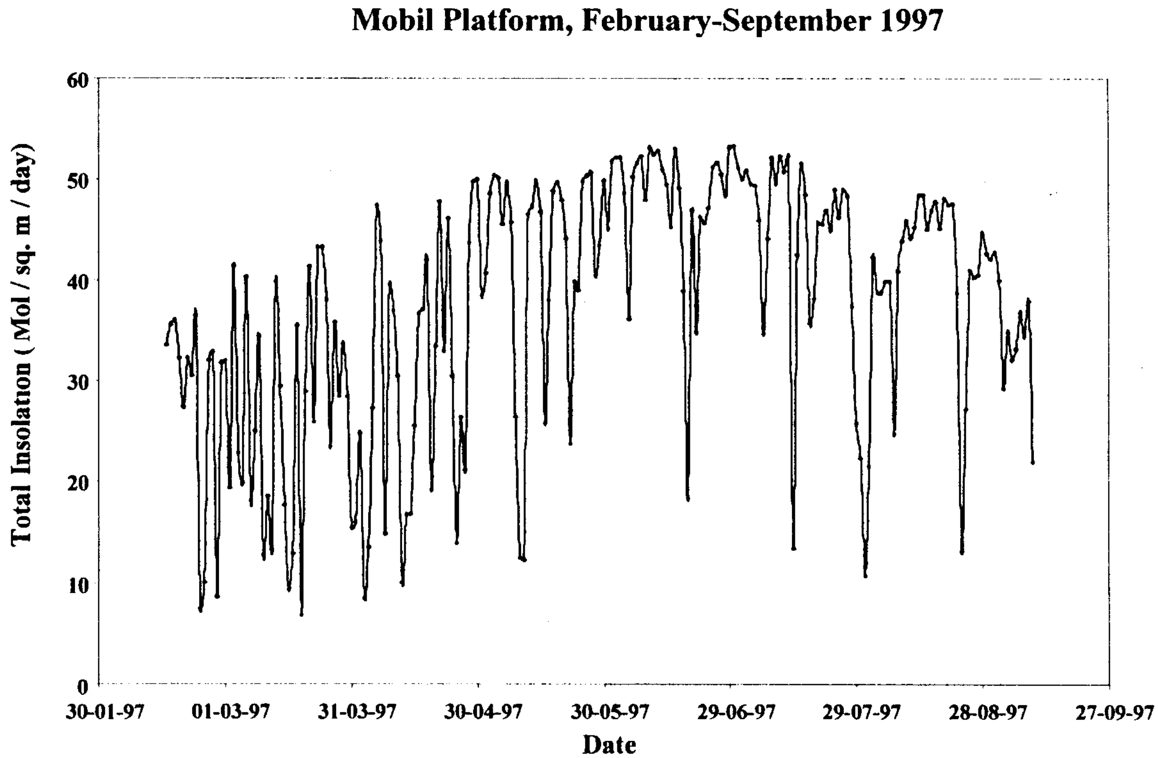


Figure 3.7.2. Attenuation coefficient calculated for East Flower Garden Bank monitoring station, 24 June to 17 October 1996.

a



b

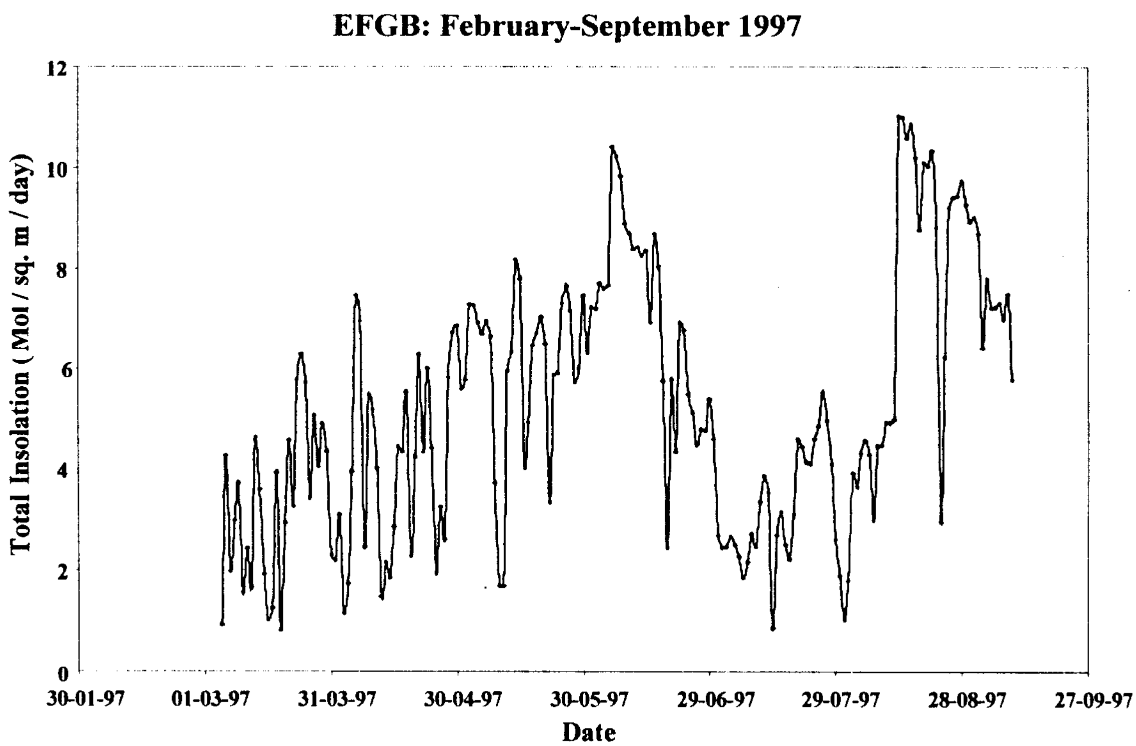


Figure 3.7.3. Total insolation at Mobil Platform (a) and at the East Flower Garden Bank (b) monitoring station (23.8m water depth) during 14 February to 9 September and 5 March to 9 September 1997, respectively.

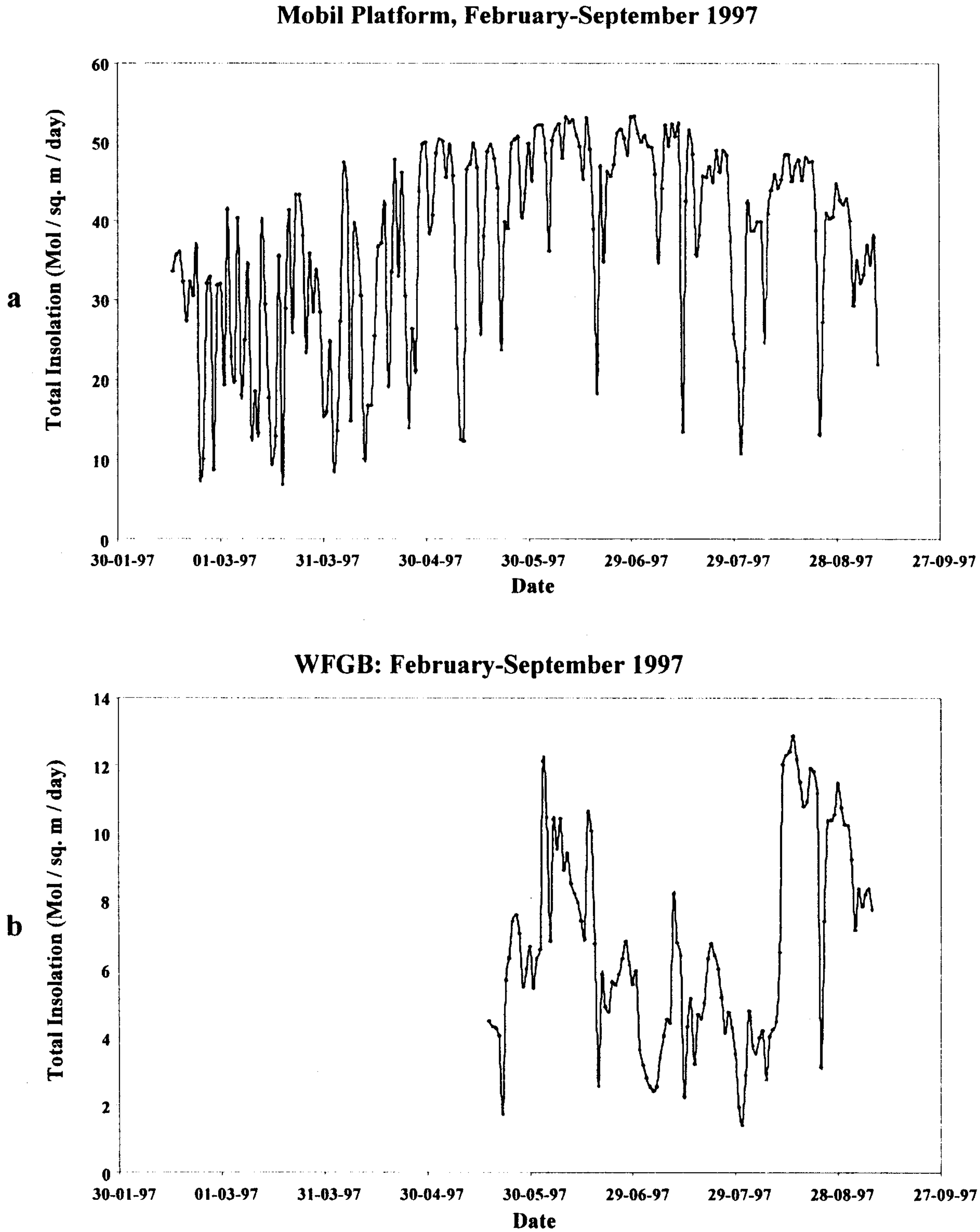
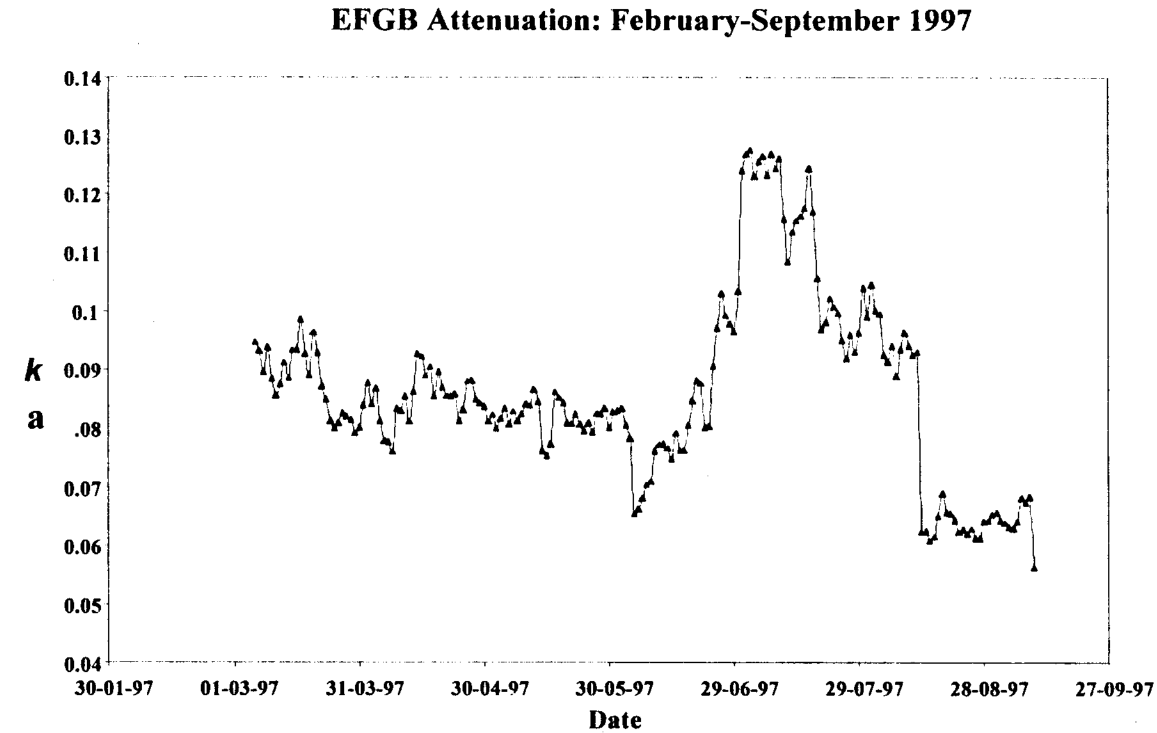


Figure 3.7.4. Total insolation at Mobil platform (a) and at the West Flower Garden Bank (b) monitoring station (23.8m water depth) during 14 February to 9 September and 17 May to 9 September 1997, respectively.



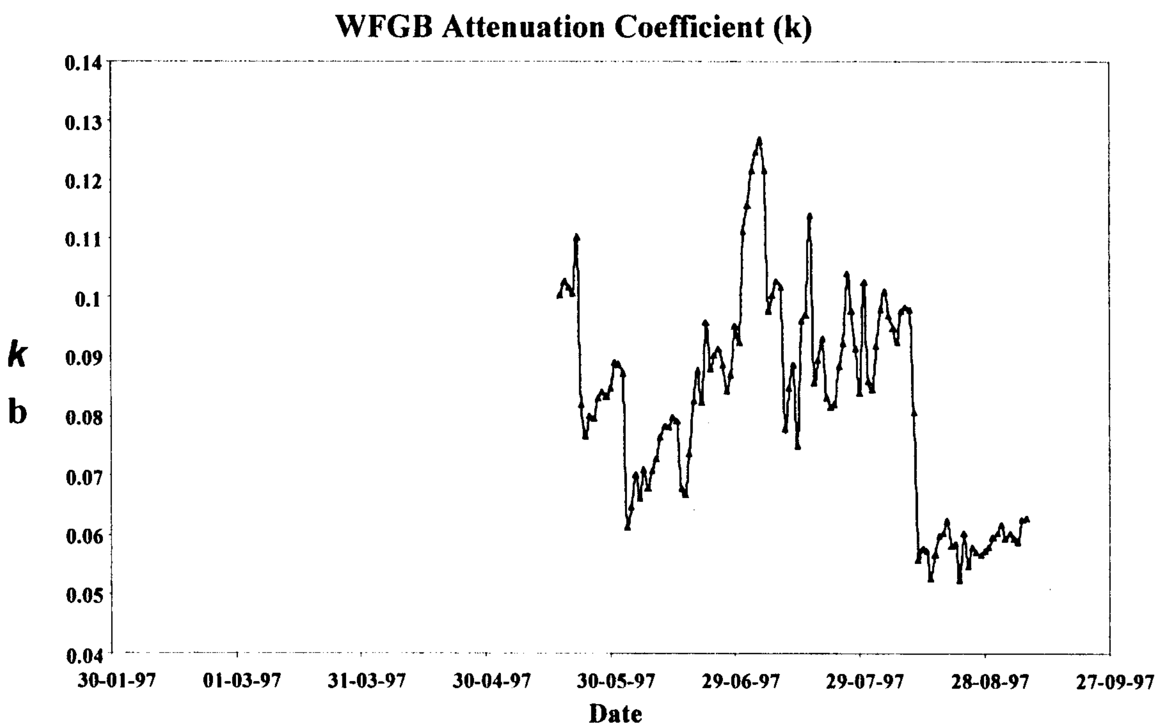


Figure 3.7.5. Attenuation coefficient calculated for East Flower Garden Bank monitoring station (a), and the West Flower Garden Bank (b) for 5 March to 9 September and 17 May to 9 September 1997, respectively.

3.7.3 Temperature

Hobo-Temp recording thermographs (Onset Instruments, Pocasset, Massachusetts) attached to bottom structure at each study site recorded water temperature at 20-minute intervals. Minimum and maximum temperatures recorded were 20.1 and 30.1 °C for the East Bank and 20.2 and 30.0 °C for the West Bank (Table 3.7.3.1).

Temperatures from both banks were compared to daily mean temperatures for the entire 7 year period from 1990 to 1997 for which temperature data was available. Thermographs at the East Bank site recorded temperatures lower than the 7 year average for the period from mid-April though mid-June, 1997 (Figure 3.7.6). Another apparent deviation occurred from late July until mid-August, 1997 when daily temperatures were higher than average. Daily water temperatures at the West Bank were higher than average from early March through the first week of April and again from mid-June through early September, 1997 (Figure 3.7.7).

Table 3.7.3.1

Minimum and maximum water temperatures (°C) recorded at the East and West Flower Garden Banks from 1993-1997

Year	**East Flower Garden Bank**		**West Flower Garden Bank**	
	Minimum °C	Maximum °C	Minimum °C	Maximum °C
1993	18.7	29.1	n/a	n/a
1994	19.0	29.5	22.1	28.9
1995	18.1	30.0	18.0	22.3
1996[1]	n/a	n/a	n/a	n/a
1997[2]	20.0	29.9	20.2	30.0

[1]1996 Sample period for West Bank only from Jan 1-June 10.
[2]1997 Sample period Jan 1-Sept 5.

3.8 DEEP REEF SURVEY

3.8.1 Deep Reef Video Survey

East Flower Garden Bank Description

The beginning point of the survey was approximately 300m east of the study site and mooring buoy 2. Results were:

Video Transects

- 51m depth: Beginning of transect, bottom habitat type was comprised of 100% algal nodules of various sizes, primarily in the range of 4-8cm in diameter (carbonate structures created from several taxa of calcareous coralline algae; Bright *et al.*, 1985). A purple branching sponge (probably *Haliclona* sp.) was common, with several individuals/m^2. Yellowish filamentous algal tufts were abundant near beginning of transect. Video frame analysis suggested 2.2 individual algal tufts/m^2 for one section of 10m along the transect at a depth of approximately 50m.

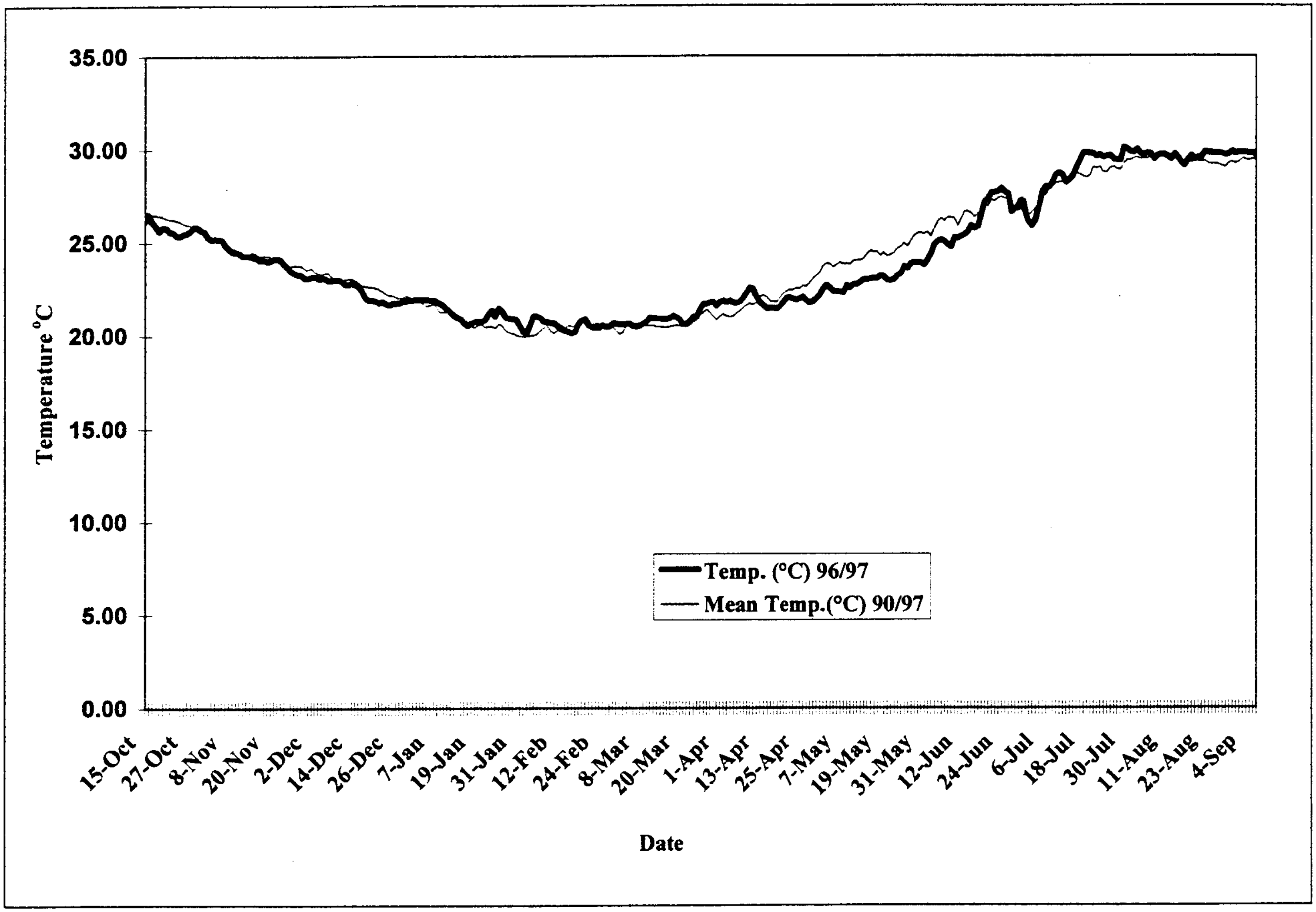


Figure 3.7.6. Actual sea floor temperature (1996/1997) and mean daily temperatures (1990/1997) at the East Flower Garden Bank.

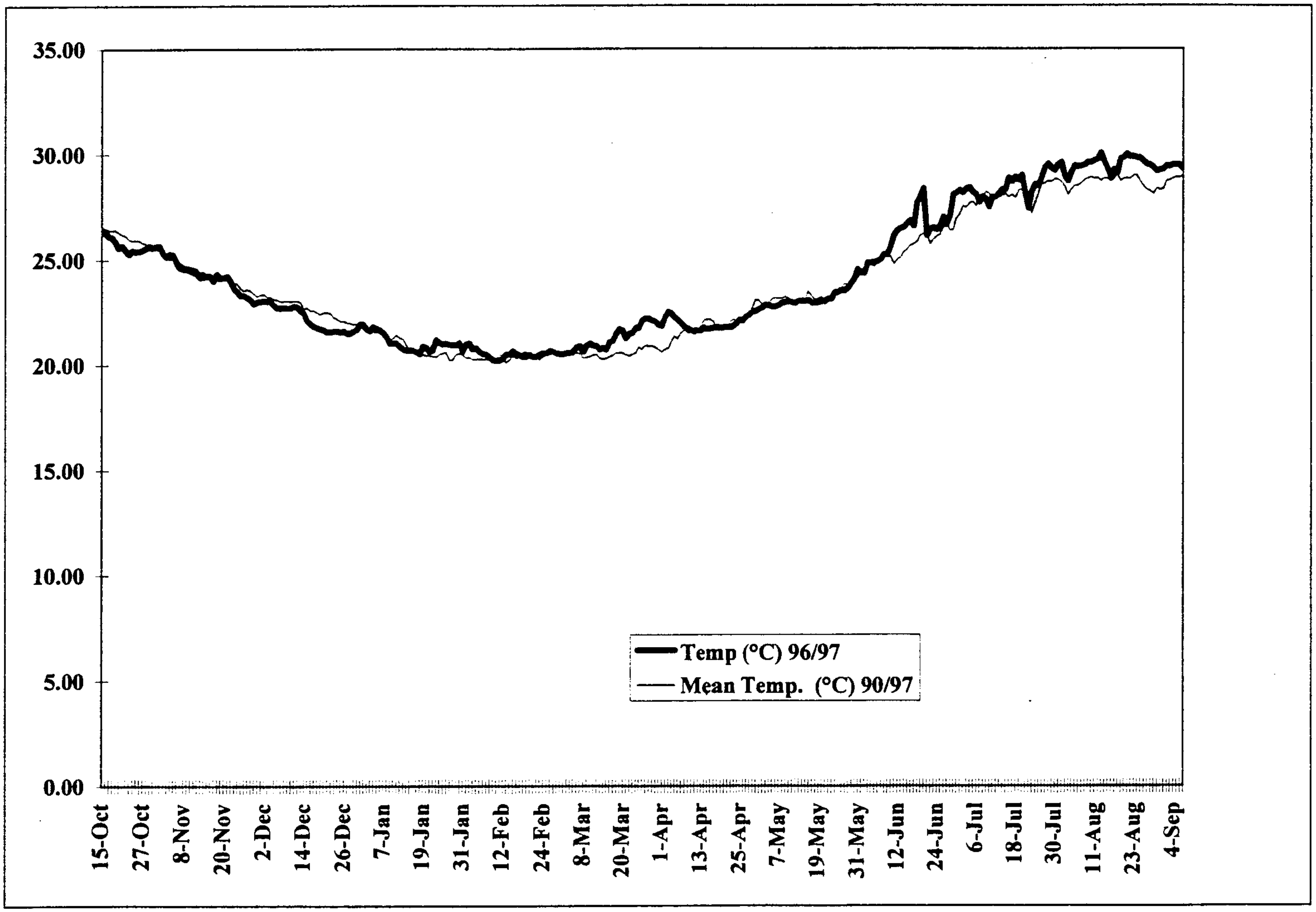


Figure 3.7.7. Actual sea floor temperature (1996/1997) and mean daily temperatures (1990/1997) at the West Flower Garden Bank.

- 48.8m depth : At a distance of 76m from the beginning of the transect, the bottom appeared flat in all directions and was composed of a solid cover of algal nodules. Branching sponges were common but shorter in length.

- A short distance further along the transect (81m from beginning, 60m from the high diversity reef), nodule size began to diminish but continued to make up nearly 100% of the substrate.

- At 129m from the transect beginning (10m from reef), a low relief, low diversity patch reef was seen to the side of the transect. It included several large coral colonies. Large *Montastraea faveolata* colonies more than 2m in diameter showed the characteristic deep water horizontally flattened morphology.

- A large 2m diameter *M. cavernosa* colony was also observed. All areas of coral tissue appeared healthy with no signs of mortality or bleaching.

- 47.5m depth: The base of the coral reef face was only about 10m away from the above patch reef (Figure 3.8.1b). The percent cover of algal nodules was reduced to approximately 50% within a few meters of the edge of the coral relief. Although the edge of the East Flower Garden coral reef habitat would not be considered a "wall" by Caribbean standards, its edge was abrupt and the reef slope was very steep, estimated to be approximately 40°.

- The distance from the base of the reef to the end of the transect at a depth of 39m was about 30m. Three images were captured along this steep rise onto the high diversity coral reef. Figure 3.8.1 shows a representative image of the exceptionally high percent cover of coral. The percent cover determined from point-intercept count was 78% for figure 3.8.1 b and 91% for 3.8.1 c. The *M. faveolata* exhibits the laterally flattened growth form that allows maximum light gathering to support symbiotic zoxanthellae.

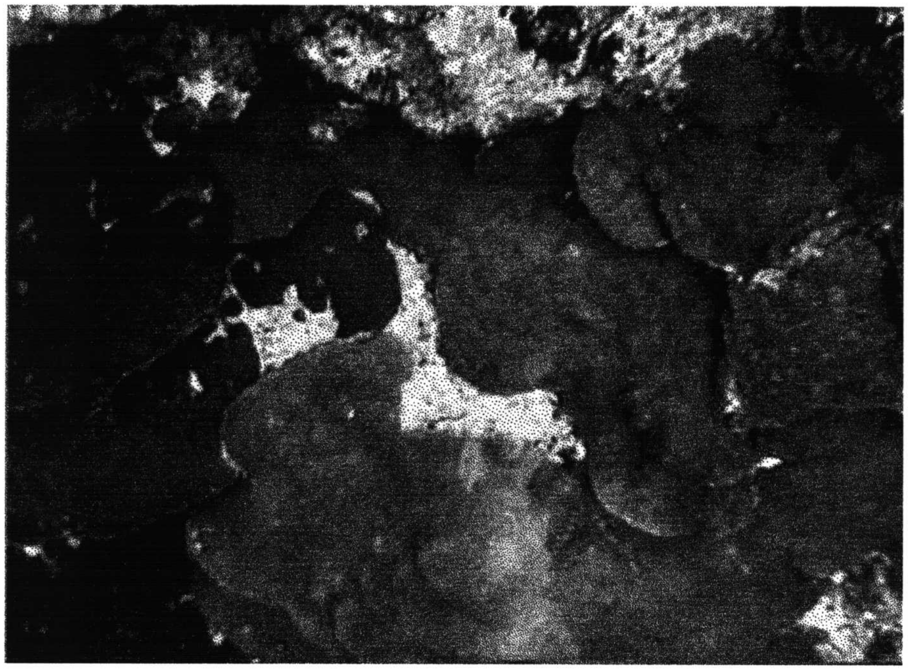
- Expansive patches of *Madracis mirabilis* were encountered just after the end of the transect while swimming along the reef at 36m. These characteristic features, also known as *Madracis* ridges, are common on the East Bank at depths between 30 and 40m (Bright *et al.* 1984).

West Flower Garden Bank

The beginning point of the West Flower Garden survey was north of the coral reef beyond mooring buoy #5. This transect began much closer to the edge of the coral reef habitat. The base of the reef could be seen from the beginning of the transect, and was about 30m away.

- Beginning of transect at 43.9m: The bottom substrate was nearly 100% cover of small coralline algal nodules nearly covered by a fleshy stalked algae (*Galaxaura* sp.). The branching algae cover diminished as the transect approached within 20m of the base of the reef.

a



b

Figure 3.8.1. Still photographs captured from deep video transects at the East Flower Garden Bank. a. high percent coral cover on reef slope 39m; b. flattened plates of *Montastraea faveolata*.

At the edge of the reef (Figure 3.8.2 a) the depth was 43.3m. The small algal nodules continued at nearly 100% cover except for a few patches of coarse carbonate sand that was within a few meters of the base of the reef.

- As the transect proceeded up the reef, the coral cover was much less than at the East Bank. This could be related to the different orientation of the transect (on the north side of the bank as opposed to the east side on the East Bank) or many other possible variables. Notably, there were areas of much higher coral cover to the sides of this transect. The calculated coral percent cover was 26% at the 43m depth 21% at 41m and 8% at 35m depth.

- A much higher percent coral cover was reached near the end of the transect at a depth of 32 m. The total live coral cover was 93%. Large groups of *Madracis decactis* colonies were encountered in this area. Extensive patches of *M. mirabilis* were also noted in the area, similar to the large meadows of this species on the East Bank.

3.8.2 Deep Reef Still Photographic Images

- 35mm still images (28mm close up) provided a partial community description of species. Three Divisions of Alga and the Phylum Porifera and Cnidaria were represented (Table 3.8.2.1. A total of 39 species were identified for the transect surveyed. The habitat was dominated by coralline algal nodules, coral rubble, and reef rock covered by an unidentified, low relief brown turf algae. In addition, seven species of scleractinian corals, one species of hydrozoan, six sponge species, and 23 species of algae were identified from analysis of the images. Mean coral cover for the transect was 14%, although cover at the end of the transect nearing the reef slope was as high as 90% with *Montastraea faveolata* and *M. cavernosa* being most common. Crustose coralline algal nodules, the branching algae *Galaxaura* sp. and *Dictyota* sp. and sponges were common at the beginning of the transect just off the reef slope.

3.9 SEA URCHIN SURVEYS

Three transects were conducted at the West Bank during the 1996 survey and eight transects were conducted at each bank during the 1997 survey. Poor weather conditions were responsible for the limited number of 1996 transects.

A single *Diadema antillarum* was present the three 1996 transects (0.003 sea urchins/m^2) and three *D. antillarum* were recorded during eight 1997 transects (0.0375 sea urchins/m^2).

3.10 MICROMOLLUSCAN FAUNAL SURVEY

To date 114 species representing 50 families and two classes have been identified from sediment samples taken at the Flower Garden Banks and are listed in a preliminary checklist, Appendix. An additional five families and approximately 20 more species need further taxonomic work (verification/confirmation) before they can be included on the list. Some species in the Appendix are listed tentatively, since identifications were made of juvenile or partial specimens. When sample identification is complete, the data will be evaluated statistically.

a

b

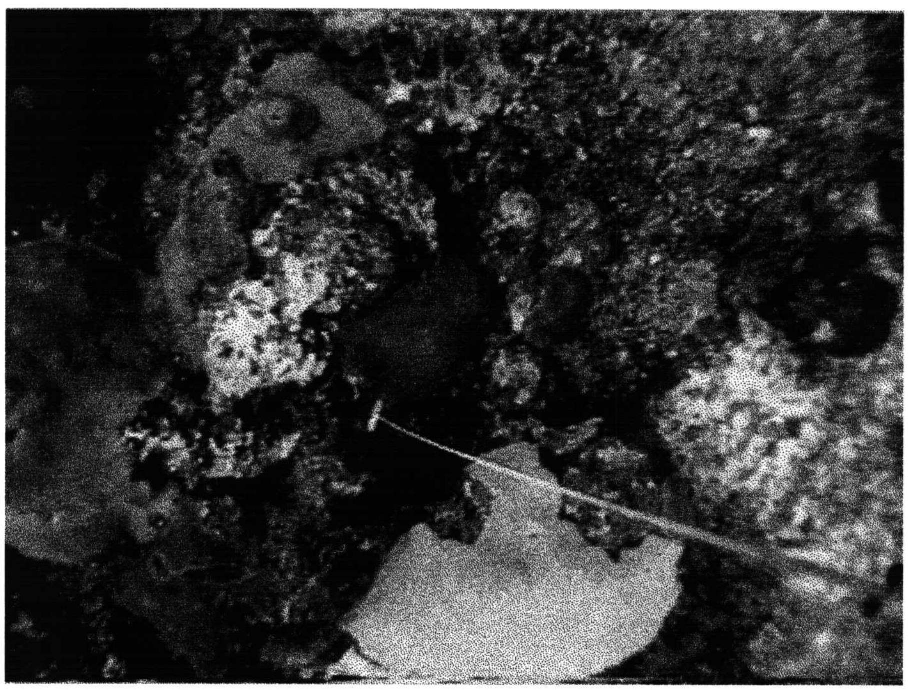


Figure 3.8.2. Still photographs captured from deep video transects at the West Flower Garden Bank. a. reef edge on WFG at depth 43m; b. low coral cover moving up reef slope at 43m.

Table 3.8.2.1

Species checklist from deep transects during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. Derived from 28mm closeup still photographs

DIVISION	CLASS	ORDER	FAMILY	GENUS/SPECIES
CHLOROPHYTA	Chlorophyceae	Cladophorales	Andyomenaceae	*Anadyomene stellata* (Wulfen) C. Agardh
		Caulerpales	Caulerpaceae	*Caulerpa racemosa* (Foreskal) J. Agardh
			Halimedaceae	*Halimeda discoidea* Decaisne
		Siphonocladales	Siphonocladceae	*Chamaedoris peniculum* (Solander) Lamouroux
PHAEOPHYTA	Phaeophyceae	Dictyotales	Dictyotaceae	*Dictyota dichotoma* (Hudson) Lamouroux *Dictyota* sp. A *Dictyota* sp. B *Lobophora variegata* (Lamouroux) Womersley
RHODOPHYTA	Rodophyceae	Rhydymeniales	Champiaceae	*Champia* sp.
		Ceramiales	Ceramiaceae	*Wrangelia argus* (Montagne) Montagne *Spyridia* sp.
			Rhodomelaceae	*Chondria* sp. *Wrightiella* sp. *Laurencia* sp. *Acanthophora* sp.
		Rhodymeniales	Rhodymeniaceae	*Botryocladia* sp.
		Nemaliales	Chaetangiaceae	*Galaxaura oblongata* (Ellis and Solander)Lamouroux *Galaxaura subverticillata* Kjellman
		Cryptonemiales	Corallinaceae	*Jania adherens* Lamouroux *Neogoniolithon* sp.
			Squamariaceae	*Peyssonnelia* sp.
		Corallinales	Corallinacea	*Amphiroa rigida* Boergesen *Amphiroa tribulus* (Ellis and Solander)Lamouroux
PORIFERA	Demospongiae	Haplosclerida	Callyspongiidae	*Callyspongia vaginalis* (Lamouroux) Sponge sp. 2 Sponge sp. 3 Sponge sp. 4 Sponge sp. 5 Sponge sp. 6 Sponge sp. 7
CNIDARIA	Anthozoa	Sleractinia	Agariciidae	*Leptoseris cucullata* (Ellis and Solander, 1786)
			Astrocoeniidae	*Stephanoceonia intersepta* Milne-Edwards and Haime, 1848

Table 3.8.2.1 (continued)
Species checklist from deep transects during the 1996 and 1997 monitoring cruises from the East and West Flower Garden Banks. Derived from 28mm closeup still photographs

CNIDARIA	Anthozoa	Sleractinia	Faviidae	*Montastraea cavernosa* (Linnaeus, 1767) *Montastraea annularis* (Ellis and Solander, 1786)
			Mussidae	*Scolymia cubensis* (Milne-Edwards and Haime, 1849)
			Pocilloporida e	*Madracis decactis* (Lyman, 1859) *Madracis mirabilis* (Duchassaing and Michelotti, 1860)
			Siderastreida e	*Siderastrea siderea* (Ellis and Solander, 1786)
	Hydrozoa	Hydrocorallin ae	Milleporidae	*Millepora alcicornis* (Linnaeus, 1758)

4.0 DISCUSSION

4.1 GENERAL – GULF OF MEXICO CORAL REEFS

Over fifty coral reefs are located in the Gulf of Mexico, with the best developed reefs located in the southern Gulf and on the far eastern margin, the Florida Keys (Rezak and Edwards, 1972, Japp, 1984; Figure 4.1.1; Table 4.1.1). Earliest studies on Gulf of Mexico coral reefs focused on their discovery, distribution, and some descriptive aspects (Agassiz, L., 1852; Agassiz, A., 1885; Heilprin, 1890). Subsequently, little research occurred in the first half of this century, but numerous studies on many aspects of coral reef geology and biology have been accomplished since the 1960's (overview by Wells, 1988).

More recently, focus has turned worldwide to concern for the environmental degradation and anthropogenic impacts of coral reefs. Johannes (1975) was one of the first to "raise the flag" and summarize existing and potential widespread problems caused by humans. Most recently, Salvat (1987) and colleagues reviewed human impacts to reefs; Ginsburg (1994) compiled a proceeding of a colloquium on the health, hazards, and history of worldwide coral reefs; and, Wilkinson and Buddemeier (1994) presented global climate change implications for reefs. The International Coral Reef Symposia, held every four years since 1969, likewise, shows an increasing trend in presentations, posters, and papers on disturbances and impacts to reefs, as well as management and monitoring symposia on how to deal with all the increasing perturbations to coral reefs worldwide. At the 1996 conference in Panama these topics received extensive coverage, along with a symposium on the "Status of Coral Reefs around the World".

Within the Gulf of Mexico anthropogenic impacts on coral reefs range from having little to no impact at the Flower Garden Banks and some Campeche Bank reefs to having moderate and

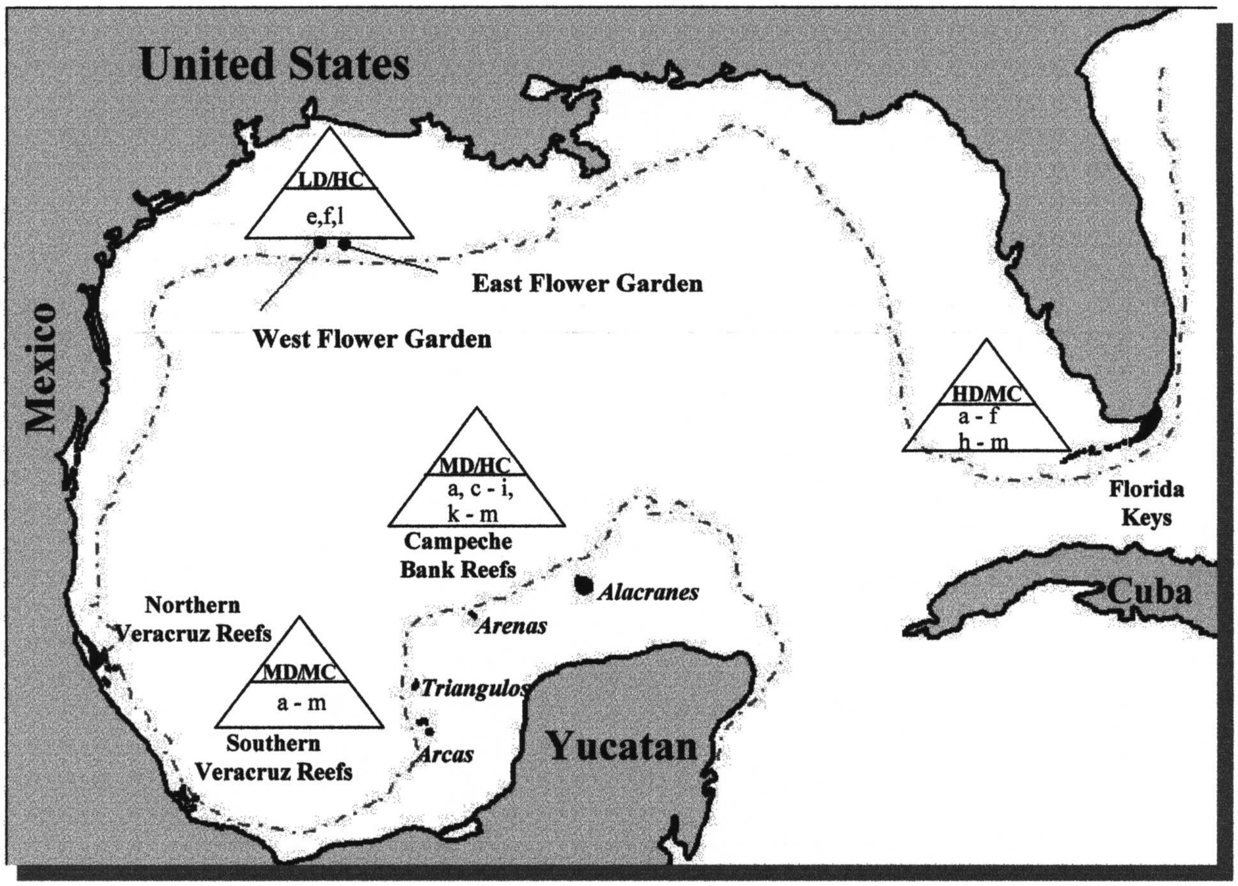


Figure 4.1.1. Map and model depicting location and status of Gulf of Mexico coral reefs (reference Table 4.1.3).

	Natural Impacts	**Anthropogenic Impacts**
D = diversity	a = salinity extremes	g = oil and gas
C = cover	b = suspended sediment	h = over fishing
H = high	c = storm waves	i = sedimentation
M = moderate	d = bleaching	j = dredging
L = low	e = cold stress or death	k = pollution
	f = *Diadema* die-off	l = anchor damage
		m= groundings

Table 4.1.1

Number of coral reefs and key references for the three coral reef areas of the Gulf of Mexico

Reef Area	Number of Reefs	Key References
Northern Gulf of Mexico		Bright and Pequenat, 1974
Flower Garden Banks	2	Rezak et al., 1985
East Gulf of Mexico		
Florida Keys	Reef Tract	Japp, 1984
Southern Gulf of Mexico		
Northern Veracruz	6	Rigby and McIntyre, 1966 Chavez et al., 1970
Southern Veracruz Reefs	21	Kuhlman, 1975 Tunnell, 1988 Lara, et al., 1992
Campeche Bank Reefs	11	Logan, 1969 Chavez et al., 1985

major impact on some Florida Keys and Veracruz reefs (Lang *et al.*, in prep). In the southern Gulf, recent summaries of natural and human-induced impacts to reefs (Chavez and Hidalgo, 1988; Tunnell, 1988, 1992; Chavez and Tunnell, 1993) and current status reviews (Horta-Puga, in prep; Ardisson *et al.*, in press), including recommendations for management and assessment methodologies (Chavez and Tunnell, 1993; Ardisson *et al.*, in press), reveal a heightened concern for conservation measures in that region. Likewise, newly designated coral reef protected areas, like the entire Veracruz Reef System and Alacran Reef, may lead to a much-needed management plan for these reefs. The Alacran Reef Management Plan should be published during 1998 (Ardisson and Duran-Najera,1997), but there is no process at present for developing the Veracruz plan. The Campeche Bank reefs are under consideration for protection by the State of Campeche. Historically, marine protected areas in Mexico are nominally protected only, since resources are lacking for enforcement and required management issues.

In the United States territorial waters of the Gulf of Mexico, protection of topographic features from adverse human activities, particularly oil and gas exploration and production, has been in effect since the early 1970's. The Minerals Management Service oversees the oil and gas industry having authority and responsibility for environmental protection and enforcement. The National Oceanographic and Atmospheric Administration established national marine sanctuaries to expand conservation efforts to cover a multitude of potential human impacts. In the northern and eastern Gulf, protection and management are established at both the Flower Gardens Banks National Marine Sanctuary (established, 1992; management plan, 1991) and the Florida Keys National Marine Sanctuary (established, 1990; management plan, 1996) (Figure 4.1.1). Long-term coral reef monitoring programs have been undertaken (since 1972 for the Flower Garden Banks, Gittings *et al.*, 1994 and since 1984 for the Florida Keys, Porter and Meier, 1992). The comprehensive and on-going yearly monitoring program, started in 1988 at the Flower Gardens with comparable data back to 1978, is one of the most extensive and longest running coral reef monitoring data sets in the world. But, direct quantitative comparisons to other localities are difficult since few comparable data sets exist for other reefs. Throughout the monitoring timeframes, Flower Garden Banks coral species richness and coral cover remained essentially the same (Gittings *et al.*, 1994). In contrast, in the Florida Keys both species richness and coral cover declined (Porter and Meier, 1992). Reasons for these declines, as well as others, are multiple, complex, and not fully understood (NOAA, 1996). However, some large-scale comparisons can be made between southern, northern, and eastern Gulf of Mexico reefs.

Tunnell (1992) presented a broad scale scheme for categorizing more and less "impacted" coral reefs in the southern Gulf (Table 4.1.2). This categorization scheme has been applied by scientists in other discussions (Ginsburg, 1994) and provides a useful guideline in considering most Gulf reefs.

Table 4.1.2

Factors affecting reef health (modified from Tunnell, 1992)

More Impacted Reefs	Less Impacted Reefs
Veracruz/Florida Keys	Campeche Bank/Flower Garden
*nearshore	*offshore
*high human population	*low human population
*high rainfall/runoff	*low rainfall/runoff

The Philippines-hosted International Coal Reef Initiative Workshop in June 1995 initiated a concise global summary of coral reefs and encouraged status reports that would evaluate environments, threats, and opportunities for improved management (ICRI, 1995; Eakin *et al.*, 1997). Many of these reports were presented at the 8th International Coral Reef Symposium in Panama in 1996, and twelve papers were later published in the proceedings (Lessios and MacIntyre, 1997). The status report for northern areas of the wider Caribbean (NAWC), including the Gulf of Mexico is currently in its final stage of development (Lang *et al.*, in prep) and gives some excellent comparisons of reefs within the region. Within the report the NAWC extends from the Dominican Republic and Bermuda in the east to the Yucatan Peninsula and Gulf of Mexico in the west. Reef development in some of these areas is naturally limited by thermal extremes (especially temperature minima), continental influences, and/or upwelling. Coral cover of *Acropora* has been reduced, apparently by disease, within the last several decades on some reefs with historically large stands in the Bahamas, Cuba, Florida Keys, and Veracruz. Due to depth, the Flower Garden Banks do not have shallow-water acroporids. Concurrent loss of some other scleractinian corals from a few coastal reefs in Cuba, Hispaniola, Veracruz, and perhaps, the Florida Keys, is attributed at least in part to their location near the center of human activity. Besides some over fishing, coral reefs in less densely populated areas, such as much of the Bahamas, Turks and Caicos, Cuba, parts of Hispaniola and the Yucatan Peninsula, as yet are relatively undisturbed by anthropogenic activities. But, these coral reefs are vulnerable to human activities such as increased tourism and associated metropolitan infrastructure development. Stocks of reef fishes are stable or increasing wherever fishing efforts have declined in Bermuda, the Dominican Republic, and some protected areas in the U.S. In other localities, reef-related fishing activities vary from slight, such as much of the Bahamas and Turks and Caicos, to severe in Haiti and Veracruz.

Populations of the important herbivore *Diadema antillarum* have remained low throughout the entire region since the 1983-84 mass mortality event. Fleshy macroalge are abundant on many NAWC reefs that have been impacted by pollution and/or intensive fishing, but scarce where large-sized herbivorous reef fishes are common, such as Bermuda, most of Cuba, and the continental U.S. Lang *et al.* (in prep) conclude that NAWC nations are becoming sensitized to the ecological value and socioeconomic benefits associated with intact/healthy coastal ecosystems. Efforts to conserve and sustainably manage coral reefs throughout the NAWC are on the increase.

Although the Florida Keys reef system is not totally within the Gulf of Mexico, being at the confluence of the Gulf, Caribbean Sea, and Atlantic Ocean, it makes an excellent regional comparison to other areas of the Gulf concerning coral reef community structure and environmental impacts. In comparing species richness (number of species) of zooxanthellate scleractinian corals, between localities, Lang *et al.* (in prep) used the species nomenclature of Chiappone *et al.*, (1996) to show the following: Florida Keys, 48; Yucatan Peninsula, 47; Veracruz, 31; Flower Gardens, 16. Although these numbers may be altered or adjusted slightly depending on whose system is used, the decreasing gradient away from the tropics is evident and well established. Reasons for this decreasing gradient vary from, 1) tropical to subtropical (Wells, 1988); 2) decreasing temperature minimal (Tunnell, 1988; Lang *et al.*, in prep); 3) movement away from the high diversity core of the Caribbean Zoogeographic Province (Briggs, 1974). Inversely, some of the regions largest, massive corals (especially *Montastraea* spp.) and highest coral cover are found at the low-diversity, deep-crested Flower Garden Banks (Lang *et al.*, in prep).

In terms of summarized environmental impacts to coral reefs in the Gulf of Mexico and adjacent regions, Lang *et al.* (in prep) present an extensive listing of natural and anthropogenic perturbations to coral reefs for six island countries and two mainland countries by level of impact. The Flower Garden Banks rank as "none" to "small" impacts in almost all categories and represents one of the least impacted and healthiest coral reefs in the region. Sanctuary status has undoubtedly raised the level of awareness, concern, and protection for the Flower Garden Banks. But two other factors however, have additionally "protected" these reefs: 1) remote, offshore location and 2) strong industry-government (oil companies with Minerals Management Service) cooperation (Gittings *et al.*, 1994).

Since 1973, the Minerals Management Service has implemented measures to mitigate possible impacts of Outer Continental Shelf (OCS) activities on environmental resources and non-OCS activities. Lease stipulations control activities such as drilling locations by defining "No Activity Zones" and controlling disposal of effluents with guidelines and restrictions for shunting drilling effluents. Through these stipulations, military and other activities such as anchoring are also managed.

A compilation of major categories of natural and anthropogenic impacts to Gulf of Mexico coral reefs (Table 4.1.3 Figure 4.1.1) reveals that the Flower Garden Banks are least impacted, the Campeche Bank reefs are moderately impacted (primarily Cayos Arcas), and the Veracruz (primarily southern Veracruz reefs) and Florida Keys reefs most impacted. Sanctuary status in the Florida Keys, coupled with a management plan to address environmental stresses, problems, and impacts should lead to progressive restoration in that area. Unfortunately, the lack of a management

Table 4.1.3

Comparison of natural and anthropogenic impacts to coral reefs from three different areas of the Gulf of Mexico. Based on information from Tunnell (1988, 1992), Wells (1988), Japp and Hallock (1990), Chavez and Tunnell (1993), Carricart-Ganivet and Horta-Puga (1993), Gittings, *et al.* (1994), Lang *et al.* (in prep)

	U. S.		**Mexico**	
Natural Impacts	**Western Gulf of Mexico**	**Eastern Gulf of Mexico**	**Southern Gulf of Mexico**	
	Flower Gardens	Florida Keys	Campeche Bank	Veracruz
Salinity Extremes		x	x	x
Suspended Sediment		x		x
Storm Waves		x	x	x
Bleaching		x	x	x
Cold Stress or Death	x	x	x	x
Diadema die-off	x	x	x	x
Anthropogenic Impacts				
Oil and Gas			x	x
Over Fishing		x	x	x
Sedimentation		x	x	x
Dredging		x		x
Pollution		x	x	x
Anchor Damage	x	x	x	x
Groundings		x	x	x

plan, or action items to address the many disturbances and impacts in the Veracruz area, will allow impacts and degradation to continue.

In the two nearest Caribbean coral reef areas to the Gulf of Mexico, Cuba and the Mexican Caribbean, reef status is similarly varied. In Cuba little is known about either the extent or status of coral reefs, but Alcolado *et al.* (1997) recently reported that reefs there were generally in fairly good condition, except for some deterioration to varying degrees near urban and industrial settlements. Along the Mexican Caribbean (State of Quintana Roo), coral reefs are, generally, in good condition with locally high coral diversity and cover, little disease, and little anthropogenic impacts, other than over fishing (Tunnell and Beaver, 1992-1998, pers. observ.). The central Quintana Roo coastline, including the Sian Ka'an Biosphere Reserve, and the southern coast have the best developed and least disturbed reefs, but tourist industry development is occurring on the southern coast between the Biosphere Reserve and Belize. The northern, tourism corridor between Cancun and Tulum has been under development for over twenty years now and certain locales, such as Cancun and Akumal, are showing signs of stress and degradation.

4.2 CORAL GROWTH AND SUBSTRATE COVERAGE

The results reported herein suggest that the Flower Garden Banks continue to thrive as a coral reef community. Current ecological and biological status is generally consistent with measures reported in past years (Table 4.2.1, 4.2.2: Figure 4.2.1). Percent cover, species diversity, and evenness have not changed significantly between banks within this study or between this study and previous studies. Significant variations of percent cover occurred in minor components of the hermatypic fauna (i.e. *Porites astreoides* and *Colpophyllia natans*), which could have been more a factor of sampling density than actual change.

Although mean total coral cover did not vary significantly between study sites (54.4% for the East Bank and 49.8% for the West Bank), total coral cover for the West Bank during 1996 was significantly greater than pooled data from all previous years. The higher cover observed on the West Bank may have been due to sampling anomalies, as no significant difference was observed in West Bank samples collected during the 1997 cruise. The *Montastraea annularis* complex continues to compose the dominant cover (28.8%) and relative dominance (57.8%) followed by *Diploria strigosa,* (8.61%) cover and a relative dominance of (17.8%).

The current study found no significant difference in percent cover of *D. strigosa* between banks or between years, a finding that mirrored results reported by CSA (1996). However, these results are different than those reported by Gittings *et al.* (1992) which found the percent cover of *D. strigosa* was higher at the West Bank. The greater number of samples examined by Gittings *et al.* (1992) may explain these differences.

Porites astreoides had a significantly higher percent cover at the East Bank study site during both years of this study. A comparison of percent cover for this species between all cruises suggests a tendency for higher percent cover at the East Bank study site; a finding in agreement with previous studies. *Colpophyllia natans* was the only species with a significantly lower percent cover and relative dominance in this study compared to previous studies. The decrease during the 1996 cruise may be an artifact of sampling density considering that in 1997 data were comparable to previous data. The more rare and unevenly distributed an organism is in its habitat, the more intense the sampling strategy must be in order to provide an accurate assessment. The sampling strategies and replications established for the Flower Garden Banks communities are adequate to accurately describe the dominant components, but may not be adequate to describe the occurrence of species such as *Colpophyllia natans*, *P. astreoides*, and *Madracis* spp. which are less evenly distributed throughout the community.

Encrusting growth data suggests conditions at the East and West Flower Garden Banks remain favorable for growth of *Diploria strigosa*. Analysis of advancing, retreating, and stable margins, indicates that greater than 50% of *D. strigosa* margins are advancing (Figure 4.2.2).

Table 4.2.1

Mean percent cover (%) of corals, reef rock, algae, sponge, and sand on random transects sampled 1992 and 1994-1997 survey cruises at the East and West Flower Garden Banks

	PERCENT COVER											
Analyzed Component	**East Flower Garden Bank**						**West Flower Garden Bank**					
	1992	**1994**	**1995**	**1996**	**1997**	**All**	**1992**	**1994**	**1995**	**1996**	**1997**	**All**
Montastraea annularis	24.12	26.93	35.65	30.39	28.0	29.02	23.02	24.95	31.0	33.98	22.63	27.12
Diploria strigosa	4.69	8.92	7.92	6.8	9.35	8.07	6.15	10.15	6.66	11.63	8.36	8.59
Porites astreoides	4.57	3.89	2.71	5.88	6.58	4.73	1.49	2.55	2.44	2.65	3.20	2.47
Montastraea cavernosa	1.49	4.80	3.20	6.00	3.73	3.84	0.87	3.15	2.33	4.69	3.26	2.86
Colpophyllia natans	2.14	1.59	3.78	0.95	3.11	2.31	3.11	2.82	0.97	1.73	1.20	1.97
Millepora alcicornis	1.30	2.49	1.66	2.31	0.79	1.71	0.80	1.91	1.87	1.50	0.89	1.39
Agaricia agaricites	0.50	0.89	0.32	0.97	0.20	0.58	0.36	0.42	0.46	0.26	0.38	0.38
Stephanocoenia intersepta	0.52	0.97	0.14	0.6	0.96	0.64	0.63	0.37	0.75	0.58	0.22	0.51
Madracis decactis	0.53	0.37	0.05	0.54	0.01	0.30	0.19	0.25	0.34	0.10	0.56	0.29
Siderastrea siderea	0.22	0.07	1.07	0.31	0.15	0.36	0.39	0.00	4.13	0.20	1.37	1.22
Mussa angulosa	0.05	0.17	0.08	0.01	0.01	0.06	0.16	0.14	0.18	0.01	0.19	0.14
Scolymia cubensis	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.00	0.01	0.01	0.01
Porites furcata	0.00	0.07	0.01	0.02	0.00	0.02	0.01	0.02	0.00	0.00	0.01	0.01
Madracis mirabilis	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00
TOTAL CORAL	**40.15**	**51.17**	**56.61**	**54.79**	**52.92**	**53.12**	**37.2**	**46.74**	**51.14**	**57.39**	**42.29**	**46.96**
Reef Rock	54.46	47.31	42.15	41.82	48.59	46.87	56.56	51.08	45.85	39.8	51.54	48.97
Leafy Algae	4.78	0.29	0.57	0.01	5.20	2.17	4.45	0.42	2.70	0.87	4.80	2.65
Sponge	0.74	1.23	0.67	1.42	2.80	1.37	1.53	1.58	0.27	0.95	0.70	1.01
Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.17	0.03	0.00	0.24	0.14

Table 4.2.2

Relative dominance (%), of all coral taxa on random transects sampled during 1992 and 1994-1997 monitoring cruises at the East and West Flower Garden Banks study sites

	RELATIVE DOMINANCE											
Taxa	**East Flower Garden Bank**						**West Flower Garden Bank**					
	1992	1994	1995	1996	1997	All	1992	1994	1995	1996	1997	All
Montastraea annularis	57.33	51.69	61.36	55.6	64.5	58.0	61.93	53.96	60.05	58.2	52.9	57.4
Diploria strigosa	12.06	18.17	14.81	12.44	17.67	15.19	16.15	21.27	12.68	19.92	19.56	17.92
Porites astreoides	12.77	8.37	5.14	10.79	6.58	8.73	4.07	6.13	4.81	4.53	7.48	5.40
Montastraea cavernosa	3.38	8.63	5.82	10.97	3.73	6.51	2.44	5.89	5.09	8.02	7.63	5.81
Colpophyllia natans	6.41	2.94	6.65	1.74	3.11	4.17	8.12	5.71	1.92	2.90	2.80	4.29
Millepora alcicornis	3.23	4.81	3.10	4.20	1.82	3.43	2.38	4.09	4.01	2.56	2.08	3.02
Agaricia agaricites	1.38	1.85	0.58	0.97	0.46	1.05	0.87	1.06	0.92	0.44	0.89	0.84
Stephanocoenia intersepta	1.41	2.04	0.24	0.97	2.21	1.37	1.97	0.85	1.60	0.99	0.50	1.18
Madracis decactis	1.41	0.76	0.09	0.98	0.09	0.67	0.55	0.64	0.63	0.16	1.30	0.66
Siderastrea siderea	0.47	0.13	2.02	0.57	0.34	0.71	1.04	0.00	7.90	3.40	3.20	3.11
Mussa angulosa	0.14	0.39	0.13	0.10	0.18	0.19	0.44	0.34	0.39	0.16	0.44	0.35
Scolymia cubensis	0.02	0.28	0.02	0.06	0.46	0.17	0.02	0.01	0.01	0.01	0.01	0.01
Porites furcata	0.00	0.17	0.02	0.03	0.00	0.04	0.02	0.05	0.00	0.00	0.01	0.02
Madracis mirabilis	0.00	0.00	0.00	0.03	0.16	0.04	0.00	0.00	0.00	0.00	0.01	0.00

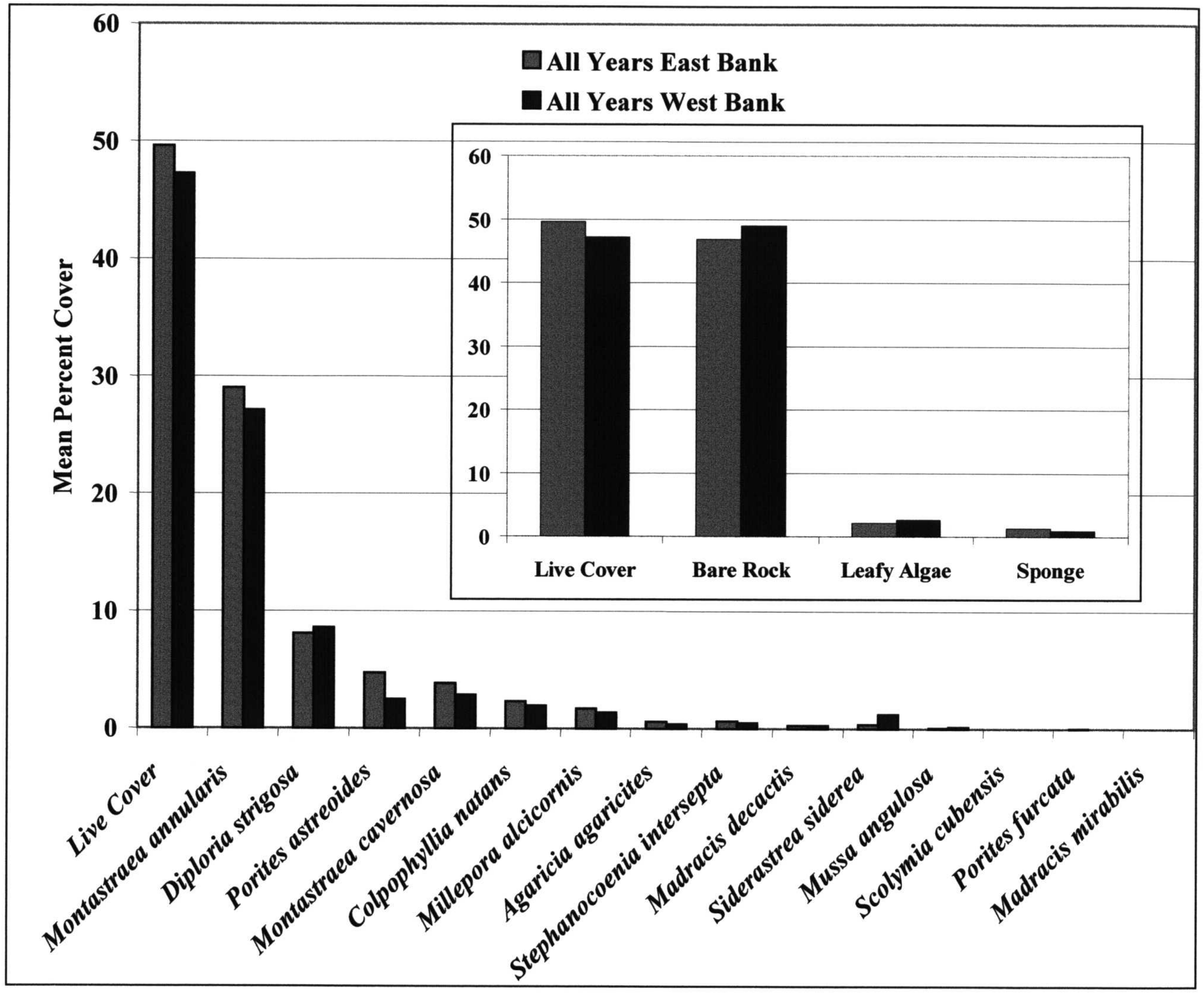


Figure 4.2.1. Comparison of mean percent coverage by site for 1992-1997 at the East and West Flower Garden Banks using data from this study, Gittings *et al.*, (1992) and Continental Shelf Associates (1995).

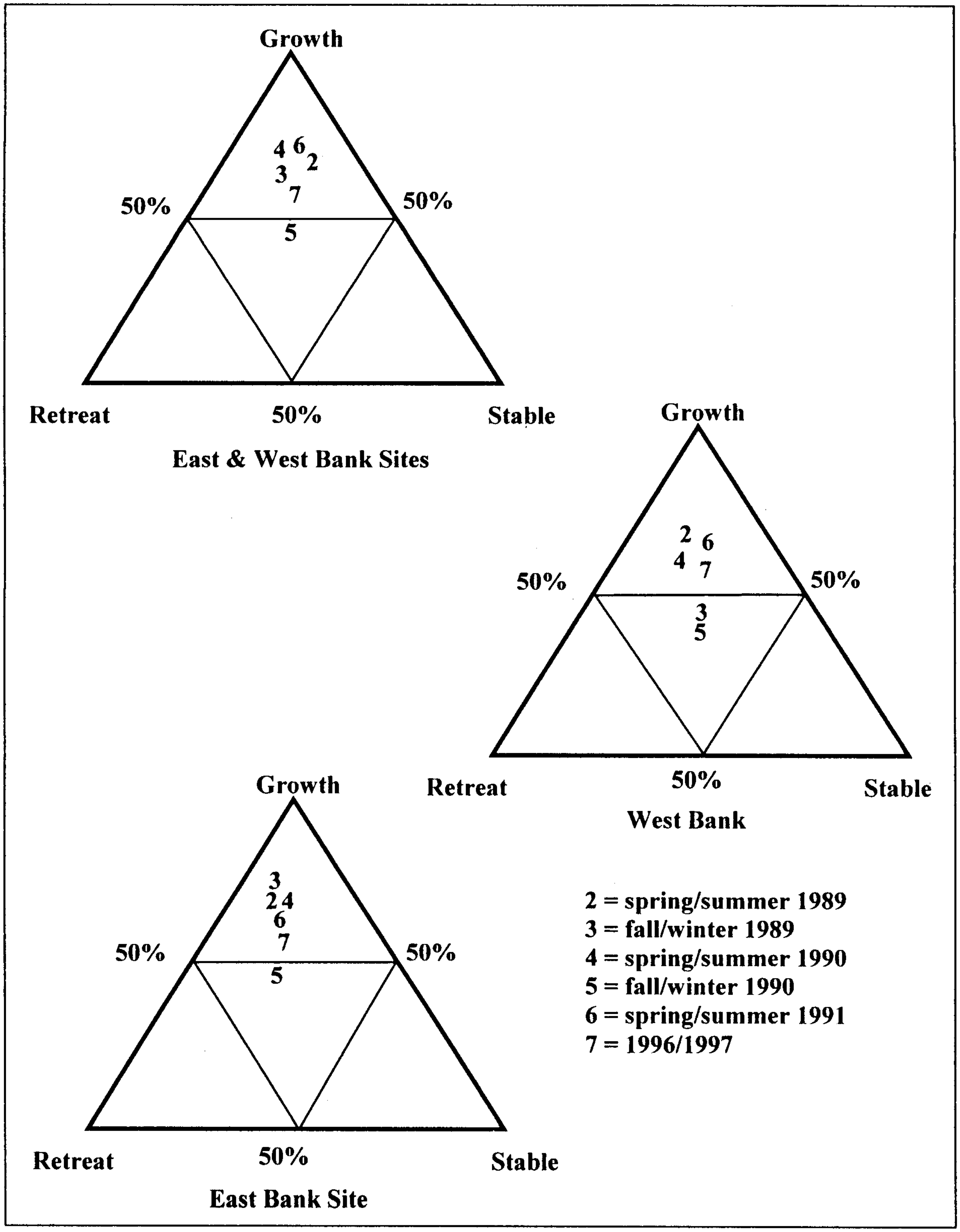


Figure 4.2.2. Ternary diagrams depicting the proportions of growing, retreating and stable coral margins of *Diploria strigosa* colonies for the East and West Flower Garden Banks.

This compares favorably to observations by Gittings *et al.* (1992). Mean advance rates have remained stable since 1992 and net growth rates have remained essentially unchanged since 1994. Retreat to advance ratios continue to be low and comparable to past studies. As suggested by Gittings *et al.* (1992) the ratio of growth to retreat, the long-term stability in net growth are evidence of environmental stability and a lack of human-induced impacts.

Hudson (1981) reported growth rates of 6.3mm/yr for *M. annularis* colonies at 6 to 12m depth in the forereef zones of barrier reefs off Key Largo, Florida. At 20m depths off St. Croix, U.S. Virgin Islands, Baker and Weber (1975) reported growth rates of 6.5mm/yr. Hudson and Robbin (1980) reported 7.4mm/yr at the East Flower Garden Bank from 1964-79. Rezak *et al.* (1985) reported 6.7 to 7.7mm/yr at the West Flower Garden Bank and 8.0mm/yr at the East Bank. Mean accretionary growth rates for 1996/97 determined from growth spikes, East Bank = 5.7mm/yr, West Bank = 7.3m/yr, are consistent with those of past Flower Garden monitoring reports and with reports from other reef systems.

Using sclerochronology, average accretionary growth rates from *M. faveolata* cores measured during this study were less than the 1993-1995 growth (Table 4.2.3). This most likely due to sampling error in that the 1996/1997 cores were taken from the side of colonies where growth bands are shorter, rather than at the apex where maximum growth rates occur.

An informative technique for analysis of growth data is to compare the ratio of one year's growth measurement to that of the previous year or group of years (Table 4.2.3). A positive ratio indicates more growth than the previous period, and a negative number represents a decrease in growth rate. Based on growth ratios, variation between

Table 4.2.3

Mean growth rates (mm/yr) and annual relative determinations from two cores collected from each of the East and West Flower Garden Banks

Year	WFG Mean (mm/yr)	Annual Ratio	EFG Mean (mm/yr)	Annual Ratio
1996	5.0	1.1	3.5	1.0
1995	4.6	1.0	3.4	1.0
1994	4.8	0.8	3.4	1.0
1993	5.7	1.0	3.5	1.1
1992	5.5	1.0	3.2	0.9
1991	5.4	1.1	3.5	0.9
1990	5.0	0.9	3.7	0.9
1989	5.3	1.0	3.9	1.0
1988	5.5	1.0	4.0	0.9
1987	5.6	1.0	4.6	1.3
Mean	5.2	1.0	3.7	1.0

years was relatively small with annual ratios ranging from 0.8 to 1.3mm. Averaging all ten years (West Bank = 0.99, East Bank = 1.0), accretionary rates have remained stable on both banks.

Net growth for the West Bank was significantly higher than that reported by Gittings *et al.* (1992) (Table 4.2.4). Net growth rates for the East Bank were significantly lower than that reported by CSA (1996), yet consistent to that reported by Gittings *et al.* (1992). Advance/retreat rates were compared to those of prior years (Table 4.2.5) with no significant differences between banks or between years.

Analysis of net tissue loss or gain ratios, determined by dividing the total tissue lost by the total tissue gained, provide an informative monitoring measure. Values above 1 represent a net loss of tissue and values below 1 represent a net tissue gain. From October 1996 to September 1997, *Diploria strigosa* colonies on both banks had a net tissue gain (Figure 4.2.3).

Relative advance, retreat, and stability (Figure 4.2.3) analysis indicates more than 50% of all margin lengths to be advancing. The proportions of advancing margin length of *Diploria strigosa* colonies for the period from October 1996 through August 1997 were 51% and 54% for the East and West Banks, respectively. The pooled average for both banks was 52%.

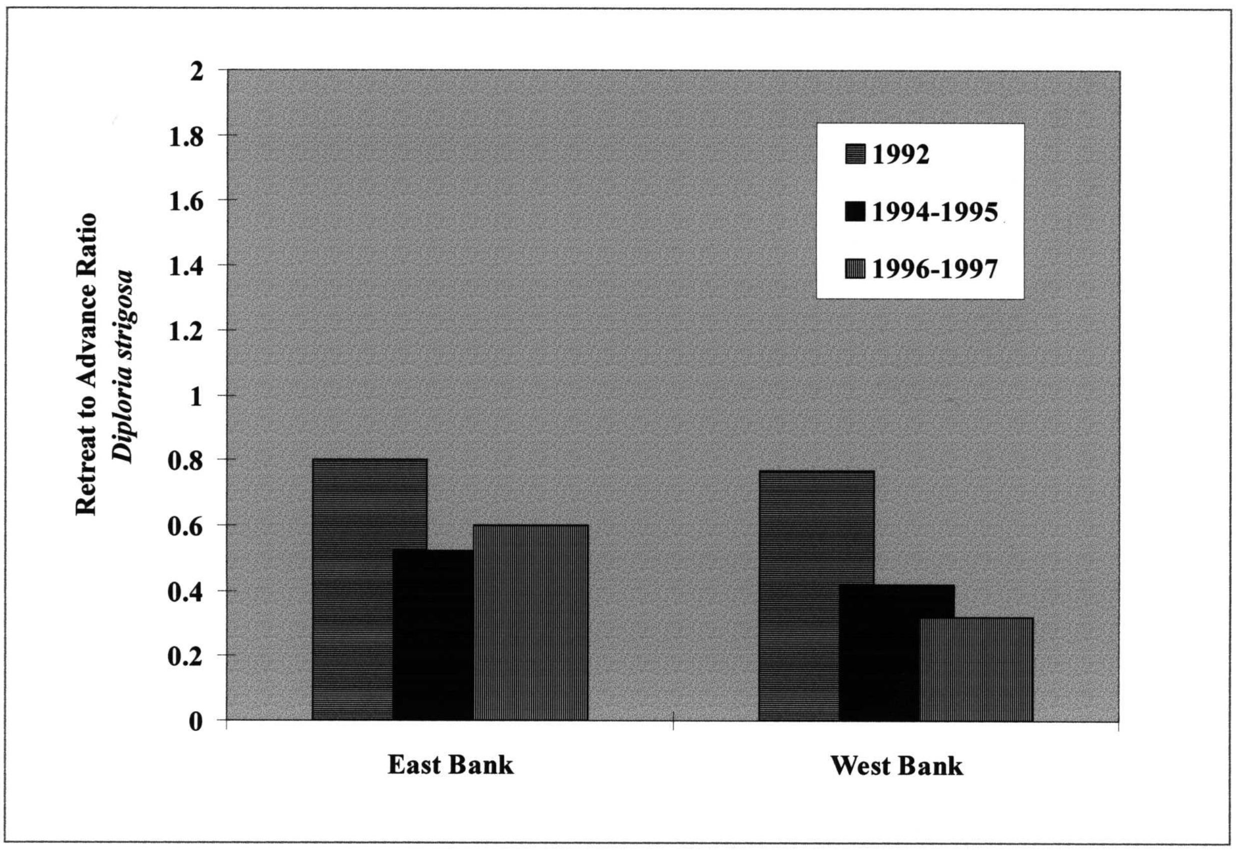


Figure 4.2.3. Retreat to advance ratios of *Diploria strigosa* for 1992 through 1997. Values above one represent net tissue loss; values below one represent net tissue gain.

Coral growth on both banks substantially exceeded incidents of tissue mortality. Algal/coral interaction was identified as the greatest source of tissue loss on the East Bank, but was not a prominent factor on the West Bank. Because corals and algae compete for benthic space and light (Littler and Littler, 1984; Pennings, 1997), higher algal cover, particularly within the entrained sediments, leads to coral tissue mortality. Though data did not suggest appreciable differences in algal cover between the banks (see Table 3.1.1), observations suggest that filamentous and leafy algae were more prevalent on the East Bank. Because of the dynamic interactions of algae, coral, and herbivores, qualitative and quantitative assessments of algal cover and biomass should be incorporated into the Flower Garden Banks long-term monitoring strategy.

Other sources of tissue loss included interspecific coral aggression, sediment accumulation, disease, and predation by scarid fishes (Lang, 1973). In addition, nearly half of all the incidents of tissue mortality noted on both banks could not be attributed to a single cause. On the whole, the greater frequency of incidents of growth, coupled with the small number of significant losses of coral cover indicate that the conditions present at the Flower Gardens are favorable for coral growth and reef development.

4.3 BLEACHING

The incidence of coral bleaching in 1997 was greater than during the 1996 sampling period. Bleaching was observed with slightly greater frequency on the East Bank during 1997, but not significantly so. Bleaching was most frequently observed in the hydrocoral *Millepora* sp. and the scleractinian coral *Montastraea cavernosa*. Previous investigations by Gittings *et al.* (1992) and Hagman and Gittings (1992), reported that significant levels of bleaching occurred in years when summer seawater temperatures exceeded 30°C, consistent with 1997 results. During the period July 7 – August 11, 1997, seawater temperatures exceeded 30°C for 36 days on the East Bank (Figure 3.8.6) and twice on the West Bank (Figure 3.8.7). Subsequently, between 1-2% of the coral cover of both banks bleached during the summer of 1997. However, since data collection is conducted as an annual event without measurements or observations between annual sampling periods, it is not possible to report the timing of the onset or duration of the bleaching phenomena.

Temperature data for the same time period during 1995 and 1996 are not available. There was however, no bleaching observed at repetitive post stations in 1996, suggesting that summer seawater temperatures did not exceed 30°C for any appreciable length of time. It is common for corals to experience varying levels of bleaching without experiencing any long-term effects (Fitt *et al.*, 1997). Gittings *et al.* (1992) and Hagman and Gittings (1992) reported that tissue loss at the Flower Gardens was low following bleaching. Mortality could be substantial however, if the prevailing environmental conditions that encourage bleaching persist for extended periods (Glynn, 1984). In the case of the 1997 bleaching event at the Flower Gardens, it is expected that cooler fall temperatures will minimize if not entirely prevent permanent tissue loss due to bleaching.

Brown (1997) presented an overview discussion of the coral bleaching phenomena and Glynn (1993) reviewed possible causes of bleaching including elevated temperature, decreased seawater temperature, solar irradiation, combined influence of elevated temperature and irradiation, reduced salinity, and bacterial and other infection. Elevated sea water temperature, solar irradiation (PAR, UVR, and blue light), and the synergistic effect of these two parameters have been cited as the most commonly implicated environmental parameters (Brown 1997). Irradiance and temperature influence on bleaching events are more commonly experienced in shallow water corals (i.e. <12m). At the Flower Garden Banks, bleached corals occurred in depths generally between 23 and 28m; depths at which one would expect irradiation impacts to be reduced due to absorption of light rays through the water column.

Goreau (1992) discussed the impact of bleaching relative to reef community change in Jamaican reefs, and Bruckner *et al.* (1997) reported the gradual shift of a Jamaican reef from a coral dominated reef to a reef dominated by macroalge. These changes were considered potential indicators of coral stress and increased susceptibility to disease.

4.4 DISEASE

Consistent with earlier reports by Abbott (1979) and Gittings *et al.* (1992), the incidence of coral diseases was low, with only 23 occurrences in more than 3,700 colonies (0.6%) observed. Ridge mortality disease in *Diploria strigosa* and an algal like infection of *Montastraea* spp., were the most commonly observed conditions. Tissue loss associated with disease can be rapid and result in substantial loss of tissue and ultimately the loss of entire colonies. Although a few colonies did exhibit substantial loss of tissue and cover during 1996 and 1997, the overall impact on coral cover was minimal (i.e. <0.15% loss).

Reporting on the spread of black-band disease in the coral reef systems of Jamaica, Bruckner *et al.* (1997) discussed the role of environmental stress in the varying susceptibility of corals to disease. Along with anthropogenic stresses, bleaching was recognized as a stressor of corals. Disease, although present, has not been described as a threat to the health of the Flower Garden Banks coral reefs. However, considering bleaching as a stressing agent, it is possible that natural and anthropogenic stresses could compound and cause increased occurrence of disease. Close scrutiny of specific potential disease agents and frequency of infection is warranted.

4.5 VIDEO TRANSECT DATA

The video transects taken on each bank during 1996 and 1997 did not result in the detection of any substantial changes in community condition. There were two notable losses of attached reef organisms within the bounds of the video transects, both on the East Bank. One, a 0.5m tall vase sponge (probably *Xestospongia* sp.) present in September 1991, was absent in the 1996 sample. This may have been caused by a storm or possibly disease. Second was a small *Diploria strigosa* head located next to a corner marker post in 1996 that was present and healthy in September 1991. Due to its elevation above the surrounding substrate and its small size, approximately 20cm diameter, it is possible a diver, for unknown reasons, removed it. Other mortality observed within video transects was minimal, all of it occurring on the East Bank and totaling less than $1.0m^2$.

Areas of bleaching were difficult to detect without simultaneously viewing the same video transect from a different time on a second monitor. The resolution, even using HI-8 video format, did not provide the detail necessary to detect small bleached areas. In the event of a massive bleaching event affecting large coral heads along the video transects, this video transecting methodology may prove valuable for determining the rates of survival and recovery.

Results from video fish censuses did not indicate any significant trends in species composition or densities. A number of simple statistical comparisons were performed, although their utility and validity are arguable. It is believed that the inclusion of this data, while not necessarily the most rigorous measure, is nevertheless important in providing baseline data for comparison to future fish composition and densities. Future video fish census data may not be needed if visual census techniques such as those applied by Pattengill *et al.* (1997) are continued.

Using one-minute transect segments as samples, 1996/1997 data comparisons were made using the Student's t test. As there were no fish count data obtained between 1991 and 1996, comparisons were made between the 1991 cruise six summary data (Gittings *et al.*, 1992) and the 1996/1997 data (Table 4.5.1). Five species contrasts resulted in significant differences ($p>0.05$), but when all species were combined for 1996 and 1997, no significant differences were detectable.

Comparing the three most abundant species, *Paranthias furcifer, Clepticus parrai*, and *Scarus vetula, P. furcifer* was significantly ($p<0.001$) more abundant in 1996 than 1997. Compared to 1991, the densities of *P. furcifer* and *C. parrai* were significantly greater in 1996 and 1997 as was the density of all large bodied fish combined at the West Bank. 1996/1997 density of *S. vetula* was significantly greater on the East Bank than in 1991.

Gittings *et al.* (1992) reported a significantly ($p<0.05$) higher density of *Sparisoma viride* and *Scarus vetula* compared to previous Flower Garden Banks data (Boland *et al.*, 1983). Gittings *et al.* hypothesized that the increased parrotfish density observations were related to the diminished sea urchin population and subsequent increase in algal food supply. This hypothesis was not supported or refuted by data obtained from the video transects collected in 1996 and 1997. During the present study, one significant difference occurred; 1996 queen parrotfish, *S. vetula*, density was significantly higher than 1991 at the East Bank.

Rooker *et al.* (1997) conducted comparative studies of the fish fauna on the Flower Garden Banks relative to a platform artificial reef within the sanctuary boundaries East Bank (Mobil HIA389 ~2.5km east of the East Bank coral cap). Using stationary diver census techniques (Bohnsack and Bannerot, 1986), Rooker *et al.* (1997) found species richness to be greater on the natural banks, dominated (i.e. 50%) by the family Pomacentridae, and seasonal variation due to the recruitment of juveniles was recorded.

Carpenter (1990), Robertson (1991), and McClanahan (1992) discussed the dynamic balance between populations of herbivorous fish and invertebrates, each competing for the same food source. Data taken from the video transects included representatives of the major feeding groups, including piscivores (e.g. groupers), planktivores (e.g. creolefish), herbivores (e.g. parrotfish), and invertebrate feeders (e.g. wrasses and angelfish). Pattengill *et al.* (1997) documented 120 species of fish from visual surveys of the Flower Garden Banks. Plankton and invertebrate feeders dominated, and herbivores accounted for <25% of the fish counted.

Table 4.5.1

Statistical comparison of reef fish sample data at the East and West Flower Garden Bank (^ indicates an increase during that year)

Comparison	Sample Description	t-Statistic	Significance	Significant at 0.05 Level
1996 vs 1997	All large bodied reef fish, EFG & WFG	1.87	0.068	No
1996 vs. 1997	Creolefish, *Paranthias furcifer* EFG & WFG	4.27	<0.001	Yes, 1996^
1996 vs. 1997	Creole wrasse, *Clepticus parrai* EFG & WFG	-0.11	0.91	No
1996 vs. 1997	**Queen parrotfish, *Scarus vetula*** EFG & WFG	-1.74	0.90	No
1996	All species, EFG vs. WFG	-1.51	0.14	No
1996	All species, EFG vs. WFG	-0.46	0.65	No
EFG vs. WFG	1996 vs. 1997	-1.30	0.20	No
1991 vs. 1996	All large bodied reef fish, EFG	1.96	0.063	No
1991 vs.1996	All large bodied reef fish, WFG	-3.96	0.01	Yes, 96^
1991 vs. 1996	Creolefish, *Paranthias furcifer* EFG	-1.33	0.20	No
1991 vs. 1996	Creolefish, *Paranthias furcifer* WFG	-3.22	0.005	Yes, 96^
1991 vs. 1996	Creole wrasse, *Clepticus parrai* EFG	1.0	0.33	No
1991 vs.1996	Creole wrasse, *Clepticus parrai* WFG	-2.59	0.018	Yes, 96^
1991 vs. 1996	Queen parrotfish, *Scarus vetula* EFG	-2.58	0.019	Yes, 96^
1991 vs. 1996	Queen parrotfish, *Scarus vetula* WFG	0.085	0.933	No

4.6 WATER CHEMISTRY (SPMD)

Semi-Permeable Membrane Devices (SPMD) appear to offer a cost-effective way to monitor for environmental contaminants at very low levels in remote marine locations. However, additional studies are required to better establish their usefulness. These studies should include analyses of field blanks and biota of opportunity to establish the environmental relevance of the SPMDs. Continuous long-term monitoring, as opposed to spot sampling, should provide an indication of steady state conditions as well as out of the ordinary events. Frequent replacement of the membrane should allow researchers to monitor fluctuations in contaminant levels.

SPMD technology showed promise as passive samplers of hydrophobic contaminants based on the limited data obtained here. Our results indicate that the area surrounding the Flower Garden Banks experiences low level exposure to polycyclic aromatic hydrocarbons (PAH) and selected organochlorine pesticides (DDE, DDT and chlordane).

The likely sources for the PAH are natural seepage, boat traffic, drilling/ production operations, and land based sources via atmospheric deposition. The likely source for the organochlorine pesticides is land based via atmospheric deposition. More studies including the use of field and laboratory blanks are required before these possible processes can be fully understood. Caution should be used in considering the PAH results reported herein since field blanks were not used to segregate atmospheric (i.e. on the boat deck) absorption of contaminants from those existing in the water column, nor were lab blanks run to test for laboratory contamination. There were no readily apparent impacts on the flora and fauna of the Flower Garden Banks.

The level of DDT relative to its derivative DDE suggest recently used DDT. DDT was banned for use in the U.S. in the 1970's, but is still used in Mexico and Central American countries. The source of the pesticide contaminants is not known. A possible, and perhaps likely, method of transport from onshore to the offshore area of the Gulf of Mexico is atmospheric transport. Hydrodynamic transport by water currents is also possible, but one could reason that there would be greater absorption by geologic and biologic components as the contaminant is transported through the water column. There was no readily apparent impact on the flora or fauna of the Flower Garden Banks. The toxicological and medical literature is voluminous with studies of the effects of such contaminants on humans and other mammals (e.g. Walker et. al., 1972; NCI, 1977; Adeshina and Todd, 1991; Fleming and Timmeny, 1993), yet the authors cannot speculate as to the impact of these contaminants in the low concentrations found on coral reef habitats and fauna.

It is estimated that SPMDs process 5 liters of water per day and may reach equilibrium for some compounds in 15 to 20 days, while other studies do not indicate equilibrium after more than 56 days. Turbulence can lead to shorter equilibration times. Fouling of the polyethylene bag can alter their sampling efficiency. The ideal sampling scenario is therefore one in which they reach equilibrium before substantial fouling occurs. For monitoring of ecosystems such as the Flower Garden Banks an initial strategy would be to deploy the SPMDs for 60 to 90 days. The SPMD should reach equilibrium in that period of time, and the amount of fouling could be assessed to see if the time frame should be reduced.

A cost effective sampling scenario would be to place three SPMDs at each sampling site; one above the surface to provide information on atmospheric concentrations of measured contaminants and two SPMDs in the water column, the first one meter below the surface and the second one-meter above the bottom. Depending on the current regime and the objectives of the study, other depths may also be appropriate. Trip blanks must be processed with each sampling batch due to the fact that the SPMDs are very efficient air samplers and can be "contaminated" from the sampling ship's air (e.g. exhaust). A processing blank to show that the dialyses step is not adding analytes of interest is also required as well as laboratory procedural blanks. The specific number of sampling stations depends on the specific study objectives, but should include a control station when possible. For the protection of a specific ecosystem (e.g. Flower Gardens) higher density sampling up current of the site is warranted. When this type of sampling scheme is undertaken, valuable information about the presence of hydrophobic contaminants in the sampling location is obtained. The use of SPMDs is still in the evaluation stages and results must be interpreted with care. The sampling scenario may need to be revised, as more information regarding the underlying theory of how SPMDs function becomes available.

The utility of the water chemistry data could be increased with continuous data reflecting air and water circulation at the banks. During the period of the study reported herein, air and water circulation data were not readily available. Hence, although contaminants were recorded, the direction of transport can only be speculated.

4.7 INSOLATION

Seasonal changes in light intensity can be discerned in both the underwater and reference sensors. Comparison of data from the underwater light sensors (Figures 3.7.1 through 3.7.5) suggests short term and seasonal changes in water clarity. Abrupt shifts in the measurement of light intensity at depth (e.g. between 16 and 17 July 1996; Figure 3.7.1, b), that are not mirrored by the reference values indicate rapid changes in the light transmission properties of the water column.

Estimates of the attenuation coefficient, k, provide information on the water column characteristics. Overall, the k values at the Flower Gardens averaging around 0.09 are between the clearest coastal water ($k = 0.15$) and the clearest oceanic waters ($k = 0.033$) (Parsons *et al.*, 1984). The growth rates reported for hermatypic corals at the Flower Garden Banks probably reflect these clear water column conditions. Monitoring light attenuation is an informative means for gauging the physical conditions that maintain coral health in this marine sanctuary. Previous reports of light intensity levels at the monitoring sites (CSA, 1996), give only the daily averages in graphic form.

Examination of k values in Figures 3.7.2 and 3.7.5 show at least two attenuation regimes probably related to plankton blooms, which would tend to reduce the transmissivity of the water column. In Figure 3.7.2, the bloom appears to be in progress at the beginning of the record, followed by an abrupt transition to oceanic water on 16-17 July 1996. In Figure 3.7.5, the bloom and subsequent reduction of water clarity appeared to begin around the end of May. The bloom declined and water clarity increased through June and July, then an abrupt change to oceanic clarity occurred on 12-13 August, 1997. S. Gittings (pers. comm.) described a thick viscous layer (i.e. "sea snot") present during these bloom events. There are interesting differences between the pre-bloom conditions at the East and West banks, but the truncated data record from the West Flower Garden Bank makes it difficult to expound on these differences. The abrupt shifts to oceanic conditions in the 1996 and 1997 records suggest flushing events. It would be valuable to compare physical records from Advanced Very High Radiometric Resolution (AVHRR) satellites or current meters to determine how bloom conditions were maintained and whether there were abrupt shifts in circulation that correspond to the shifts in attenuation rates. Efforts to expand the available information on circulation and other water column properties at the sanctuary are therefore recommended.

The occurrence of nighttime mass-spawning events on the Flower Garden Banks has been documented by previous work and is predicted to occur eight nights after the full moon in August. The correlation of moon phase and seasonal temperature regimes to spawning events (i.e. 8 to 10 nights after the first full moon in August) raises the question whether or not "moon light" intensity serves as a partial trigger to the spawning event. Is there a synergistic triggering effect between light intensity and temperature?

In all cases, the data records overflowed the data loggers with resulting loss of data. This is unfortunate because it reduces the ability to understand how light levels affect reef ecology. The situation was partially relieved by adjusting the threshold of the light sensor to exclude nighttime records. This is not an optimal solution, however because the availability of moonlight at depth is a potential parameter of interest. It is therefore strongly recommended that a new solution to recording light data be found. Use of the Li Cor sensors should be continued, but a redesigned housing and a different data recording device (e.g. Tattletale) would help. It would be possible to redesign the data logger to record water temperature as well as light and thus provide some thermograph redundancy.

4.8 ANCILLARY STUDIES

An objective of this project was to stimulate and support other studies of the Flower Garden Banks ecosystem. Ancillary studies (i.e. studies/measurements not specified as part of the suite of measurements in the RFP and contract) undertaken included those that were conducted as studies of opportunity for the purpose of expanding knowledge of the Flower Garden Banks ecosystem, and those that could have direct application to the assessment of the health and well being of the Flower Garden Banks ecosystem with subsequent application to management decisions.

4.8.1 Mollusca

Studies of the Flower Garden Banks molluscan fauna have dealt primarily with macromolluscs (Bright *et al.*, 1974; Lipka, 1974). This report contains the first description of micromolluscs at the Flower Garden Banks. Although only partially complete, the results significantly increased the reported invertebrate species of the Flower Garden Banks by more than 100 species.

4.8.2 Sea Urchin Population Density

Sea urchins (Echinodermata: Echinoidea), grazing herbivores, are recognized as keystone organisms existing in dynamic balance with finfish, scleractinian corals, and algal biomass in coral reef ecosystems (Ogden and Lobel, 1978; Hay and Taylor, 1985; Carpenter, 1986 and 1990; Hughes *et al.*, 1987; Lessios, 1988; Levitan, 1988; McClanahan and Shafir, 1990; Hughes, 1994; McClanahan and Mutere, 1994; Roberts, 1995; McClanahan *et al.*, 1996). Sammarco (1982), Carpenter (1986), and Levitan (1988) described the controlling influence of sea urchin grazing on algal biomass, which subsequently affects population densities of herbivorous fish (Carpenter 1990; Roberston, 1991; McClanahan, 1992). Downing and El-Zahr (1987) and McClanahan and Muthiga (1988) reported on reef degradation impacts of sea urchins through mechanical erosion and reduction of calcium carbonate accretion rates. Lessios (1988) reported an increase in carbonate accretion rates following the mass mortality of *Diadema antillarum* in the Caribbean. Wells (1995) advocated that a greater understanding of keystone species, including sea urchins, other herbivores and certain predators is "essential" to support management efforts.

Rezak *et al.* (1985) reported crustose coralline algae abundant in the "high diversity" *Diploria-Montastraea-Porites* Zone of the Flower Garden Banks, and crops of leafy algae "consistently" low. They speculated that grazing activities of fish and mobile invertebrates such as gastropods and *D. antillarum* acted to keep the crops of leafy algae low. Rezak *et al.* footnoted the mass mortality of *D. antillarum* reaching the Flower Garden Banks between November 1983 and August 1984, killing large numbers of the "previously abundant" *D. antillarum*. Gittings (unpubl.) estimated *D. antillarum* abundance to be just under $2/m^2$ using transect photographs taken during daylight hours prior to the mass mortality. Bright and Pequegnat (1974) reported "soft" algae as poorly developed, covering 1 to 5% coverage on upper sides of dead coral rock, and 60 to 80% coverage on the undersides. Gittings and Bright (1987) discussed the mass mortality of *D. antillarum* and the subsequent increase of alga cover to 14% in less than one year. They further reported that algae cover diminished after 1985. Gittings *et al.* (1992) reported an increase in the numbers of the herbivorous parrotfishes *Sparisoma viride* and *Scarus vetula*, and speculated that increased algae consumption by these fish compensated for the loss consumption by *D. antillarum*.

Observations suggest that *D. antillarum* was an abundant inhabitant of the Flower Garden Banks community prior to the 1983-84 mass mortality event (Rezak *et al.*, 1985; Gittings unpubl.). Surveys of sea urchin densities during 1996 and 1997 field assessments indicated the *D. antillarum* population to be reduced ($0.003/m^2$). Following the conclusions of the researchers cited above, one would expect to see either the populations of herbivorous fish to increase or the algal biomass to increase along with an increase in carbonate accretion rates. Further, if sea urchin densities increased a corresponding decrease in herbivorous fish numbers and carbonate accretion rates would be predicted. An increase of algal biomass without a corresponding increase in herbivorous organisms to control its areal coverage would be detrimental to the scleractinian corals as the algae occupied more substrate area limiting growth area for the corals (Hughes, 1994).

The community structure of a coral reef exists in a dynamic equilibrium (Hatcher, 1997), and the Flower Garden Banks are no exception. The transformation of light energy into biological mass is the foundation of a coral reef ecosystem; and through trophic phase shifts scleractinian corals can be expected to respond accordingly. Describing and monitoring the relative balance of the community structure, one can evaluate changes of the community structure resulting from natural and anthropogenic causes. Subsequently, appropriate management actions can be formulated and implemented. Hay (1997) described seaweeds as, "exceptional tools for studying the basic processes affecting population and community organization on coral reefs." Hay further stated, "The high productivity of reefs combined with the tight coupling between production and consumption, result in plant-herbivore interactions being one of the dominant forces affecting community structure as a whole." Based on this understanding of significant importance, sea urchin surveys were conducted and reported herein, and it is recommended that they be continued.

4.8.3 Deep Reef Survey

It is possible, perhaps likely, that the "coral cap" habitats of the Flower Garden Banks are dynamically linked with those biogenic zones/habitats deeper on the bank, the water column above, and the atmosphere above the sea surface (Figure 4.8.3.1). However, any existing linkages have not been described. The extensive coral cap zone has dominated the interests and efforts of scientists, and is the principal justification for the National Marine Sanctuary designation. From a management perspective, it is important to understand the linkage of coral reefs with adjacent habitats (Wells, 1995). In the case of the Flower Garden Banks, further research of adjacent habitats and respective faunal components and linkages to the coral cap is recommended.

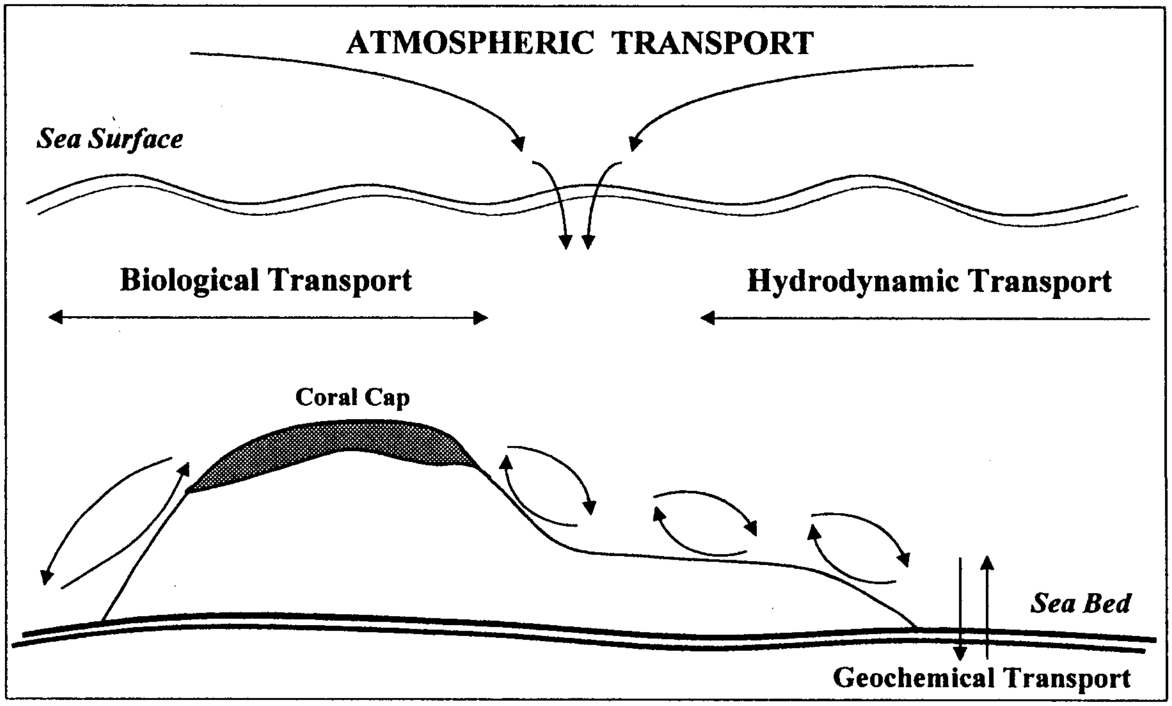


Figure 4.8.3.1. Schematic representation of dynamic linkages between habitat/ biogenic zones of the Flower Garden Banks.

Wells (1995) cited the global need for further descriptive research to determine the biota of reefs and their adjacent habitats. Flower Garden Banks monitoring studies since 1989 have been restricted to the "coral cap" of the banks at depths generally less than 31m in the *Diploria-Montastraea-Porites* Zone (Bright and Pequegnat, 1974; Rezak *et al.*, 1985). This has been primarily due to safety considerations relative to SCUBA diving technology and cost of deep-water submersibles. Bright and Pequegnat used the submersible *Nekton Gamma* to begin characterization studies of those depths below the *Diploria-Montastraea-Porites* Zone, reporting distinct biotic zonation with depth. Rezak *et al.* (1985) employed the submersible *Diaphus* to observe deep-water communities and used Bray-Curtis cluster analysis techniques to describe vertical zonation. Rezak *et al.* (1985) reported "...strong, segregation of taxon type and abundance by depth..." with the "*Stephanocoenia-Millepora* Zone" beginning between 36 to 38m and extending generally down to 46m with components to 52m.

Rezak *et al.* (1985) reported the application of "quasi-quantitative compilation and ranking of observations" to assess relative abundance of benthic algae, scleractinian corals, octocorals, and antipatharians below 30m depth. Bright and Pequegnat (1974) did not conduct quantified studies of the biogenic zones below the *Diploria-Montastraea-Porites* Zone, nor have any studies of the ecosystem dynamics of the Flower Garden Banks describing interactive relationships between biogenic zones been reported.

Just as with the micromolluscs, it is likely that more exhaustive collections below the *Diploria-Montastraea-Porites* Zone will result in the discovery of other as yet unreported species. Quantitative studies will provide greater insight into population trends and a greater understanding of the dynamics of the Flower Garden Banks ecosystem. This in turn would provide essential information to assess cause and effect relationships, and understanding necessary to develop and implement management strategies.

Weather/sea-state in 1996 and equipment (i.e. camera) malfunction in 1997 limited the still photographic data taken during deep-water surveys. However, despite these limitations, results obtained from the deep-water (i.e. 46 to 52m) survey dives on both banks were very informative. From 18 random photographic images (28mm close-up; $262cm^2$), seven species of scleractinian corals, one species of hydrozoan, seven sponge species, and 23 algal genera and species were identified (Table 3.8.1).

These efforts were preliminary and should lead to more extensive efforts in future research/monitoring projects. The random still photographic and diver-held video transects provided a new look at reef/community structure below the traditional study site depths (i.e. $\leq$ 31m). Continued video transects along with permanent and random still photographic stations should be established to begin comprehensive community descriptions and assess short and long-term community trends. Random still photographic sampling as done on the coral cap and the establishment of permanent photographic stations would provide comparable data.

Although earlier work by Bright and Pequegnat (1974) presented preliminary data of the benthic fauna of the algal nodule zone, more laboratory work is needed to fully understand the habitats, flora, and fauna of this area. For example, although 23 genera/species of algae were identified from the photographic images, we believe that laboratory analysis will substantially increase the known number of species. This information will also allow for the increased understanding of linkages between the various depth defined biogenic zones.

4.9 SAMPLING STRATEGIES

Sampling strategies can have a profound effect on data interpretation and conclusions. To monitor the Flower Garden Banks, sampling strategies have been designed to be efficient, non-destructive, and cost effective. However, it is prudent to periodically critique the sampling strategy to test its efficacy at any point in time.

4.9.1 Temporal

Due principally to financial considerations, monitoring efforts at the Flower Garden Banks have been reduced from a biannual to an annual event. This is appropriate for measuring coral growth, but inadequate to address other ecological or biological measures such as bleaching events, population fluctuations of keystone organisms such as sea urchins and herbivorous fish, or water chemistry. Under the current temporal monitoring strategy, neither the onset nor demise of a bleaching event can be documented. And, subsequently important information such as temperature tolerance and recovery rates cannot be assessed. Descriptions of important ecological relationships such as herbivore density versus algal biomass are not possible through an annual sampling strategy. Light and temperature were measured on a relatively continuous basis, but the technology of assessing water chemistry with semi-permeable membrane devices (SPMD) requires retrieval of field units (SPMDs) no less than every 90 days (preferably more often) to be effective.

Water current regimes of the Flower Garden Banks area are dynamic, changing with season, cyclonic eddies from the Loop Current, and atmospheric/storm events. Consequently, water quality will reflect different characteristics depending upon the water mass present during any sampling period. Concentrations of contaminants and nutrients may fluctuate depending upon the origin of the water mass at any given time. Hence, water quality sampling would be more representative and descriptive of cyclic conditions if taken frequently throughout the year.

Coral growth is a relatively slow process compared to other dynamic balances/cycles in a coral reef habitat, such as algal growth and population changes in herbivores. Coral growth as a benchmark for ecosystem/habitat health requires multiple years of data to describe a trend. For management purposes there must be appropriate and adequate data to describe the cause of a trend, whether it be of natural or anthropogenic origins. In the event of an anthropogenic-induced long-term trend, from a management perspective, there is always the chance that by the time a negative trend is scientifically verifiable it may be irreversible. Consequently, an effective monitoring strategy must be a balance of long-term measurements, as well as measurements for short-term changes.

Of the monitoring program core measurements (i.e. encrusting growth, accretionary growth, random photographic transects, and quadrat photographs), encrusting and accretionary growth transect measurements provide insight into long-term trends. Random and photographic data are useful in describing acute and catastrophic events on an annual cycle (e.g. increase in occurrence of disease). These measurements, coupled with measurements of seasonally cyclic phenomena (e.g. algal biomass, population density of herbivores, and water borne nutrients and contaminants), could better provide insight into cause and effect relationships, separation of natural versus anthropogenic influences, and ecosystem dynamics.

For the most part, those elements recommended for more frequent sampling (i.e. algal biomass, counts of selected fauna, and water chemistry) could be accomplished at reasonable cost for ship time, laboratory analysis, and personnel expenses.

4.9.2 Spatial

An assumption of the Flower Garden monitoring strategy is that the 100 m^2 study area at each bank remains representative of the coral reef ecosystem character and condition of the entire bank. No sampling provision for confirming/refuting the validity of this assumption has been included in the annual sampling strategy. This could be accomplished by the inclusion of random photographic transects, quadrat photographs, and video transects taken outside the designated study area annually. Statistical comparisons for eveness, percent cover, diversity, and incidence of disease between the data collected outside the designated study area and within the study area would confirm or refute the assumption of representative conditions. Addition of this effort would require more field effort during the annual sampling cruise and subsequent laboratory analysis.

4.9.3 Techniques of Data Collection

Although growth spikes were used to estimate accretionary growth of *Montastraea faveolata* during this study (1996/1997), decisions regarding the elimination of aberrant data continued to be difficult. Continuous problems and unreliable measurements make this technique ineffectual, both because of the time required for collection and analyses, and the unreliability of the data due to abnormal coral growth patterns at the spike and or loose and missing spikes. It is recommended that growth spikes be dropped as a measure of accretionary growth, and sclerochronology be accepted at the method of choice.

With standardized collection and analysis guidelines, data obtained from sclerochronology measurements are straightforward and accurate. Short cores representing ten or more years of growth can be collected easily and quickly. Successive core samples serve to replicate data for multiple year comparisons. The number of cores collected should be minimized to reduce the chance of collateral damage to coral colonies as well as limit aesthetic impact. The use of year to year growth ratios best describes changes in growth rates over time. Using ratios, growth bandwidths are compared directly against others from the same core, in effect standardizing the measurements. Cores do not need to be taken anymore frequently than every other year, and perhaps even less frequently if other measures indicate no change in coral conditions.

4.10 ECOSYSTEM MODELING

Interactive dynamic models are widely applied to assessment of cause and effect relationships and as predictive tools for establishing long-term management strategies. Models require data to develop and operate, and management objectives should drive the selection/development of the model(s) and parameters to be monitored. Ecosystem models have not been applied or developed for the management of the Flower Garden Banks.

McClanahan *et al.* (1996) provides a simplified conceptual model of interactive relationships between corals, algae, and selected herbivores. Arias-Gonzalez *et al.* (1997) modeled the trophic functioning of fringing and barrier reefs in French Polynesia, reporting that, according to the models, most primary productivity is processed and recycled in the web through detritus based, microbially mediated food webs with a secondary flux through grazer-based webs. The dynamic balance in ecosystem functioning is evident in each model, and it can be predicted that in the event that of significant change in any major component, the other components will respond accordingly.

The first step in applying modeling science to the study/management of the Flower Garden Banks coral reef ecosystem would be to compile a static conceptual model of the trophic dynamics, focusing on known keystone components (Figure 4.10.1). Through this model one can visualize the area in which the current monitoring strategy is focused making it possible to critically review the

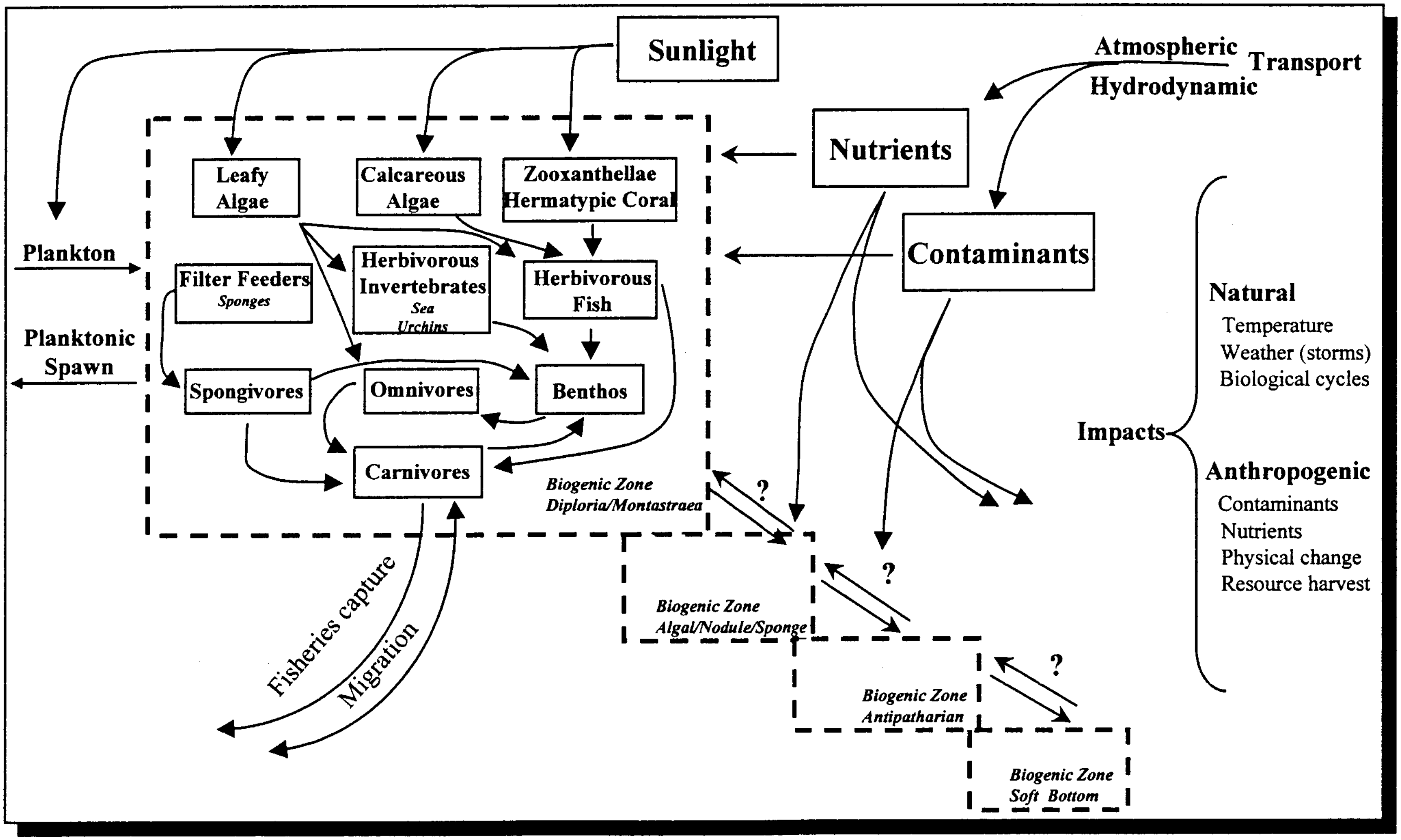


Figure 4.10.1. Preliminary conceptual model of trophic dynamics of the Flower Garden Bank's ecosystem. Arrows indicate principal direction of energy/nutrient flow. Nutrients/energy are obtained through photosynthesis, grazing, predation, filter feeding, and reduction of waste products (e.g., fecal matter).

pertinence of the current data base. This visual clarification allows for a comprehensive assessment of data needs. The next step following the development of a comprehensive conceptual model is to transform this model into dynamic models that demonstrate cause and effect relationships allowing for prediction of short and long-term trends in response to changing environmental conditions. Subsequently, management can be proactive rather than reactive.

4.11 WATER QUALITY

The monitoring strategy should incorporate measures of water quality including contaminants and nutrients. Concurrently, laboratory studies need to be conducted to assess the sensitivity of the flora and fauna of the coral reef habitat to those toxic substances and enriching nutrient compounds resulting from human activities. Based on the results of the initial SPMD (semi-permeable membrane device) studies reported herein, there is some indication that water quality could be less than optimal due to contamination with PAH (polycyclic aromatic hydrocarbon) compounds and DDT and its derivatives. Yet, without definitive understanding of the tolerance of the reef community's flora and fauna to these substances, it is not possible to predict whether or not the impact will be no effect *or* long term chronic degradation *or* short term catastrophic degradation of the reef ecosystem.

To be most informative, water quality should be measured *in situ* and continuously. Although further field and laboratory testing of SPMD utility is warranted, it appears that the application of SPMD technology provides a cost-effective mechanism to measure for selected industry derived contaminants such as polycyclic aromatic hydrocarbons and agricultural pesticides. Nutrient enrichment is a potential impact that has not been investigated, perhaps because the Flower Garden Banks' distance from shore creates a sense that watershed impacts would not be likely. However, this perception may be in error. The occurrence of freshwater detritus such as water hyacinths and occluded surface waters at the banks during flood events of the Mississippi River suggests that the Banks are not isolated from watershed non-point source pollutants.

Nutrients can be measured periodically through laboratory techniques that require water samples to be collected and returned to the laboratory. The challenge of this technique is that samples must be collected on a prescribed schedule throughout the year, which, in the case of the Flower Garden Banks, is difficult due to the distance from shore, and seasonally unfavorable sea conditions that impede collection schedules during winter and spring months. At best, this methodology provides a snapshot of isolated data points. On the plus side, the cost of analysis is minimal.

A second option would be to employ automated technology such as the Nutrient Monitor produced by W.S. Ocean Systems LTD of the United Kingdom. The NAS-2E (nitrite/nitrate) and 2EP (phosphate) Nutrient Monitor are *in situ* nutrient analyzers for the automated measurement and recording of nutrient data. These instruments can be deployed for periods of up to 60 days of continuous data collection. Although this technology provides a continuous *in situ* measurement of selected nutrient concentrations, the instrumentation must be serviced every 60 days and its initial cost is substantial (approximately $25,000/instrument) as is the operational cost.

4.12 RECREATIONAL DIVING

Recreational diving is perhaps the primary socioeconomic exploitation of the Flower Garden Banks. The most active tour operator to the Flower Garden Banks, Fling Charters/Rinn Boats, takes an average of 2,200 divers to the Banks each year (pers. comm. G. Rinn, Owner). Estimating an average of five dives per person, we derive 11,000 dives per year are made on the Flower Garden Banks through this one tour operator. Allowing for smaller tour operators and private boats, we can increase the per year estimate to an even greater number of dives. There is no existing data assessing the economic or environmental impact of recreational diving.

4.13 COMMERCIAL/RECREATIONAL FISHING

Another potential socioeconomic exploitation of the Flower Garden Banks is commercial fishing and recreational fishing. There are no existing data describing the amount or type of commercial or recreational fishing that occurs at the Flower Garden Banks. It has been assumed to be minimal, but fishing line and fish with hooks are frequently encountered. Of primary concern would be commercial fishing due to the efficiency of the gear used and experience of the fishers. Modern gear is not only efficient in catching fish, but it can be applied with equal ease to shallow and deep water habitats of the Flower Garden Banks. The potential fishery resources of the deeper habitats below the coral cap are not known.

4.14 OTHER MONITORING CONSIDERATIONS

Ideally, an ecological monitoring program is undertaken to provide insight into status, trends, and cause. In theory, having this information, managers can determine and implement the necessary management guidelines for human activities to maintain the desired conditions. By design, the primary purpose/product of the Flower Garden Banks monitoring strategy is a current and continuous assessment of status and trends of hermatypic scleractinian coral growth as a measure of the well being of the ecosystem. The habitat assessment measures taken each year at the Flower Garden Banks are adequate to accomplish this. These data constitute one of the most complete coral reef data sets in the world, and will be invaluable in the event of a catastrophic impact requiring damage assessment. However, there are limitations to the utility of the data collected and results derived, arising both from the strategy and methodology.

The most important steps in developing a successful monitoring strategy are: 1) development of clear and concise statement of purpose and objectives, and 2) development of specific questions to be addressed that provide the necessary information to achieve the objectives. For the Flower Garden Banks monitoring strategy, we can work in reverse order to 1) define what questions the core data base answer, and 2) what objectives this knowledge can be applied to.

Considering the suite of measurements taken (not including the ancillary studies) we can answer the following questions:

1) What is the accretionary and encrusting growth rate of selected scleractinian corals?
2) What is the species diversity of scleractinian corals?
3) What is the extent of horizontal coverage of scleractinian corals?

4) What is the frequency of disease of the scleractinian corals?
5) What is the frequency of bleaching of scleractinian corals during the sampling period?
6) What proportion of surface cover is coral, bare rock, or algal cover rock?
7) What is the difference between the most recent data and those data from previous samples?

Answering these questions, we can extrapolate that our objective is to assess the growth and health of scleractinian corals over time. The underlying assumption is that this information and resulting understanding is adequate to describe the ecosystem/habitat health and sustainability of the Flower Garden Banks coral communities.

In efforts to advance development of regional monitoring strategies for the Gulf of Mexico (Dokken and Cox, 1998) scientists, resource managers, and private sector representatives in a workshop format defined a living resource to be *"...healthy when its population density, biomass, and integrity are sustainable at levels not significantly different from historical accounts. Patterns of abundance and natural and anthropogenic forces (including natural mortality, disease, ecosystem health, and harvest pressure) should remain stable across long-term time frames (historical, current, and future)."* This group defined an ecosystem to be healthy when *"...it is characterized by a persistence of productivity and integrity not significantly different from historical patterns and is in balance with natural and anthropogenic forces (current and future). Productivity and integrity will be spatially and temporally measured in terms of bio-diversity, biomass, structure, function, resiliency, aesthetics, and value."*

Applying the Flower Garden Banks monitoring data to these definitions, we can conclude that the scleractinian corals are "healthy." However, the data are not adequate to conclusively assess ecosystem health or sustainability. The monitoring strategy does not record status and trends of bio-diversity, biomass, structure, function, resiliency, aesthetics, or value. Nor have the interactive dynamics of the Flower Garden ecosystem been described adequately to understand cause and effect relationships from which to develop dynamic predictive models. Wells (1995) stated that prediction and control are essential for good management, and research to provide the necessary knowledge should be a high priority.

Renewable resources can only reproduce and sustain themselves in ecosystems in which natural controls and influences are in balance with human influences (Dokken, 1997) (Figure 4.14.1), and the influences remain within the tolerance limits of the living resource in question. Human influences are the sum result of population growth, demand on the resource, economics, and technology pressures. Management strategies must integrate research, knowledge, and understanding to achieve that balance of natural and

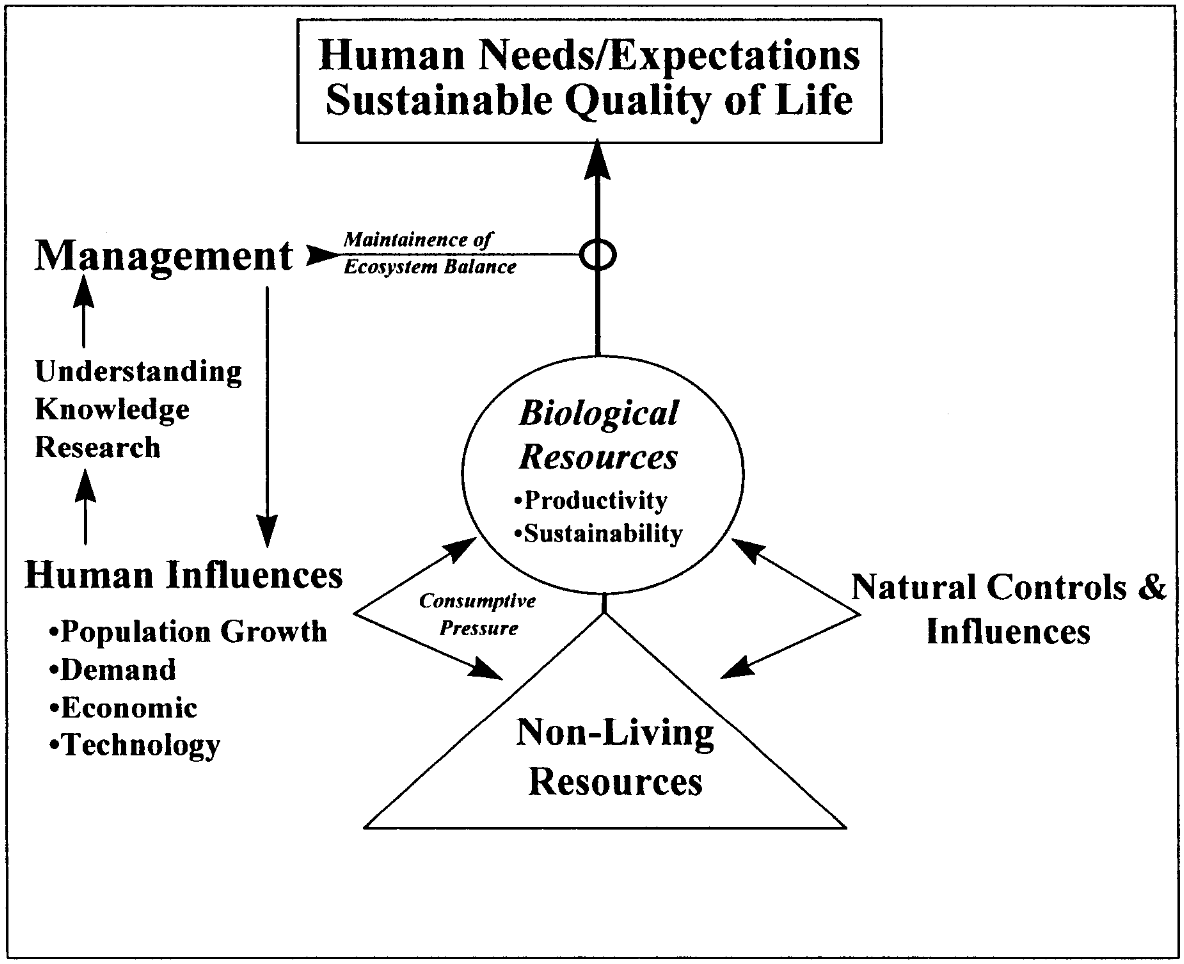


Figure 4.14.1. Balance of ecosystem health, integrity, and productivity (from Dokken, 1997).

anthropogenic influences that maintain adequate ecosystem integrity to allow the resource to sustain itself. Following an idealized "cycle of ecosystem management" (Dokken and Cox, 1998) (Figure 4.14.2), the monitoring data collected is eventually integrated into dynamic ecosystem models that, based on observed changes over time, can predict future changes under varying environmental scenarios. From this insight, proactive management actions can be implemented.

In the case of the Flower Garden Banks National Marine Sanctuary "management" implies the option and ability to make decisions relative to human activities and impacts. From this perspective, the data collected are inadequate to provide resource managers the necessary information from which to make management decisions relative to ecosystem degradation caused by sub-lethal chronic conditions. Growth is a time-based measurement, and negative results can only be observed after an impact has occurred. Additionally, with the exception of catastrophic events, it is typically difficult to distinguish natural growth cycles from growth changes caused

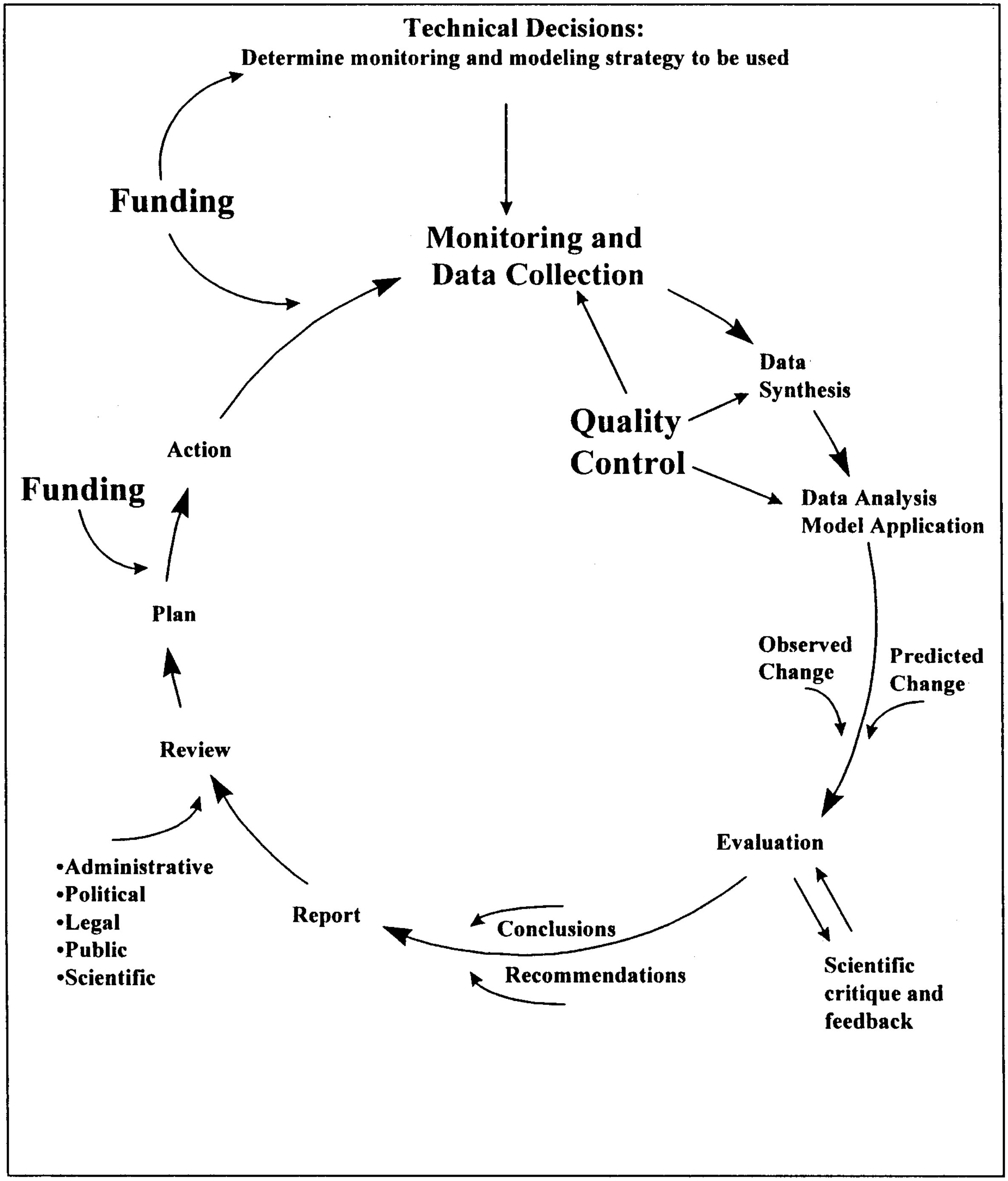


Figure 4.14.2. Cycle of ecosystem management (from Dokken and Cox, 1998).

by environmental conditions due to human activities. Growth trends can only be applied to retroactive management responses and not proactive efforts.

Hypothetically, assuming that the monitoring report presents results of "no net growth" or net loss of scleractinian coral coverage or loss of biodiversity or increased incidence of disease, without knowing the cause, what management action could be taken? What measurement(s) historically and currently specified in the contract for monitoring services illuminates the possible cause of a zero or negative growth rate? How many years of a negative growth measure is required to define a trend as opposed to a short-term aberration? How do we separate natural cycles and impacts of natural phenomena from anthropogenic impacts?

Historically, the Flower Gardens monitoring program has included two measures that could be tested for correlation with zero or negative growth rate or loss of biodiversity - temperature and light attenuation. Temperature effects can be tested for implication with bleaching events, and loss of light through reduced water clarity could be implicated in the event of reduction in coral growth and death. Added during the monitoring period reported herein, the observation of water chemistry measures, collected via semi-permeable membrane devices (SPMD), presents additional data that can be tested for correlation to the occurrence of no net growth or loss of scleractinian coral coverage or loss of biodiversity results. To date, no measure of dissolved nutrients in the water column has been undertaken.

The suite of possible human impacts (Table 4.1.3) on the Flower Garden Banks health and productivity is diverse (Deslarzes, 1998). Oil/gas exploration, production, and transport, and marine shipping constitute the greatest threats of catastrophic impact. Along with other impacts such as non-point source pollution and recreational diving, these activities could also be implicated in sub-lethal long-term chronic impacts. The monitoring strategy should include measures that provide insight into the impacts of these human activities.

All monitoring results to date indicate that no human impact has affected the sustainable growth and health of the coral habitats and biota of the Flower Garden Banks. In the event results did indicate adverse human activities, managers would then be forced to more clearly determine the cause and effect relationships in order to establish the necessary management guidelines, a time intensive activity.

5.0 SUMMARY AND RECOMMENDATIONS

The Flower Garden Banks coral reefs are healthy and growing based on the measures taken. The monitoring database is perhaps the most complete long-term database from a coral reef ecosystem in existence, and has substantial value. However, the database has limitations from a management perspective and the authors recommend the following actions to increase its value and utility:

1) Eliminate growth spikes as a method for measuring accretionary growth. Use sclerochronology measurements to measure accretionary growth exclusively.
2) Continue and expand water chemistry analysis using SPMD technology. Record data no less than quarterly.

2) Continue and expand water chemistry analysis using SPMD technology. Record data no less than quarterly.
3) Expand water chemistry analysis to include nutrients (nitrogen and phosphorous) on a schedule no less than quarterly.
4) The protocol and technology applied to the measurement of light characteristics should be enhanced to allow diurnal collections, particularly during the late summer months before and after the annual spawning event.
5) Use random photographic transects outside the boundaries of the $100m^2$ study sites to test the representativeness of the designated study sites.
6) Continue analysis of sea urchin population densities on a quarterly basis.
7) Add qualitative and quantitative analysis of macroalgae.
8) Add fish census (stationary visual and/or roving diver census) to suite of measurements.
9) Add seasonal photographic transects to assess temporal occurrences, such as disease and bleaching.
10) Continue and expand monitoring and studies of the biogenic zones below the coral cap. Trophic structure analysis should be undertaken to describe biological energy linkages between the biogenic zones.
11) Measure seasonal and annual current patterns around and above the Flower Garden Banks.
12) Develop and apply dynamic ecosystem models to research and management decision making.

These recommendations will require an increase in the investment of time and money. However, this increased effort must be evaluated relative to the purpose and objectives of the monitoring effort. The authors believe that the additional effort is warranted and necessary.

6.0 LITERATURE CITED

Abbott, R.E. 1979. Ecological processes affecting the reef coral population at the East Flower Garden Bank, northwest Gulf of Mexico. Ph.D. Dissertation, Texas A&M Univ., College Station, Texas. 154 pp.

Adeshina, R. and E.L. Todd. 1991. Application of biological data in cancer risk estimations of chlordane and heptachlor. Regul. Toxicol. Pharmacol. 14:59-77.

Agassiz, A. 1885. The Tortugas and Florida reefs. Mem. Am. Acad. Arts Sci. 11:107-134.

Agassiz, L. 1852. Florida reefs, keys and coast. Annu. Rep. Supt. Coast Surv. 1866: 120-130.

Alcolado, P.M., R. Claro, G. Menendez, and B. Martinez-Daransa. 1997. General status of Cuban coral reefs. Proc. 8th Int. Coral Reef Symp. 1:341-344.

Ardisson, P.-L. and J.J. Duvan-Najera. 1997. Programa de manejo del Parque MarinoNacional Arrecife Alacranes. Estudio presentado por la Unidad Merida del CINVESTAV-IPN ante la Coordinacion General del Programa Nacional deApoyo para los Empresas de Solidanidad y el Instituto Nacional de Ecologia. Merida, Yucatan. 114 pp.

Ardisson, P.-L., A. Cuevas-Jimenez, and J.J. Duran-Najera. (in press) Assessment of the status of Mexico's coral reefs, Phase II: overview of existing methodologies for the assessment of coral reefs. Study conducted in support of the International Coral Reef Initiative. Prepared for Commission for Environmental Cooperation.

Arias-Gonzalez, J.E., B. Delesalle, B. Salvat, R. Galzin. 1997. Trophic functioning of the Tiahura reef sector, Moorea island, French Polynesia. Coral Reefs 16:231-246.

Baker, P.A. and J.N. Weber. 1975. Skeletal growth variations in the reef coral, *Montastraea annularis*, with depth. Geol. Soc. Am., Abstracts. 7:24.

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

Boland, G.S., B.J. Gallaway, J.S. Baker, and G.S. Lewbel. 1983. Ecological effects of energy development on reef fish of the Flower Garden Banks. National Marine Fisheries, Galveston, Texas. Contract No. NA80-GA-C-00057. 466 pp.

Briggs, J.C. 1974. Marine zoogeography. McGraw-Hill. New York, 475 pp.

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. pp. 4-54, *In* T.J. Bright and L.H. Pequegnat (eds.) Biota of the West Flower Garden Bank. Gulf Publ. Co., Houston, Texas.

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 Interior Minerals Management Service, Gulf of Mexico OCS Region Office, New Orleans, Louisiana. OCS Study MMS 85-0024. 103 pp.

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.

Brown, B.E. 1997. Coral bleaching causes and consequences. Coral Reefs 16, Suppl.:S129-S138.

Bruckner, A.W., R.J. Bruckner, and E.H. Williams, Jr. 1997. Spread of a black-band disease epizootic through the coral reef system in St. Ann's Bay, Jamaica. Bull. Mar. Sci. 61(3):919-928.

Carpenter, R.C. 1986. Partitioning herbivory and its effects on coral reef algal communities. Eco. Monog. 56:345-363.

Carpenter, R.C. 1990. Mass mortality of *Diadema antillarum*. II. Effects on population densities and grazing intensity of parrotfishes and surgeonfishes. Mar. Biol. 104:79-86.

Carricart-Ganivet, J. P. and G. Horta-Puga. 1993. Arrecifes de coral en Mexico. pp. 80-90, *In* S. I. Salazar-Vallejo and N. E. Gonzalez (eds.) Biodiversidad marina y costera de Mexico. CONABIO y CIQRO, Mexico, D.F.

Chavez, E.A., and E. Hidalgo, and M.A. Izaguirre. 1985. A comparative analysis of Yucatan coral reefs. Proceed. 5th Int. Coral Reef Congress. 6:355-361.

Chavez, E.A. and E. Hidalgo 1988. Los arrecifes coralinos del Caribe noroccidental y Golfo de Mexico en el contexto socioeconomico. An. Inst. Cinc. Mar y Limnol. Univ. Nal. Auton. Mex 15(1): 167-176.

Chavez, E. A., E. Hidalgo, and M. L. Sevilla. 1970. Datos acerea de las communidates, bentonicas del arrecife de Lobos, Veracruz. Rev. Soc. Mex. Hist. Nat. 31:211-280.

Chavez, E.A. and J.W. Tunnell. 1993. Needs for management and conservation of the southern Gulf of Mexico. Proc. 8th Symp Coastal and Ocean Management, pp 2040-2053.

Chiappone, M., K.M. Sullivan, and C. Lott. 1996. Hermatypic scleractinian corals of the southeastern Bahamas: a comparison to western Atlantic reef systems. Carib. J. Sci. 32:1-13.

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

Deslarzes, K.J.P., ed. 1998. The Flower Garden Banks (northwest Gulf of Mexico): Environmental characteristics and human interaction. OCS Report MMS 98-0010. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, Louisiana. 100 pp.

Dokken, Q.R. (compiler). 1997. Workshop: models and mass balance calculations for the Gulf of Mexico. Gulf of Mexico Program, Stennis, MS. Gulf of Mexico Foundation, Corpus Christi, Texas. 92 pp.

Dokken, Q.R. and S. Cox. 1998. Monitoring considerations for health of living aquatic resources in the Gulf of Mexico. Gulf of Mexico Program, Stennis, MS. Center for Coastal Studies, Texas A&M University-Corpus Christi TAMU-CC-9805-CCS. 81 pp.

Downing, N. and C.R. El-Zahr. 1987. Gut evacuation and filling rates in the rock boring sea urchin, *Echinometra mathaei*. Bull. Mar. Sci. 41:579-584.

Eakin, C.M., J.W. McManus, M.D. Spalding, and S.C. Jameson. 1977. Coral reef status around the world: where are we and where do we go from here? Proc. 8th Int. Coral Reef Symp. 1:277-282.

Fitt, W.K., F.K. McFarland and M.E. Warner. 1997. Seasonal cycles of tissue biomass and zooxanthellae densities in Caribbean reef corals: a new definition. Amer. Zool. 37(5) Abstract #255.

Fleming, L.E. and W. Timmeny. 1993. Aplastic anemia and pesticides: an etiologic association? Occup. Med. 35(1):106-1,116.

Ginsburg, R.N. (compiler) 1994. Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards and History, 1993. Rosenstiel School of Marine and Atmospheric Science, University of Miami, June 1993. 420 pp.

Gittings, S.R. and T.J. Bright. 1987. Mass mortality of *Diadema antillarum* at the Flower Garden banks, northwest Gulf of Mexico: effect on algae and coral cover. Benthic Ecology Meetings, Raleigh, North Carolina. (abstract)

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. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, Louisiana. OCS Study MMS 92-0006. 206 pp.

Gittings, S.R., T.J. Bright, and D.K. Hagman. 1994. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992. pp 181-187, *In* R.N.Ginsburg (compiler) Proceedings of the Colloquium on Global Aspects of Coral Reefs: Health, Hazards ad History, 1993. Rosenstiel School of Main and Atmospheric Science, University of Miami.

Glynn, P.W. 1984. Widespread coral mortality and the 1982-1983 El Niño warming event. Environ. Conserv. 11:133-146.

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

Goreau, T.J. 1992. Bleaching and reef community change in Jamaica: 1951-1991. Amer. Zool. 32:683-695.

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

Hatcher, B.G. 1997. Coral reef ecosystems: How much greater is the whole than the sum of the parts? Coral Reefs 16, Suppl.:S77-S91.

Hay, M.E. and P.R. Taylor. 1985. Competition between herbivorous fishes and urchins on Caribbean coral reefs. Oecologia 65:591-598.

Hay, M.E. 1997. The ecology and evolution of seaweed-herbivore interactions on coral reefs. Coral Reefs 16, Suppl.:S6 S76.

Heilprin, A. 1890. The corals and coral reefs of the western waters of the Gulf of Mexico. Proc. Acad. Natl. Sci. Phila. 42:301-316.

Horta-Puga, G, G. Barba-Santos, and J.L. Tello-Musi. (in preparation) The status of the Veracruz Reef System in the Gulf of Mexico.

Hudson, J.H. 1981. Growth rates of *Montastraea annularis*: A record of environmental change in Key Largo Coral Reef Marine Sanctuary, Florida. Bull Mar. Sci. 31(2):444-459.

Hudson, J.H. and D. M. Robbin. 1980. Effects of drilling mud on the growth rate of the reef-building coral, *Montastraea annularis*. pp. 455-470, *In* R. A. Geyer (ed.) Marine Environmental Pollution, Vol. 1:Hydrocarbons. Elsevier Scientific Publishing Company, New York. 591 pp.

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

Hughes, T. P., D.C. Reed, and J.J. Boyle. 1987. Herbivory on coral reefs: Community structure following mass mortalities of sea urchins. J. Exp. Mar. Biol. Ecol. 113:39-59.

Hughes, T.P. 1994. Catastrophes, phase shifts and large-scale degradation of a Caribbean coral reef. Science 265:1547-1551.

ICRI (International Coral Reef Initative). 1995. Partnership building and framework development: Final Report of the ICRI Workshop, Sillima University. Dumagrete City, Philippines. May 29-June 2, 1995. 64 pp.

Japp W.C. 1984. The ecology of the south Florida coral reef: a community profile. U. S. Fish Wild Serv. FWS OBS-82/08 138 pp.

Japp, W.C. and P. Hallock, 1990. Coral reefs. pp 574-616, *In* R.L Myers and J.J. Ewel (eds.) Ecosystems of Florida. University of Florida, Orlando.

Johannes, R.R. 1975. Pollution and degradation of coral reef communities. pp. 13-51, *In* R. E. Johannes and E. J. Ferguson Wood (eds.) Tropical marine pollution. Elsevier Scientific Publishing Co., Amsterdam, Netherlands.

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

Kuhlmann, D. H. H. 1975. Charackterisierung der Korallenriffe vor Veracruz Mexico. Int. rvue. ges. Hydrobiol 60(4): 495-521.

Lang, J.C. 1973. Inter-specific aggression by Scleractinian corals. 2. Why the race is not only to the swift. Bull. Mar. Sci. 23:260-279.

Lang, J.C., P.M. Alcolado, J.P. Carricart-Ganivet, M. Chiappone, H. A. Curran, P. Dustan, F.X. Geraldes, S.R. Gittings, S.R. Smith, J.W. Tunnell, and J. Wiener. (In Preparation) Status of western Atlantic coral reefs in the northern areas of the wider Caribbean.

Lara, M., C. Padilla, C. Garcia, and J.J. Espegel. 1992. Coral reefs of Veracruz Mexico zonation and community. Proc. 7^{th} Int.Coral Reef Symp. 1:535-544.

Lessios, H.A. 1988. Mass mortality of *Diadema antillarum* in the Caribbean: What have we learned? Ann. Rev. Ecol. and Systematics 19:371-393.

Lessios, H.A. and I.G. Macintyre. Eds. 1997. Proceedings of the 8^{th} International Coral Reef Symposium. 2 vols. Panama, June 1996. 2119 pp.

Levitan, D.R. 1988. Algal-urchin biomass responses following mortality of *Diadema antillarum* Philippi at Saint John, U.S. Virgin Islands. J. Exp. Mar. Biol. Ecol. 119:167-178.

Littler, M.M. and D.S. Littler. 1984. Models of tropical reef biogenesis: the contribution of algae. Progress in Phycological Records. Vol 3, pp. 323-364.

Lipka, D.A. 1974. Mollusks. pp. 141-196, *In* T.J. Bright and L.H. Pequegnat (eds.) Biota of the West Flower Garden Bank. Gulf Publ. Co., Houston, Texas.

Logan, B.W. 1969. Coral reefs and banks, Yucatan shelf, Mexico (Yucatan Reef Unit). pp.129-198, *In* Logan, B.W., J.L. Harding, W.M. Ahr, J.D. Williams and R.S. Sneed (eds.) Carbonate sediments and reefs, Yucatan shelf, Mexico. Am. Assoc. Petrol.Geol.,Memior II.

McClanahan, R.R. and N.A. Muthiga. 1989. Changes in Kenyan coral reef community structure and function due to exploitation. Hydrobiologia 166:269-276.

McClanahan, T.R. and S.H. Shafir. 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. Oecologia 83:362-370.

McClanahan, T.R. 1992. Resource utilization, competition and predation: A model and example from coral reef grazers. Ecol. Model. 61:195-215.

McClanahan, T.R. and J.C. Mutere. 1994. Coral and sea urchin assemblage structure and interrelationships in Kenyan reef lagoons. Hydrobiologia 286:109-124.

McClanahan, T.R., A.T. Kamukuru, N.A. Nuthiga, M. Gilagabher Yebio, and D. Obura. 1996. Effect of sea urchin reduction on algae, coral, and fish populations. Conserv. Biol. 10(1):136-154.

McGrail, D.W., M. Carnes, D. Horne, T. Cecil, J. Hawkins, and F. Halper. 1982. Water and sediment dynamics at the Flower Garden Banks. pp. 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.

NCI (National Cancer Institute). 1977. Bioassay of chlordane for possible carcinogenicity. Tech. Rpt. Ser. No. 8. U.S. Dept. Health, Educ., and Welfar. National Instutites of Health. PB 271977.

NOAA (National Oceanic and Atmospheric Administration). 1996. Florida Keys National Marine Sanctuary Final Management Plan/Environmental Impact Statement, 3 vols.

Ogden, J.C. and P.S. Lobel. 1978. The role of herbivorous fishes and urchins in coral reef communities. Environ. Biol. Fish. 3:49-63.

Parsons, T. R., M. Takahashi, and B. Hargrave. 1984. Biological oceanographic processes. 3rd Edition. Pergamon Press. 330 pp.

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. Vol.1, pp. 1023-1028.

Pennings, S.C. 1997. Indirect interactions on coral reefs. pp. 249-272, *In* C. Birkeland's (ed) Life and Death of Coral Reefs. Chapman & Hall, International Thomson Publishing, NY..

Porter J.W., and O.W. Meier. 1992. Quantification of loss and change in Florida reef coral populations. Amer. Zoo. 32:625-640.

Rezak, R. 1981. Geology pp. 23-59, *In* R. Rezak and T.J. Bright (eds.) Northern Gulf of MexicoTopographic Features Study. Final Report to the U.S. Department of Interior, 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, 259 pp.

Rezak, R. and G.S. Edwards. 1972. Carbonate sediments of the Gulf of Mexico. pp. 263-280, *In* R. Rezak and V.J. Henry (eds.) Contributions of the geological and geophysical oceanography of the Gulf of Mexico. Tex. A&M Univ. Oceanogr. Stud. 3.

Rigby, J.K. and W.G. McIntyre. 1966. The Isla de Lobos and associated reefs, Veracruz, Mexico. Brigham Young Univ. Geol. Stud. 13:3-46.

Roberts, C.M. 1995. Effects of fishing on the ecosystem structure of coral reefs. Conserv. Biol. 9(5):988-995.

Robertson, D.R. 1991. Increases in surgeonfish populations after mass mortality of the sea urchin *Diadema antillarum* in Panama indicate food limitations. Mar. Biol. 111:437-444.

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

Salvat, B. (ed.) 1987. Human impacts on coral reefs: facts and recommendations. Antennae Museum EPHE, French Polynesia. 253 pp.

Sammarco, P.W. 1982. Echinoid grazing as a structuring force in coral communities: Whole reef manipulations. J. Exp. Mar. Biol. Ecol. 61:31-55.

Tunnell, J.W. 1988. Regional comparison of southwestern Gulf of Mexico to Caribbean Sea coral reefs. Proc 6th Int.Coral Reef Symp. 3:303-308.

Tunnell, J.W. 1992. Natural versus human impacts to southern Gulf of Mexico coral reef resources. Proc 7th Int. Coral Reef Symp. 1:300-306.

Walker, A.I.T., E. Thorpe and D.E. Stevenson. 1972. The toxicology of dieldrin (HEOD). I. Long term oral toxicity studies in mice. Food Cosmet. Toxicol. 11:415-432.

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. franksi* (Gregory, 1895). Bul. Mar. Sci. 55(1):151-175.

Wells, S.M. (ed.). 1988. Coral reefs of the world. Volume 1: Atlantic and Eastern Pacific. UNEP Regional Seas Directories and Bibliographies. UNEP, Nairobi, Kenya and IUCN, Gland, Switzerland and Cambridge.

Wells, S. M. 1995. Science and management of coral reefs: problems and prospects. Coral Reefs 14:177-181.

Wilkinson, C.R. and R.W. Buddemeier. 1994. Global climate change and coral reefs: implications for people and reefs. Report of the UNEP-IOC-ASPEI-IUCN Global Task Team on the Implications of Climate Change on Coral Reefs. IUCN. Gland, Switzerland. 124 pp.

7.0 APPENDIX

Appendix. 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.

PHYLUM MOLLUSCA

Class Gastropoda

Subclass Prosobranchia

Order Archaeogastropoda

SCISSURELLIDAE

Scissurella sp.

FISSURELLIDAE

Emarginula phrixoides Dall, 1927
E. tuberculosa Libassi, 1859
E. pumila (A. Adams, 1851)
Diodora listeri (Orbigny, 1842)
Rimula frenulata Dall, 1889
R. aequisculpta Dall, 1927
Lucapina sowerbii (Sowerby, 1835)
L. aegis (Reeve, 1850)
Luapinella limatula (Reeve, 1850)
Zeidora bigelowi Farfante, 1947

ACMAEIDAE

Acmaea sp.

SKENEIDAE

Cyclostremiscus ornatus Olsson and McGinty, 1958

CYCLOSTREMATIDAE

Cyclostrema tortuganum (Dall, 1927)
C. amabile (Dall, 1889)

TURBINIDAE

Arene cruentata (Mühlfeld, 1829)
A. tricarinata (Stearns, 1872)
Astraea phoebia Röding, 1798

Order Mesogastropoda

RISSOIDAE

Alvania auberiana (Orbigny, 1842)
Zebina browniana (Orbigny, 1842)
Rissoina cancellata Phillipi, 1847
R. cf. *decussata* (Montagu, 1803)
R. cf. *multicostata* (C.B. Adams, 1850)

BARLEEIDAE

Amphithalamus vallei Aguayo and Jaume, 1947

CAECIDAE

Caecum pulchellum Stimpson, 1851
C. johnsoni Winkly, 1908
C. floridanum Stimpson, 1851
C. cf. *vestitum* Folin, 1870

C. cf. *cornucopiae* Carpenter, 1858
C. cooperi S. Smith, 1860
C. cf. *ryssotitum* Folin, 1867
VITRINELLIDAE
Vitrenella sp.
Pleuromalaxis cf. *pauli* Olsson and McGinty, 1958
Parviturboides interruptus (C.B. Adams, 1850)
Sansonia tuberculata (Watson, 1886)
Teinostoma incertum Pilsbry and McGinty, 1945
T. cocolitoris Pilsbry and McGinty, 1945
MODULIDAE
Modulus modulus (Linné, 1758)
CERITHIIDAE
Cerithium litteratum (Born, 1778)
C. exile (Adams, 1850)
LITIOPIDAE
Alaba incerta (Orbigny, 1842)
DIASTOMATIDAE
Obtortio dubia (Orbigny, 1842)
TURRITELLIDAE
Vermicularia knorrii (Deshays, 1843)
SILIQUARIDAE
Siliquaria squamata Blainville, 1827
VERMETIDAE
Petaloconchus erectus (Dall, 1888)
P. cf. *mcgintyi* (Olsson and Harbison, 1953)
Spiroglyphus annulatus Daudin, 1800
S. irregularis (Orbigny, 1842)
Serpulorbis cf. *decussatus* (Gmelin, 1791)
CREPIDULIDAE
Crepidula cf. *plana* Say, 1822
ATLANTIDAE
Atlanta peronii Lesueur, 1817
NATICIDAE
Haliotinella patinaria Souverbie, 1875
RANELLIDAE (Cymatiidae)
Cymatium cf. *pileare* (Linné, 1758)
Suborder Heteroglossa
CERITHIOPSIDAE
Cerithiopsis crystallinum Dall, 1881
C. emersoni (C.B. Adams, 1838)
C. fusiforme (C.B. Adams, 1845)
C. greeni (C.B. Adams, 1839)
C. latum (C.B. Adams, 1850)
Seila adamsi (H.C. Lea, 1845)
TRIPHORIDAE

T. melaneura (C.B. Adams, 1850)
T. turristhomae (Holten, 1802)
T. sp. A
EULIMIDAE
Melanella arcuata C.B. Adams, 1850
M. sp *A*
Strombiformis auricinctus Abbott, 1958
Order Neogastropoda
COLLUMBELLIDAE
Mitrella sp.
MARGINELLIDAE
Persicula lavelleena Orbigny, 1842
VEXILLIDAE
Vexillum sp.
CONIDAE
Conus sp.
OMALOGYRIDAE
Ammonicera minortalis Rolán, 1992
A. albospiciosa Rolán, 1992
A. familiaris Rolán, 1992
Omalogyra zebrina Rolán, 1992
RISSOELLIDAE
Rissoella caribeae Rheder, 1943
R. cf. *galba* Robertson, 1961
Subclass Heterobranchia
Superorder Allogastropoda
PYRAMIDELLIDAE
Odostomia dydima Verrill and Bush, 1900
O. impressa (Say, 1821)
O. (*Cingulina*) *babylonia* (C.B. Adams, 1845)
Cyclostremella humilis Bush, 1897
Subclass Opisthobranchia
Order Cephalaspidea
HAMINEIDAE
Haminoea succinea (Conrad, 1846)
Order Thecosomata
CAVOLINIDAE
Cavolinia tridentata (Niebuhr, 1775)
C. longirostris (Blainville, 1821)
C. unicinata (Rang, 1825)
Creseis acicula (Rang, 1828)
Diacria quadridentata (Blainville, 1821)
D. cf. *trispinosa* (Blainville, 1821)
Subclass Pulmonata
Order Basomataphora

SIPHONARIIDAE
Willimia krebsii (Mörch, 1877)
Class Bivalvia
Subclass Pteriomophia
Order Arcoida
ARCIDAE
Arca zebra (Swainson, 1833)
Barbatia cancellaria (Lamarck, 1819)
B. candida (Helbling, 1779)
B. domingensis (Lamarck, 1819)
Arcopsis adamsi (Dall, 1876)
Anadara baughmani Hertlein. 1951
GLYCYMERIDIDAE
Glycymeris pectinata (Gmelin, 1791)
Order Mytiloida
MYTILIDAE
Gregariella coralliophaga (Gmelin, 1791)
Order Limoida
LIMIDAE
Lima tenera Sowerby, 1843
PECTINIDAE
Chlamys benedicti (Verrill and Bush, 1897)
Argopecten gibbus (Linné, 1758)
SPONDYLIDAE
Spondylus sp.
ANOMIIDAE
Anomia simplex Orbigny, 1842
Subclass Heterodonta
Order Veneroida
LUCINIDAE
Codakia orbicularis (Linné, 1758)
UNGULINIDAE
Diplodonta punctata (Say, 1822)
CARDITIDAE
Glans domingensis (Orbigny, 1845)
CONDYLOCARDIIDAE
Carditopsis smithii (Dall, 1896)
CHAMIDAE
Chama cf. *congregata* Conrad, 1833
C. macerophylla (Gmelin, 1791)
Arcinella cornuta Conrad, 1866
CRASSITELLIDAE
Crassinella martinicensis (Orbigny, 1842)
MESODESMATIDAE
Ervilia concentrica (Holms, 1860)

TRAPEZIIDAE

Coralliophaga coralliophaga (Gmelin, 1791)

VENERIDAE

Gouldia cerina (C.B. Adams, 1845)

Ventracolaria rugitina (Heilpren, 1877)

Dosinia elegans Conrad, 1876

D. discus (Reeve, 1850)

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.