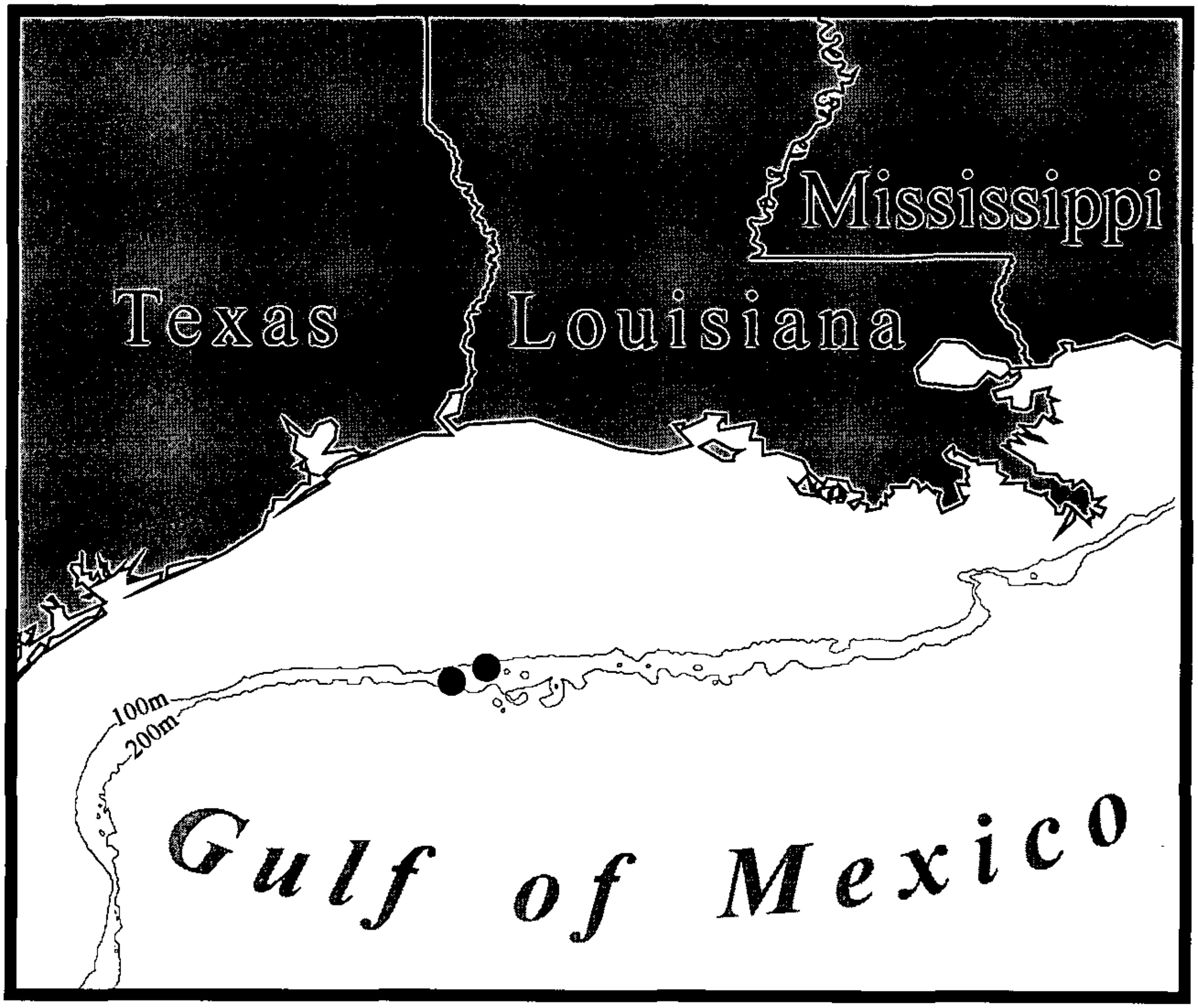
OCS Study
MMS 96-0046

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



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

OCS Study
MMS 96-0046

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

Prepared by

Continental Shelf Associates, Inc.

Prepared under MMS Contract
14-35-0001-30662
by
Continental Shelf Associates, Inc.
759 Parkway Street
Jupiter, Florida 33477

Published by

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

New Orleans
January 1997

DISCLAIMER

REPORT AVAILABILITY

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

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

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

CITATION

Suggested citation:

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

ABSTRACT

This study was designed to be a continuation of the long-term monitoring study conducted from 1989-1991. Study sites and selected permanent stations established at the East and West Flower Garden Banks during the previous study were used, when possible, during the present study in an effort to maintain a database consisting of comparable data sets between banks and between years.

Coral cover, relative dominance, diversity, evenness, and accretionary and encrusting growth rates were estimated from data collected in 1992 (prior to field efforts for this study), and during field efforts conducted in 1994 and 1995. Significant differences were found in the population levels of certain coral species for the 1992, 1994, and 1995 data sets, both between banks and between years. Comparisons with similar data collected during 1989-1991 suggest no significant long-term trends or degradation of habitat, but rather suggest spatial variability in the distributions of individual coral species within the two study sites.

Permanent stations established during the 1989-1991 study for the measurement of accretionary and encrusting coral growth of *Montastrea annularis* and *Diploria strigosa* were found during the 1994 field effort to be unsuitable for further use. This was primarily due to natural changes in the measured coral tissue borders which would not permit accurate measurement of subsequent accretionary or encrusting growth estimates. Estimates of accretionary growth rates of *M. annularis* from 1994-1995 for permanent stations and coral core samples, which were also collected and analyzed, agree well with the range of values collected during the 1989-1991 monitoring study.

Problems were discovered in the lateral growth photographic data collected at permanent stations in 1992. In addition to the aforementioned tissue border changes, many permanent station photographs taken during this period were unsuitable for analysis due to incorrect camera angle. Statistical comparisons between lateral growth data collected during 1992 and those collected during the 1994-1995 period were not performed as a result of the relative low number of suitable 1992 photographs. However, estimates of encrusting growth rates of *D. strigosa* between 1991-1992 and 1994-1995 suggest favorable conditions of growth at the two study sites. Relative tissue growth (advance) and retreat rates during these two periods were comparable.

Encrusting growth rates of *M. annularis* were estimated only from data collected during 1992. Net growth rates were negative at the East Flower Garden Bank study site and positive at the West Flower Garden Bank study site. Retreat to advance ratios for this species indicate net tissue loss at both study sites during this period. Due to aforementioned problems in data collected in 1992, these data may also be an artifact of sample error and not realistic estimates. From these data, it is apparent that the period of time over which permanent stations for the measurement of accretionary and encrusting growth of corals may be reliably used is finite.

Coral bleaching was observed in repetitive quadrat photographs taken in 1992, 1994, and to a much greater extent during 1995. The extent of bleaching within the study sites was even more pronounced in November 1995. Bleaching during these periods

coincided with periods of elevated bottom temperatures (above 30°C) which are not uncommon during late summer. Colonies that exhibited bleaching usually sustained only minor tissue loss.

Accidents resulting in the release of oil in the vicinity of the Flower Garden Banks remains a realistic threat. Impacts to the reefs resulting from offshore oil and gas exploration and development have not been detected. Regulations at the Flower Garden Banks associated with their National Marine Sanctuary status will decrease or alleviate potential threats from commercial fishing, spearfishing, vessel anchoring, and the unregulated collections of reef resources.

TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

Page

TABLE OF CONTENTS
(Continued)

LIST OF FIGURES

LIST OF FIGURES
(Continued)

LIST OF FIGURES
(Continued)

LIST OF TABLES

ACKNOWLEDGEMENTS

Continental Shelf Associates, Inc. recognizes the support of Contract No. 14-35-0001-30662 with joint sponsorship of the project by MMS and the NOAA National Marine Sanctuary Program.

Several non-CSA divers participated on field data collection efforts. These included the following:

Glen Armand
Jan Culbertson
Les Dauterive
Ken Deslarzes
David French
Stephen Gittings
Coley Groth
Judith Ovard
Douglas Peter
Gary Rinn

Their efforts are herein acknowledged and greatly appreciated. Thanks also to the crew of the R/V FLING for logistic support during field efforts and assistance in the periodic cleaning of underwater light meter sensors during subsequent sport diving trips. Mobil personnel on the High Island 389A platform were supportive in the deployment and maintenance of the terrestrial light meter and datalogger. Mr. Harold Hudson is acknowledged for his expertise in the processing and analysis of accretionary growth rates from collected coral cores.

EXECUTIVE SUMMARY

INTRODUCTION

The Flower Garden Banks are located on the outer continental shelf of the Gulf of Mexico, approximately 204 km (110 nmi) southeast of Galveston, Texas. They are topographic prominences of bedrock that have been uplifted by the upward intrusion of underlying salt deposits, or diapirs. The bedrock has been capped with a layer of hard bottom, formed from the skeletons of corals and other calcareous organisms, and biogenic calcareous sands and gravels.

The Flower Garden Banks are unique in many respects. Thriving coral reefs comprising 18 species of hermatypic (reef-building) scleractinian corals occur on the banks in a geographic area that is considered to be near their northern physiological limits. Reef-building activity at the Flower Garden Banks is due to favorable conditions of substrate, water depth, temperature, salinity, and water clarity. The Flower Garden Banks are the northernmost thriving tropical coral reefs on the North American continental shelf. Because of their latitude and relative isolation, the biological communities on the Flower Garden Banks are less diverse than typical western Atlantic and southern Gulf of Mexico coral reefs. Nevertheless, abundance and growth rates of corals at the Flower Garden Banks compare favorably with those in more tropical regions at similar depths.

Potential environmental threats to the Flower Garden Banks from development of petroleum hydrocarbon resources and other human activities on and in proximity to the banks, and the sensitive nature of their coral reef communities, prompted the U.S. Department of the Interior, Minerals Management Service (USDOI, MMS) to conduct a long-term monitoring program on the banks which addresses concerns regarding both chronic and acute impacts. These studies were initiated in the mid-1970s. MMS required monitoring and studies have also been conducted by oil companies since the late 1970s in conjunction with the development of petroleum hydrocarbon resources in regulated lease areas in the vicinity of the banks.

The Flower Garden Banks were designated as a National Marine Sanctuary in January 1992. Regulations and restrictions associated with Sanctuary status have greatly increased the level of protection afforded to the banks. However, increased levels of public awareness of the banks has also brought about a marked increase in the recreational use of the area.

The primary objectives of the present long-term monitoring study at the Flower Garden Banks were:

(1) to provide relevant and timely environmental data to agencies that develop policies concerning oil and gas exploration and development in the vicinity of biologically sensitive habitats;

(2) to document acute and long-term changes in reef-building and other associated communities within the high-diversity *Diploria-Montastrea-Porites* Zone at the Flower Garden Banks that may be attributed to

impacts of oil and gas exploration and development or other human activities (e.g., recreational diving);

(3) to document natural variation in reef-building and associated communities within this biotic zone on the banks; and

(4) to duplicate methodologies and, whenever possible, to utilize study stations developed during the previous long-term monitoring study in an effort to maintain a continuous database of information on the banks.

Contract requirements for this study specified field data collections and analyses to be completed in 1994 and 1995, and the analysis of photographic data which had been collected in 1992 at both East and West Flower Garden Bank study sites by Texas A&M University. The 1992 data set was collected between the 1989-1991 and present contract periods, and was representative of conditions on the Flower Garden Banks from 1991-1992.

METHODS

The scope of the present monitoring contract specified analyses of field data collected during 1992 (which had not been analyzed) and the collection of field data and associated analyses during 1994 and 1995. Field sampling efforts were conducted during 11-16 September 1994 and 20-25 August 1995.

Field efforts in 1994 and 1995 were conducted within a previously established 100 m by 100 m study site on each bank. These sites were marked with permanent mooring lines and attached surface floats. Their corners were demarcated using subsurface marker floats attached to small stainless steel eyebolts cemented into areas of reef rock. During each field effort, the sites were clearly defined by extending color coded, graduated polypropylene lines between the corner marker eyebolts, forming an enclosed square. On the West Flower Garden Bank, additional site boundary lines were extended between halfway marks on each line, forming four smaller squares, or blocks within the site. These lines were invaluable for relocation of permanent stations and diver navigation within the sites.

During each field effort, fourteen, 10 m (33 ft) stratified random transects were photographed within each site. Population levels of corals and other associated reef biota were determined planimetrically by their areal coverage and abundance in transect photographs. Each transect photograph was analyzed separately. Corals were identified to species level within the photographs. The sum of areas for each coral species, and all sponges, leafy algae, and reef rock in each set of transect photographs were converted to values of relative percent cover. The areas and numerical densities of each coral species were then used to calculate relative dominance (specific percent coral cover relative to total percent coral cover), species diversity (H') (the natural log variant of the Shannon Weaver Diversity Index), and species evenness (J) (species diversity divided by the maximum possible diversity, i.e., the natural log of the total number of species present). The dominant coral species on the Flower Garden Banks, *Montastrea annularis*, has recently been subdivided into three separate species, *M. annularis*, *M. faveolata*, and *M. franksi* (Holland, 1991). Data analyses in this report have combined these species as *M. annularis*.

Two methods were used for the estimation of accretionary growth rates in the coral *Montastrea annularis*. These included permanent growth stations, which involve repetitive measurements of stainless steel spikes implanted within live coral, and sclerochronological measurements from two coral core samples collected during the 1995 field effort. Most permanent accretionary growth stations established during previous studies and located in 1994 were found to be unusable. Therefore, a set of 20 new stations were established within each site during this field effort. Estimates of accretionary growth by this method were made during the 1994-1995 period only.

Encrusting growth rates of the coral *Diploria strigosa* were estimated by measurement of change along a specific coral-dead reef rock interface, or border, within each permanent station. Similar to the case of accretionary growth stations, all encrusting growth stations used during previous studies and located in 1994 were found to be unusable. Therefore, 60 permanent stations were established at each site during the 1994 field effort. Each station was marked with two spikes permanently affixed within dead reef rock adjacent to the selected coral tissue border. These spikes were positioned in such a manner to facilitate alignment of a camera close up framer device for repetitive photography of the border area. Encrusting growth and retreat of the coral tissue were estimated by superimposing the original coral border traces, made on sheets of clear acetate, onto sequential photographs. Planimetric measurements were then made of areas of growth and retreat, along with the border length over which these changes occurred.

Forty permanent 8 m^2 quadrat stations, established during the previous monitoring study, were photographed during the 1994 and 1995 field efforts to monitor changes in individual coral colonies. Photographs were taken using a camera attached to a T-shaped frame, at a distance of 2 m (6.6 ft) from the bottom. Comparisons of these photographs and those collected in 1992 (using transparency film) were made by superimposing sequential images onto a baseline template, produced by tracing colony outlines onto a sheet of paper, and comparing the dimensions of each colony. Counts of coral growth, disease, bleaching, algae mediated or algae/sediment mat-mediated retreat, and unexplained mortality were made from each station photograph. In addition, estimates of percent coral cover and percent coral bleaching were made from each photograph using a series of paper templates containing 100 randomly located crosses.

Two diver-held, repetitive video transects of 100 m (328 ft) length were filmed at each site during the 1994 and 1995 field efforts. Each transect followed a specific boundary line for scale reference and to provide some degree of repetition between field sampling efforts. The boundary lines selected for video transects duplicated those used during the previous monitoring study. Each video transect was filmed from approximately 2 m (6.6 ft) above the bottom and at an angle of 45°. A baseline working map of each transect filmed during the 1994 field effort which depicted large or conspicuous coral colonies and areas of coral disease or bleaching, sand flats, sponges, etc., was constructed to provide a reference for changes observed in 1995 transects.

Ancillary measurements included the collection of recording thermographs on each site which were programmed to record water temperature every two hours, daily measurements of water temperature, salinity, dissolved oxygen, and ambient light from near-surface (1 m [3.3 ft] depth) and near-bottom depths, and the deployment and service of recording light meters at the two study sites and on the Mobil HI-389 A platform near the East Flower Garden Bank.

Acquisition of the recording light meters occurred subsequent to a contract modification in August 1995. These instruments are designed to measure and record Photosynthetically Active Radiation (PAR) in the 400 to 700 nm waveband. Data were presented as total daily irradiance from each light meter and percent light transmission on each site, by dividing underwater irradiance values by the surface reference values collected by the surface meter on the HI-389 A platform. Each underwater unit consisted of a spherical (omnidirectional) quantum light sensor and datalogger, which was placed in sealed, acrylic housings and secured on relatively flat areas of solid reef rock located in proximity to the study site mooring buoys. The surface reference light meter consisted of a surface quantum light sensor and datalogger. The surface sensor was fastened to the HI-389 A platform's helipad, an area that will be least affected by daytime shading from the platform structure. Both underwater and surface reference light meters were programmed to record ambient light readings on an hourly basis. At this frequency, the internal memory of the dataloggers was filled in approximately three months. The three meters were serviced and their datasets collected during 15-16 November 1995 and 2-3 March 1996.

CORAL COMMUNITY - STATUS AND TRENDS

The mean percent cover of all coral species (total coral cover) estimated from random transects sampled during the 1992, 1994, and 1995 field efforts was significantly greater at the East Flower Garden Bank study site than the West (48.2% and 44.1%, respectively). Total mean percent coral cover was also significantly greater on transects collected during 1995 and 1994 than those collected in 1992. In terms of percent cover and relative dominance, *M. annularis* was the dominant species of coral at the two study sites (28.3% on the East Flower Garden Bank and 25.9% on the West Flower Garden Bank), followed by *D. strigosa* (6.9% on the East Flower Garden Bank and 7.5% on the West Flower Garden Bank). *Porites astreoides* was the only species that showed a significant difference in percent cover between study sites during certain years. Species diversity and evenness based on coral colony counts was significantly greater on transects sampled during 1992 than those sampled during 1995, but not significantly different between study sites. Species diversity and evenness based on coral cover showed no significant differences between years or study sites.

Data collected from the 1989-1991 monitoring study reported total coral cover of 46.0% and 46.5% at the East and West Flower Garden Banks study sites, respectively. Estimates of percent cover of individual coral species during this study were similar to the present study, with the exception that some differences between study sites. Unlike the present study, species diversity and evenness estimates during the 1989-1991 study showed significant differences between sites.

Comparison of data collected during the present study from stratified random transects with those from previous studies indicated that the coral community structure of the Flower Garden Banks has been stable over time; there was no evidence of habitat deterioration.

CORAL GROWTH - STATUS AND TRENDS

Estimates of accretionary growth rates of *M. annularis* between 1994 and 1995 using growth spikes at permanent stations averaged 5.7 and 5.5 mm/yr at the East and West Flower Garden Banks study sites, respectively. Mean accretionary growth rates of *M. annularis* from 1973-1995, as determined from sectioned core samples collected from the East and West Flower Garden Banks study sites, were 6.8 and 8.1 mm/yr, respectively. These rates closely compare with the range of values collected during the 1989-1991 monitoring study. Estimates of accretionary growth rates during this period averaged 7.0 and 6.0 mm/yr at the East and West Flower Garden Banks study sites, respectively. Growth rates determined with coral core samples also compare with those collected during previous studies.

Estimates of encrusting growth rates of *D. strigosa* between 1991-1992 and 1994-1995 suggest favorable conditions of growth at the Flower Garden Banks. Relative tissue growth (advance) and retreat rates during these two periods were comparable. Net growth rates, defined as the mean rate of change of coral areas observed to advance or retreat, were positive during the 1991-1992 and 1994-1995 periods. Net growth rates were substantially lower during the 1991-1992 period, indicating that greater numbers of permanent stations during the 1994-1995 period had measurable growth than those selected for analysis from the 1991-1992 period. This may be explained by the fact that over 60% of photographs collected for the quantitative measurement of encrusting growth during 1992 were rejected for analysis, due to either the effects of natural changes observed along coral tissue-reef rock borders in certain stations or the effects of inconsistent camera angle. Because of these problems and the relative low resultant sample size, it is possible that the differences may be an artifact of sampling error. Retreat to advance ratios of encrusting growth for *D. strigosa* also indicate net tissue gain during both 1991-1992 and 1994-1995 periods.

Encrusting growth rates of *M. annularis* were estimated only from data collected during 1992. Net growth rates during the 1991-1992 period were negative (-0.05 cm/yr) at the East Flower Garden Bank study site and positive (0.68 cm/yr) at the West Flower Garden Bank study site. Overall net growth was positive (0.60 cm/yr) during this period. Retreat to advance ratios for this species indicate net tissue loss at both study sites during this period. Due to aforementioned problems in data collected in 1992, these results may also be an artifact of sampling error.

Encrusting growth rates that were estimated during the present study indicate favorable growth conditions for *D. strigosa* at both study sites. Because of the problems associated with the 1992 data, it is unclear that estimates of relative growth made during this period are representative. From these data, it is apparent that the period of time over which permanent stations for the measurement of encrusting growth of corals may be reliably used is finite.

CORAL BLEACHING

Coral bleaching, the expulsion of symbiotic algae (zooxanthellae) by corals when under stress, was observed in repetitive quadrat photographs taken in 1992, 1994, and to a much greater extent during 1995. The extent of bleaching within the study sites was most pronounced in November 1995, when the two study sites were visited to conduct periodic maintenance of recording light meters. Bleaching during these periods coincided with periods of elevated bottom temperatures (above 30°C), which are not uncommon during late summer. As observed in November 1995, the effects of bleaching may appear to persist long after temperatures drop below 30°C. Other conditions reported to cause bleaching in corals include high/low light levels, high levels of ultraviolet radiation, high/low salinity, sub-aerial exposure, excessive sedimentation, storm shock, and anthropogenic sources such as petroleum hydrocarbons and oil dispersants. Data indicate that coral bleaching can affect calcification rates, metabolic functions, and in severe cases lead to localized or widespread mortality of tissue.

Coral bleaching events have been documented on the Flower Garden Banks on many occasions, although coral mortality associated with bleaching is low. Colonies which exhibited bleaching usually sustained only minor tissue loss (1992 - 0.5%; 1994 - 0.2%; 1995 - 2.8%). Mortality appeared to be no higher in colonies which exhibited recurrent bleaching than in other colonies.

CORAL DISEASES

Coral "disease", resulting in the necrosis of coral tissue, remains the most serious natural threat to corals at the Flower Garden Banks. The number of coral colonies observed at repetitive quadrat stations affected by diseases were significantly higher in 1995 than 1994 and 1992. Similarly, numbers of colonies affected in 1995 photographs were also appreciably higher than during the previous monitoring study, which ranged from approximately 10 to 25 colonies per bank per survey. It is not known whether the increased numbers of coral colonies affected by diseases can be attributed to the same environmental conditions on the banks (e.g., elevated water temperatures during the summer and early autumn) which led to significant coral bleaching during this period. Despite the marked increase in bleaching observed in 1995, the number of colonies exhibiting disease was low when compared to the 3,902 colonies analyzed in quadrat photographs (6.0% occurrence).

INDUSTRIAL THREATS TO THE FLOWER GARDEN BANKS

Oil and gas exploration and production continues in the vicinity of the Flower Garden Banks. Potential sources of petroleum input to the offshore marine environment of the Flower Garden Banks include natural seeps, marine transportation, and offshore operations for the exploration and production of hydrocarbons. Accidents related to offshore operations that result in the release of oil include well blowouts and transportation incidents.

Generally, oil spills at the Flower Garden Banks and their vicinity could originate both at the surface and on the seafloor. Because of the banks' depths, surface spills and resultant slicks would produce minimal to negligible impacts to major reef constituents, such as scleractinian corals, other invertebrates, and reef fishes. Surface winds and currents would carry spilled oil or fuel away from the vicinity of the banks in a relatively short time period. Surface slicks could, however, impact marine mammals, sea turtles, seabirds, certain pelagic fish, and floating marine plants. An oil spill occurring during the annual coral reproductive spawning period could also severely impact or entirely destroy the floating spawn. Modelling studies of the predicted effects of subsurface spills originating from oil pipelines in the vicinity of the banks indicated minimal to non-existent effects on the sensitive benthic biota of the Flower Garden Banks (Continental Shelf Associates, Inc., 1992).

Chemical dispersants are agents designed for reducing the surface tension of spilled oil on the water surface. Surface oil treated with a dispersant mixes within the water column as fine droplets and is dispersed by currents. Rationale for treating spilled oil with chemical dispersants includes the prevention of a concentrated surface slick from moving into biologically sensitive environments; a reduction of direct impacts of surface oil to offshore natural resources such as marine birds, marine mammals, sea turtles, and pelagic fish; or the prevention of surface oil from stranding onshore, thus reducing or eliminating impacts to important coastal habitats, biological communities, or coastal facilities. Because of the uncertainties associated with vertical transport of oil and dispersant, the MMS has historically banned their use within the 1-Mile Exclusion Zone of the Flower Garden Banks. This was felt to be an adequate mitigative measure for unknown and unquantifiable impacts of the dispersed oil and dispersant to reef biota on the banks. Recent studies (Fucik et al., 1994) have reported that the application of dispersants to surface oil did not increase its toxicity to species indigenous to the Gulf of Mexico. Furthermore, the application of dispersants served to dilute the concentration of surface oil to approximately 0.1 ppm at depths of approximately 10 m (33 ft). At this dilution, the resultant dispersed oil plume is not considered acutely toxic. These data have led to a decision by the Flower Garden Banks National Marine Sanctuary that the application of dispersants may be advantageous to Sanctuary resources in the event of a surface oil spill, as surface oil would be more harmful than dispersed and diluted oil to certain pelagic fish, marine mammals, and sea turtles. Therefore, the Sanctuary approves of the use of oil dispersants on the Flower Garden Banks when deemed appropriate and conducive by the Federal On-Scene Coordinator.

Current National Pollutant Discharge Elimination System (NPDES) permits limit oil and grease levels in produced waters, restrict flow rates, require chronic, static, aquatic toxicity analyses of produced water effluents, and require monitoring of produced water discharges. Regulations also require that all drill cuttings and drilling fluids must be shunted through a downpipe which terminates at a distance of no more than 10 m (33 ft) from the seafloor. Presently there are no production platforms near enough to the Flower Garden Banks to produce detectable impacts to the bank's biotic communities resulting from the regulated discharge of produced waters and drilling fluids.

RECREATIONAL THREATS TO THE FLOWER GARDEN BANKS

Historically, all recreational diving activities on the Flower Garden Banks were unregulated. Their distance from shore has made visitation to the banks very difficult and costly for recreational divers. Negative impacts on the banks were associated with activities such as the anchoring of boats on the live coral reef, spearfishing, collecting reef biota, and physical damage to living corals from divers. Public awareness of the banks subsequent to their designation as a National Marine Sanctuary has led to a marked increase in numbers of recreational divers visiting the area each year.

Historically, the greatest physical impacts to the Flower Garden Banks associated with recreational diving were due to the anchoring of vessels on live coral areas of the banks. Permanent mooring lines with surface floats were installed in 1990 at several locations on the high diversity reef areas of both banks in an effort to reduce anchor damage. Activities such as spearfishing, collections of reef biota, and destruction, additions, or modifications to the seabed of the Sanctuary are also prohibited. Despite the protection afforded to the Flower Garden Banks from regulations associated with Sanctuary status, negative impacts resulting from physical contact between recreational divers and sensitive reef biota remain an issue of concern. The use of mooring lines tends to focus the numbers of divers within repetitively used areas and thus increases the probability of localized damage caused by physical contact with corals and other reef biota, and displacement of certain fish species. Currently, no studies have been conducted to assess the impacts of recreational diving pressures within the area. Utilization of several alternative mooring line sites for divers during alternate years may serve to reduce localized pressure on recreational dive sites on the banks.

CONCLUSIONS

Present estimates of coral community structure and coral growth rates are comparable to those made during the 1989-1991 study, and reveal no significant long-term changes in these communities or evidence of the deterioration of habitat quality. Permanent accretionary and encrusting growth stations at both East and West Flower Garden Banks study sites were found during the 1994 field effort to be in unusable condition. It is recommended that these types of permanent study stations be re-established when deemed necessary in order to minimize the possibility of sampling error caused by the degradation of the station. No evidence of catastrophic coral diseases such as band diseases were detected in permanent stations or video transects. Coral bleaching was detected in the 1992, 1994, and 1995 data and appears to be an annual event, presumably triggered as a result of elevated sea water temperatures. Bleaching may persist for several months subsequent to recorded temperature maxima. Bleaching, however, appears to result in minimal coral tissue mortality. No substantial changes in coral communities on the Flower Garden Banks, attributable to human activities, were detected during the present study. Protective regulations of activities on the Flower Garden Banks, associated with their status as a National Marine Sanctuary, have served to minimize impacts such as anchor damage, occurrence of debris on the banks, and impacts to fish resources from commercial fishing and spearfishing.

1.0 INTRODUCTION

1.1 OVERVIEW OF THE FLOWER GARDEN BANKS

The East and West Flower Garden Banks are located on the outer edge of the Gulf of Mexico continental shelf, approximately 193 km and 172 km (104 nmi and 93 nmi) respectively, southeast of Galveston, Texas (**Figure 1**). The banks are topographic prominences of bedrock which have been uplifted and fractured by the intrusion of underlying Jurassic evaporite salt deposits, or diapirs, which are located at a distance of 15 km (8 nmi) below the seafloor (Bright et al., 1984). The bedrock is capped with a relatively thin layer of calcareous reef-building organisms. The Flower Gardens are the two largest of more than 130 calcareous banks charted in the northwest Gulf of Mexico that exhibit topographic elevation above an otherwise smooth continental shelf (Bright et al., 1985).

The East Flower Garden Bank is located at 27°54.5′ North latitude and 93°36.0′ West longitude (**Figure 2**). The bank is pear-shaped and covers an area of approximately 67 km^2 (19.5 nmi^2) (Rezak et al., 1985). Topographic relief is pronounced on the east and south sides of the bank and gentle on the west and north sides due to the asymmetric nature of the underlying diapiric core (Bright et al., 1985). The shallowest depth on the East Flower Garden Bank is approximately 20 m (66 ft). Surrounding water depths range from approximately 100 to 120 m (328 to 394 ft) (Rezak et al., 1985).

The West Flower Garden Bank lies 12 km (6.5 nmi) west of the East Flower Garden Bank at 27°52.4′ North latitude and 93°48.8′ West longitude (**Figure 3**). The bank is characterized by three main crests separated by grabens which are aligned parallel to the long axis of the underlying diapiric core (Bright et al., 1985). The bank covers an area of approximately 137 km^2 (40 nmi^2). The shallowest depth on the West Flower Garden Bank is approximately 15 m (49 ft). Surrounding water depths vary from 100 to 150 m (328 to 492 ft) (Rezak et al., 1985).

The sediments found on the Flower Garden Banks are principally biogenic in origin, consisting of calcareous sands and gravels. The hard bottom structure of the banks has been formed from the skeletons of corals and other calcareous organisms. Sediments surrounding the banks are principally terrigenous sands and muds (Rezak et al., 1985). The presence of a series of brine seeps and a documented brine lake on the Flower Gardens indicates the dissolution and removal of sizeable quantities of solid salt from subbottom locations beneath the reef crests, and creates conditions of seafloor instability and faulting in those areas (Rezak et al., 1985).

1.1.1 Habitat Description and Zonation

The Flower Garden Banks appear to constitute elements of a discontinuous ring of reefal structures found on the Gulf of Mexico continental shelf. These reefal structures, consisting of a combination of thriving coral reefs and scattered hard banks and patches, bear elements of typical Caribbean reef biota (Bright et al., 1985). The Flower Gardens, however, are unique in many respects. They are considered to be near the northern physiological limits for tropical hermatypic (reef-building) corals in the Gulf of

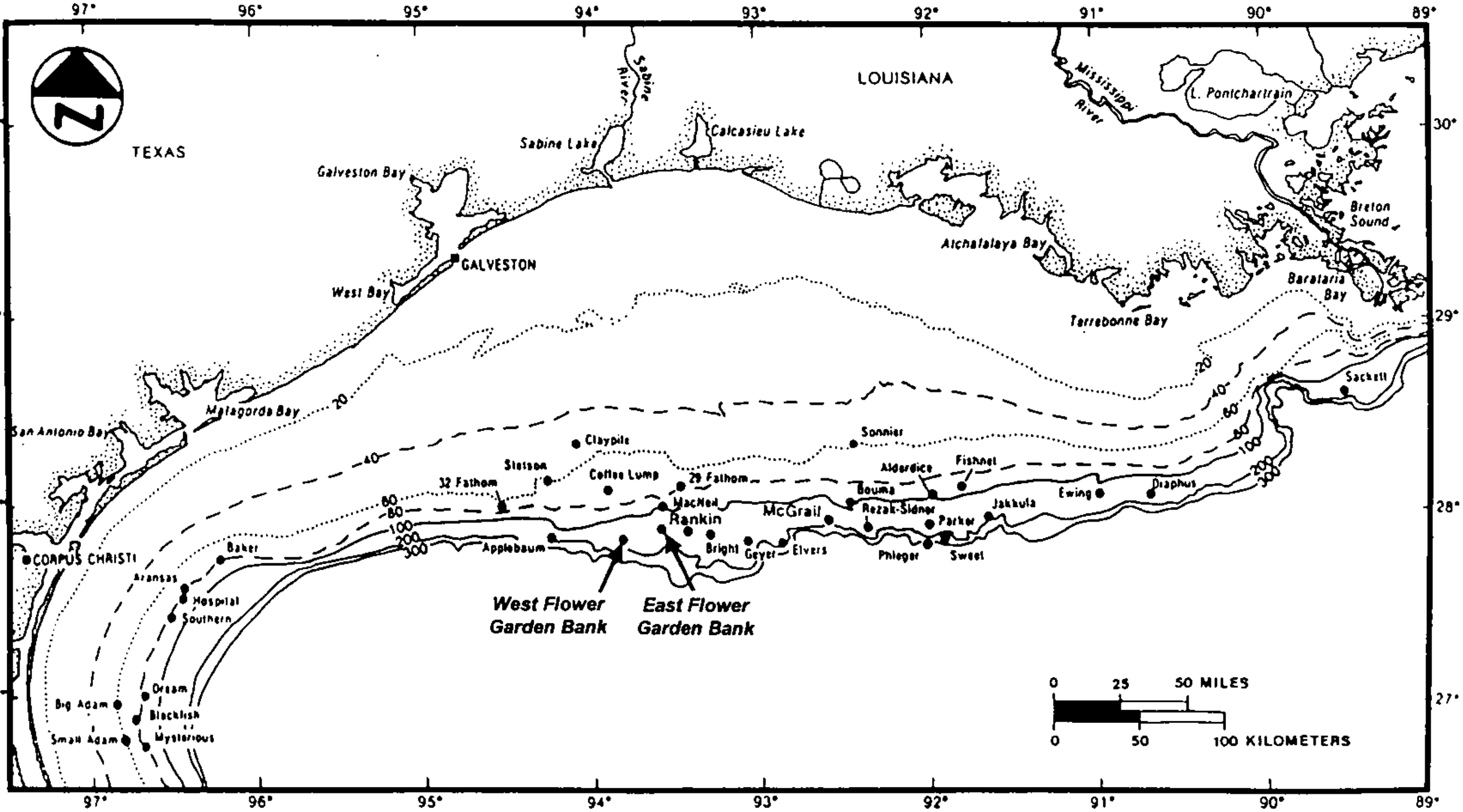


Figure 1. Location of the East and West Flower Garden Banks relative to other topographic features in the northwestern Gulf of Mexico.

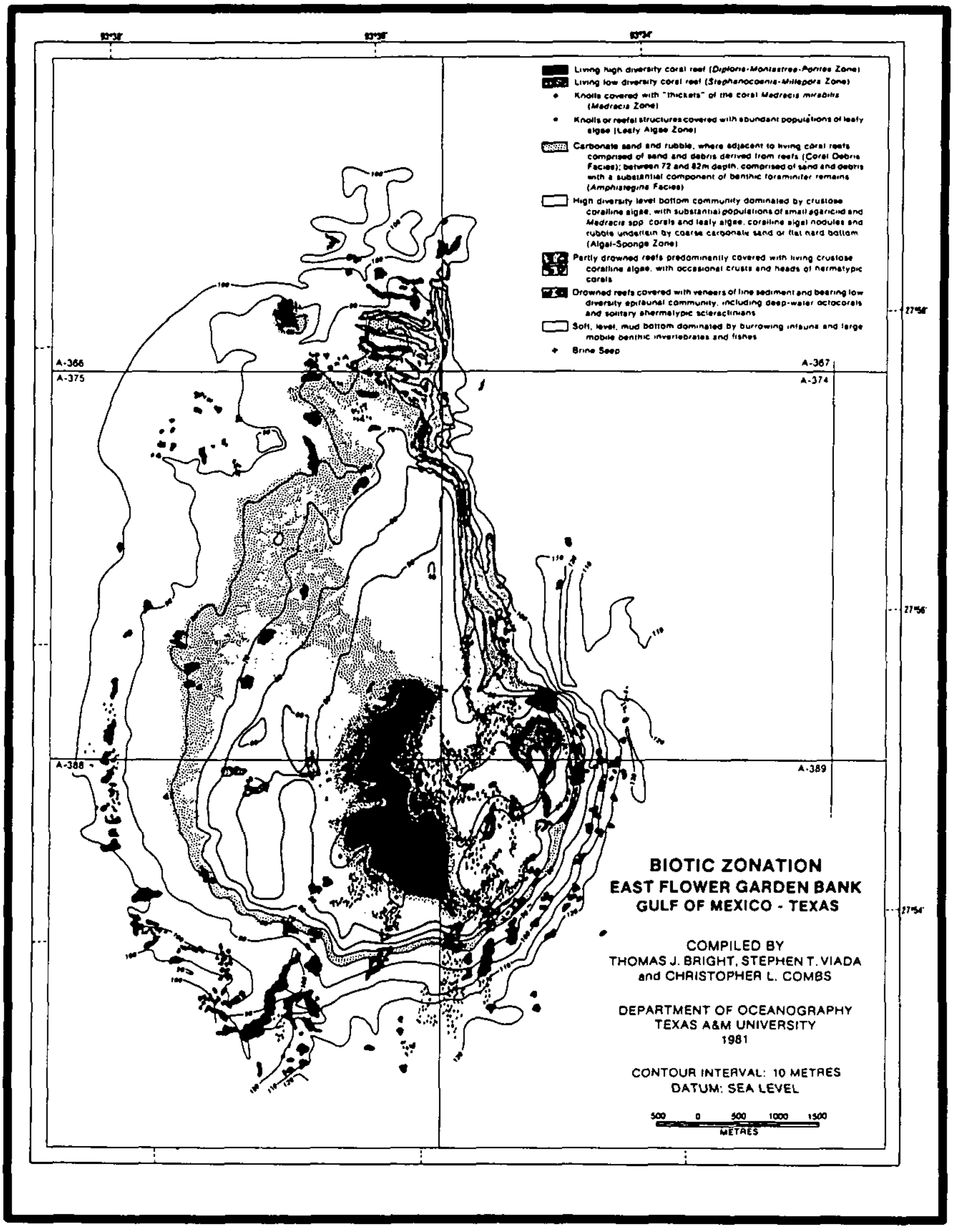


Figure 2. Topography and biotic zonation of the East Flower Garden Bank (From: Bright et al., 1985).

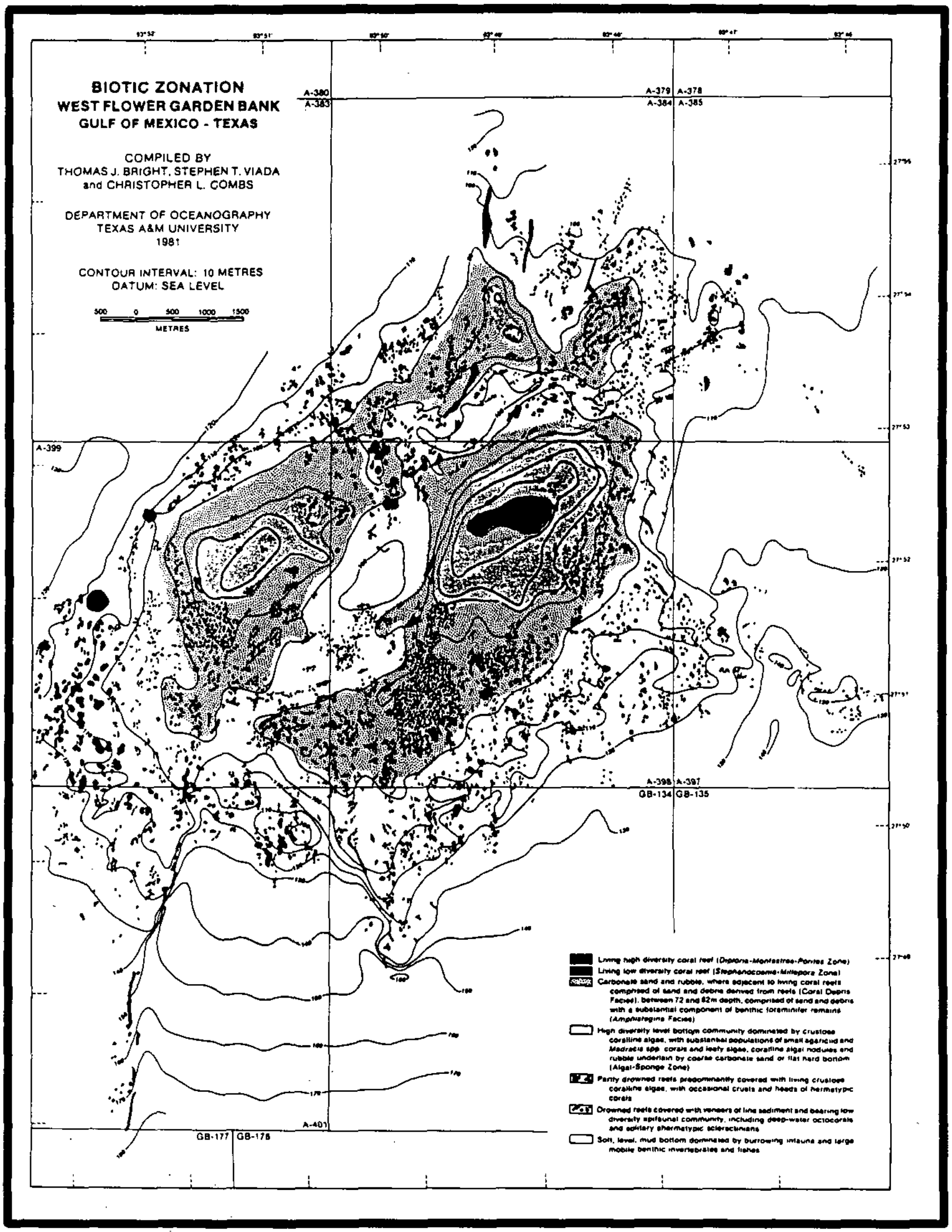


Figure 3. Topography and biotic zonation of the West Flower Garden Bank (From: Bright et al., 1985).

Mexico and are thus the northernmost thriving tropical coral reefs on the North American continental shelf (Bright et al., 1984; Rezak et al., 1990). Winter temperatures less than 50 km (27 nmi) to the north are too low for reef-building (Rezak et al., 1990). Because of its latitude and relative isolation from other regional coral reefs, the biological communities of the Flower Garden Banks are less diverse than typical western Atlantic and southern Gulf of Mexico reefs (Bright et al., 1984). For example, only 18 of the 65 western Atlantic hermatypic coral species occur on the Flower Garden Banks (Gittings et al., 1992). Acroporid scleractinians (including elkhorn and staghorn corals) and shallow water octocorals (sea fans, sea whips, and other gorgonians) which are common constituents of other western Atlantic reefs at these depths are absent on the Flower Garden Banks. Nevertheless, coral abundance and specific growth rates at the Flower Garden Banks compare closely with those in more tropical locales at similar depths (Rezak et al., 1985). The presence and extent of reef-building activity on the Flower Garden Banks is due to favorable conditions of substrate, water depth, temperature, salinity, and water clarity. At their location on the shelf edge, they are exposed almost continually to tropical-subtropical, clear, oceanic water. Salinities in the area average over 36 ppt, but have been recorded as low as 32 ppt at the surface and 34 ppt at the reef tops. Above 25 m (82 ft) depth, water temperatures on the Flower Garden Banks range annually from approximately 30°C (86°F). Water transmissivity is generally greater than 75% per meter for white light and light penetration is generally 40% to 50% of the surface light at 37 m (121 ft) depth (McGrail et al., 1982).

The closest coral reefs in the Gulf of Mexico off Cabo Rojo (Mexico) are more than 600 km (324 nmi) from the Flower Garden Banks. The Flower Garden Banks may have depended upon these reefs for their initial colonization (Rezak et al., 1985; Bright et al., 1991; Gittings et al., 1992). Because of their isolated location, the reef corals at the Flower Garden Banks rely on their own reproductive viability for successful colonization and development of coral communities (Holland, 1991). Mass spawning, defined as the synchronous release of gametes by multiple species has been documented annually at the Flower Garden Banks since 1990 (Gittings et al., 1992). Corals species are either dioecious "broadcasters" which release eggs or sperm into the water column for external fertilization, or hermaphroditic "brooders" which release discrete gamete bundles. Mass spawning observations, together with data collected from coral recruitment studies which show routine reproduction by brooding corals, and recruitment activities of both broadcaster and brooder species on nearby oil platforms, suggest that the coral communities at the Flower Garden Banks are capable of both self-seeding following disturbance and of supplying viable larvae for colonization of natural and artificial substrates (Gittings et al., 1992).

Biotic zonation at the Flower Garden Banks is distinct and stringently depth related (**Figures 2 and 3**). These biotic zones and their specific depth ranges in turn correlate consistently with those of known sedimentological facies, though commonly overlap or grade into one another to some degree (Rezak et al., 1985). **Figure 4** is a schematic depiction of biotic zonation on the southeastern part of the East Flower Garden Bank. Flourishing coral reefs constitute the largest reefal component on the Flower

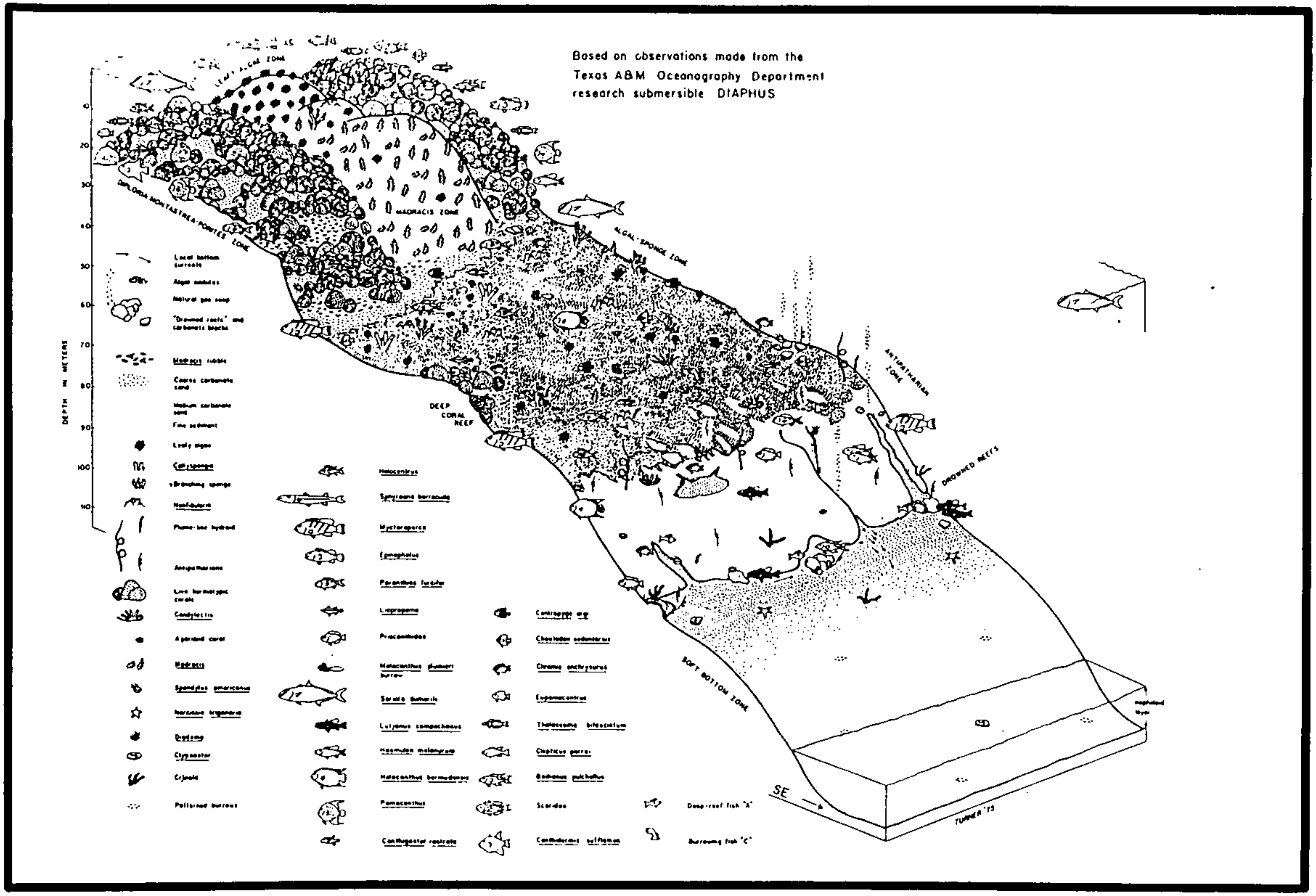


Figure 4. Schematic depiction of the biotic zones and conspicuous biota of the East Flower Garden Bank (From: Bright and Rezak, 1976).

Garden Banks, occupying the crests of the banks at depths of 15 to 52 m (49 to 171 ft) in some areas. Biotic zones on the banks that correspond to specific depth ranges have been described as follows:

- *Diploria-Montastrea-Porites* Zone, 15 to 36 m (49 to 118 ft);
- *Stephanocoenia-Millepora* Zone, 36 to 52 m (118 to 171 ft);
- Leafy Algae Zone and the *Madracis* Zone, 28 to 46 m (92 to 151 ft);
- Algal-Sponge Zone, 46 to 88 m (151 to 289 ft);
- Antipatharian Zone, 52 to 90 m (171 to 295 ft); and
- Soft Bottom Zone, <88 m (<289 ft).

1.1.1.1 *Diploria-Montastrea-Porites* Zone

The *Diploria-Montastrea-Porites* Zone extends from the reef crests to a depth of approximately 36 m (118 ft), and includes an assemblage of 16 species of hermatypic, or reef-building coral species. This relatively high-diversity zone is dominated by the scleractinian corals *Montastrea annularis*, *Diploria strigosa*, *Porites astreoides*, *Montastrea cavernosa*, *Colpophyllia natans*, *Colpophyllia amaranthus*, and the hydrozoan coral *Millepora alcicornis*. This zone is platform-like with broad tops composed of primarily hard substratum formed by hermatypic corals (85%) and carbonate sand and gravel. Coral reefs within this zone are typically made up of closely spaced, massive coral colonies, or heads, up to 3 m (10 ft) in both diameter and height. Percent coral cover in this zone averages over 46% (Gittings et al., 1992). Historical data have shown minor spatial variability in abundance of certain coral species at the East and West Banks. However, it is felt that the high-diversity reef communities of the two banks are essentially similar with respect to coral cover, species composition, dominance hierarchy, diversity, and evenness. *M. annularis* is the most abundant hermatypic species, typically covering from 20% to 40% of the hard substratum in this zone. No other coral species cover more than 9% of the substratum (Bright et al., 1984). Calcareous sand and gravel are commonly found in large flats and as isolated patches among the coral heads. Evidence of extensive bioerosion of the coral heads is common. At least nine genera of crustose coralline algae (Corallinaceae) are found at the Flower Gardens. *Hydrolithon* spp. is most abundant in the *Diploria-Montastrea-Porites* Zone. As a group, crustose coralline algae are abundant within this zone, covering approximately 15% to 20% of the hard substratum, and contribute substantial calcium carbonate to the reef substratum and sediments. The algae tend to inhabit cryptic as well as exposed substratum and appear to be pervasive opportunists, capable of rapid colonization of exposed substrate but incapable of preventing subsequent encroachment by the dominant hermatypic corals. Other conspicuous biota include sponges, which occupy a small portion of the high-diversity reef, and leafy and filamentous algae. A total of 253 species of reef invertebrates and 103 reef fishes were reported by Bright and Pequegnat (1974) from the West Flower Garden Bank. Most of these species were collected from within the *Diploria-Montastrea-Porites* Zone. Subsequent studies suggest nearly identical community structure and diversity of associated reef invertebrates and reef fishes from within this zone at the East Flower Garden Bank (Gittings et al., 1992).

1.1.1.2 *Stephanocoenia-Millepora* Zone

The *Stephanocoenia-Millepora* Zone is a narrow and relatively low-diversity zone on both banks which ranges from approximately 36 to 46 m (118 to 151 ft), with components to 52 m (171 ft), and comprises 12 species of hermatypic scleractinian corals. Eight varieties are conspicuous within this zone, and include *Stephanocoenia michelini*, *Millepora alcicornis*, *Montastrea cavernosa*, *Colpophyllia* spp., *Diploria strigosa*, *Agaricia* spp., *Mussa angulosa*, and *Scolymia cubensis*. Unlike the high-diversity zone, the percent cover and relative abundances of corals within the *Stephanocoenia-Millepora* Zone shows substantial spatial variability. Crustose coralline algae cover probably equals or exceeds that of the corals in this zone, but the basic reefal substratum is coral (Bright et al., 1984).

1.1.1.3 Leafy Algae Zone and the *Madracis* Zone

Two minor zones, the Leafy Algae Zone and the *Madracis* Zone are located intermittently on the peripheral parts of the East Flower Garden Bank between 28 m (92 ft) and 46 m (151 ft) depth. These zones exist on large knolls made of thick deposits of skeletal remains of the thin, branching coral *Madracis mirabilis*. These knolls of coral gravel support thriving populations of leafy algae (Leafy Algae Zone) or living *M. mirabilis* (*Madracis* Zone). Comparable knolls bearing *Madracis* Zone biotic communities, but not Leafy Algae Zones, have been documented on the eastern extremity of the main reef structure at the West Flower Garden Bank (Bright et al., 1985).

1.1.1.4 Algal-Sponge Zone

Hermatypic coral abundance tends to decrease with increasing depth, leading to virtual dominance by coralline algae. The Algal-Sponge Zone ranges from approximately 46 to 88 m (151 to 289 ft) in depth and includes a number of biotope types, including an upper carbonate sand/rubble transition zone and a broad platform covered with sand, rubble, rhodoliths, and partly drowned reefal structures. Rhodoliths, or nodules formed by *Lithothamnium* and *Lithoporella*, along with the encrusting foraminiferan, *Gypsina plana*, range in size from <1 to >10 cm (<0.4 to >4 in.) in diameter and form a terrace which in most places covers 50% to 80% of the bottom (Bright et al., 1985). The nodule terrace creates a biotope that harbors a diverse benthic community which may be comparable in diversity to the shallower coral reefs. Associated organisms include an abundance of algae dominated by *Lithothamnium* spp., *Tenarea* spp., and *Peyssonnelia* spp.; boring, attached, and mobile invertebrates; and small fishes (Abbott, 1975). Also within this zone are found relic reefal structures termed "partly drowned reefs" that now exist at depths in which hermatypic corals have limited capabilities for growth. These reefs are predominantly covered with living crusts of coralline algae and occasional veneers and heads of several species of hermatypic corals, such as *Helioseris cucullata*, *Agaricia* spp., *Madracis* spp., and *M. cavernosa*. Deep-water octocorals, primarily from the families Ellisellidae and Paramuriceidae, and several species of sponges are abundant in the Algal-Sponge Zone. The most distinctive sponge species is *Neofibularia nolitangere*, which forms crusts of approximately 1 m (3 ft) in diameter on nodules, sand, and exposed rock within the zone (Rezak et al., 1985). Numerous species of fishes, mobile and sessile invertebrates, and plants also commonly occur within the Algal-Sponge Zone. Many species are involved to varied extents in the formation of carbonate substratum in this zone.

1.1.1.5 Antipatharian Zone

The antipatharian zone constitutes a transition zone between shallow-water and deep-water assemblages on both banks and ranges from 52 m (171 ft) to more than 90 m (295 ft) in depth within the Algal-Sponge Zone. This zone is characterized by the presence and abundance of white, loosely coiled antipatharians (*Cirrhipathes* spp.).

1.1.1.6 Soft Bottom Zone

At depths below 88 m (289 ft) sediments change from coarse carbonate sand, mixed with an abundance of nonliving foraminifera (*Amphistegina*) tests, to fine silt- to clay-sized particles which are easily and commonly resuspended in the water column. This area has been termed the Soft Bottom Zone. "Drowned reefs," which are at depths too great for hermatypic corals to exist and for crustose coralline algae to thrive, are found in areas of relatively fine sediment and are thus commonly covered with veneers of fine sediment, with veneers being thicker on the deeper reefs. These relict structures are typically covered with sponges, deep-water octocorals, comatulid crinoids, and ahermatypic (nonreef-forming) scleractinian corals. The drowned reefs also attract a number of fish species, many of which are substantially different and of much lower diversity than that of the partly drowned reefs of the Algal-Sponge Zone and high diversity coral reefs (Rezak et al., 1985).

1.1.2 Human Activities

Although known by turn-of-the-century fishermen, the Flower Garden Banks were first charted by the U.S. Coast and Geodetic Survey (C&GS) in 1936. Protective lease stipulations were developed for the Flower Garden Banks by the U.S. Department of the Interior (USDOI), Bureau of Land Management (BLM) in 1974. These included a "No-Activity Zone" which was based on the 100-m isobath and corresponds roughly with the edge of the banks; a "1-Mile Zone" around the No-Activity Zone in which all drill cuttings and discharges were required to be shunted to within 10 m (33 ft) of the seafloor and monitoring studies of the effects of operations on the biota of the bank were performed; and a "4-Mile Zone," based on a 4-mile radius of the banks, where shunting of all drill cuttings and discharges was required but not biological monitoring.

Present MMS regulatory zones for the Flower Garden Banks include the No-Activity Zone and 4-Mile Zone. Exploration, development, and production of oil, gas, or minerals are prohibited within the No-Activity Zone. However, geophysical surveys and seismic exploration are allowed within this zone provided that seismic techniques do not involve the use of explosives or the release of electrical discharges. The 1-Mile Zone has been removed, as requirements for industry monitoring studies associated with production activities inside of this regulatory zone have been lifted. Shunting of drill cuttings and discharges to within 10 m (33 ft) of the seafloor is still required within the 4-Mile Zone.

Early research efforts on the Flower Garden Banks showed significant mechanical damage to the high diversity coral reef zones as a result of vessel anchoring. Consequently, BLM/MMS prohibited all anchoring of oil and gas industry vessels on these biologically sensitive areas of the banks. However, no regulations were in effect to prohibit the anchoring of recreational vessels or large merchant vessels such as freighters and tankers on the banks. In 1982, an attempt was made to restrict vessel anchoring on the banks through the National Marine Fisheries Service's Coral Fishery Management Plan for the Gulf of Mexico. This attempt failed, as it was declared that vessel anchoring did not constitute a fisheries issue. In 1986, the Flower Gardens were formally labelled on National Oceanic and Atmospheric Administration (NOAA) navigational charts and related publications as a "Protected Area," requesting that large vessels avoid anchoring in the area. In 1990, local volunteers installed 12 buoys on the banks to provide moorage for small vessels. Since their installation, these buoys have successfully mitigated mechanical damage to the high diversity reefs by small vessel anchors (Gittings et al., 1993).

In 1978, the Flower Garden Banks were nominated for National Marine Sanctuary status by NOAA but were withdrawn from consideration in 1982 amid controversy over proposed sanctuary borders and the methods of disposal of drilling effluents in the area (Bright et al., 1984). Following an incident involving anchoring by a large tug in 1983, the Flower Garden Banks were again placed on the list of active candidates for sanctuary designation. They were formally designated as a National Marine Sanctuary on 17 January 1992. Sanctuary boundaries roughly correspond with those of the MMS No-Activity Zone. Within Sanctuary boundaries, regulations prohibit exploration, development, or production of oil and gas resources; anchoring of vessels greater than 100 ft in length; possessing, collecting, injuring, and altering Sanctuary resources; all fishing other than by hook-and-line; most discharges; possessing or using explosives; and releasing electrical discharges (Gittings et al., 1993). **Figure 5** shows MMS regulatory zones and Sanctuary boundaries around the Flower Garden Banks.

1.1.3 Historical Research

The first hydrographic survey of the Flower Garden Banks was conducted by the C&GS in 1936. Stetson (1953) first proved the presence of living coral at the banks, and presumed they were bioherms on top of salt diapirs. This theory was proved by L.L. Nettleton (1957) after completion of a series of bottom gravity surveys of the West Flower Garden Bank in 1957. In 1961 Dr. Thomas E. Pulley substantiated the fact that the Flower Garden Banks were flourishing coral reef communities (Pulley, 1963). From 1961 to 1974, research at the Flower Garden Banks was conducted through Texas A&M University and the Flower Garden Ocean Research Center at the University of Texas Marine Biomedical Institute (Galveston, Texas). The BLM, and later the MMS began funding studies on the topographic features of the Gulf of Mexico continental shelf, including the Flower Garden Banks, in 1974. Due to their biological complexity and sensitivity, studies of the Flower Garden Banks has been much more extensive than those of the other banks. These studies focused on the collection of baseline biological and geological data to assist in the establishment of policy for protective regulations to be imposed on drilling operations near these banks. Techniques for the collection of baseline data of coral community structure and growth rates were developed during this period (Bright et al., 1981, 1982). These techniques were later used in damage assessment (Continental Shelf Associates, Inc., 1984; Gittings and Bright, 1986) and monitoring studies on the banks (Continental Shelf Associates, Inc., 1985, 1990). The present study involves analyses of photographic data collected in 1992 during a previous monitoring study (Gittings et al., 1992), and collections and analyses of data collected in 1994 and 1995.

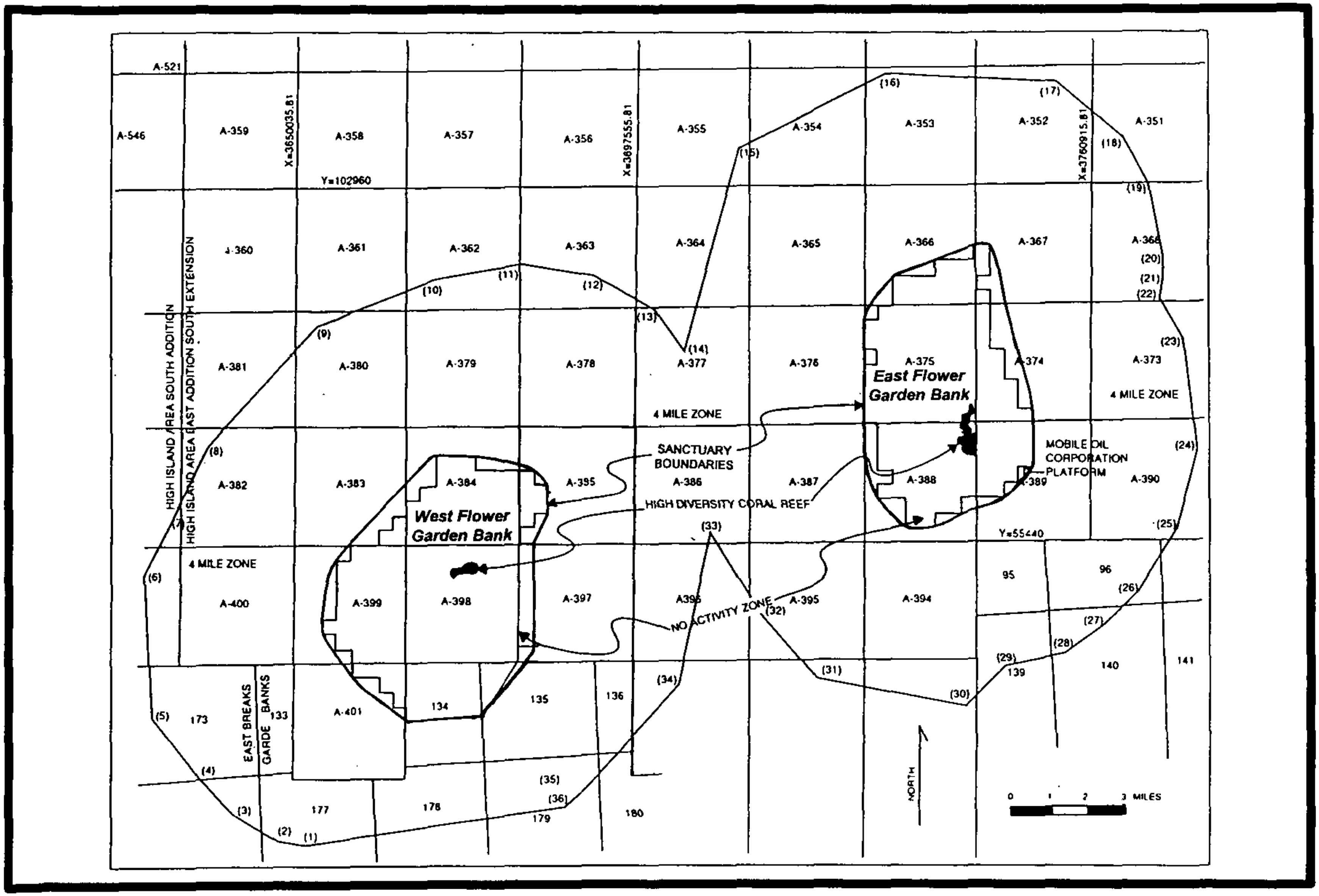


Figure 5. Location of MMS regulatory zones and National Marine Sanctuary boundaries around the East and West Flower Garden Banks.

1.2 STUDY OBJECTIVES

The primary objectives of the present long-term monitoring study at the Flower Garden Banks were as follows:

- provide relevant and timely environmental data to agencies which develop policies concerning oil and gas exploration and development in the vicinity of biologically sensitive habitats;
- document acute and long-term changes in reef-building and other associated communities within the high-diversity *Diploria-Montastrea-Porites* Zone at the Flower Garden Banks which may be attributed to impacts of oil and gas exploration and development or other human activities;
- document natural variation in reef-building and associated communities within this biotic zone on the banks; and
- duplicate methodologies and, whenever possible, utilize study stations developed during the previous long-term monitoring study in an effort to maintain a continuous database of information on the banks.

Contract requirements for this study specified field data collections and analyses to be completed in 1994 and 1995, and the analysis of photographic data which had been collected in 1992 at both East and West Flower Garden Banks study sites by Texas A&M University. The 1992 data set was collected between the 1989-1991 and present contract periods, and was representative of conditions on the Flower Garden Banks from 1991-1992.

2.0 METHODS

2.1 FIELD LOGISTICS

Field sampling efforts were conducted during 11-16 September 1994 and 20-25 August 1995. Weather conditions during the 1994 field effort were generally poor, greatly reducing the efficiency of field operations and at times creating potential safety hazards for divers. Therefore, operations conducted in 1995 were scheduled slightly earlier in the year to reduce the chances of encountering inclement offshore weather conditions which are common during autumn months.

2.2 STUDY SITES

Field efforts in 1994 and 1995 were conducted within a previously established 100 m by 100 m study site on each bank. The East Flower Garden Bank site was initially established by Texas A&M University investigators during the previous monitoring program (Gittings et al., 1992). The West Flower Garden Bank site was initially established by CSA during 1988 for monitoring efforts conducted for Union Oil Co. (Continental Shelf Associates, Inc., 1990) and later occupied by the Texas A&M University investigators (Gittings et al., 1992). **Figures 6** and **7** represent working maps of the East and West Flower Garden Banks study sites, respectively.

During the previous monitoring study, permanent markers were deployed within the two sites to facilitate their relocation and to demarcate their boundaries. Large, stainless steel U-bolts were cemented within solid reef rock near the center of each site for initial site location and moorage of the support vessel. A mooring line and large surface float is kept affixed to each U-bolt during spring, summer, and autumn months. These mooring lines and floats, and others located outside of the study sites and used for recreational dive boats, are owned by the NOAA Sanctuary Office and maintained by contract through Buoy Services, Inc. (Freeport, Texas). The four corners of both sites have been demarcated using subsurface floats attached to small stainless steel eyebolts cemented into areas of reef rock. During the 1994 field effort, plastic marker floats painted with marine antifouling paint were permanently attached to the corner marker bolts at a height of approximately 1 m (3 ft) off the seafloor. These floats were replaced during the 1995 field effort to reduce their chance of loss by fish bites and abrasion. The freshly painted floats also provide less water resistance (and thus resist drag from currents) and higher visibility to divers than floats which become fouled.

During each field effort, the sites were clearly defined by extending color coded, graduated polypropylene lines between the 100 m (328 ft) corner marker eyebolts, forming an enclosed square. On the West Flower Garden Bank, additional site boundary lines were extended between halfway marks on each line, forming four smaller squares, or blocks within the site. Though tightened snugly when extended, the lines would tend to float a meter or two above the reef contours, especially along the middle sections. This increased the line's visibility and reduced abrasion across the tops of the reef contours. All lines that extended North-South were yellow in color and those which extended East-West were white in color. The color coding and graduations on boundary lines greatly facilitated diver navigation and accurate mapping of all permanent study stations within

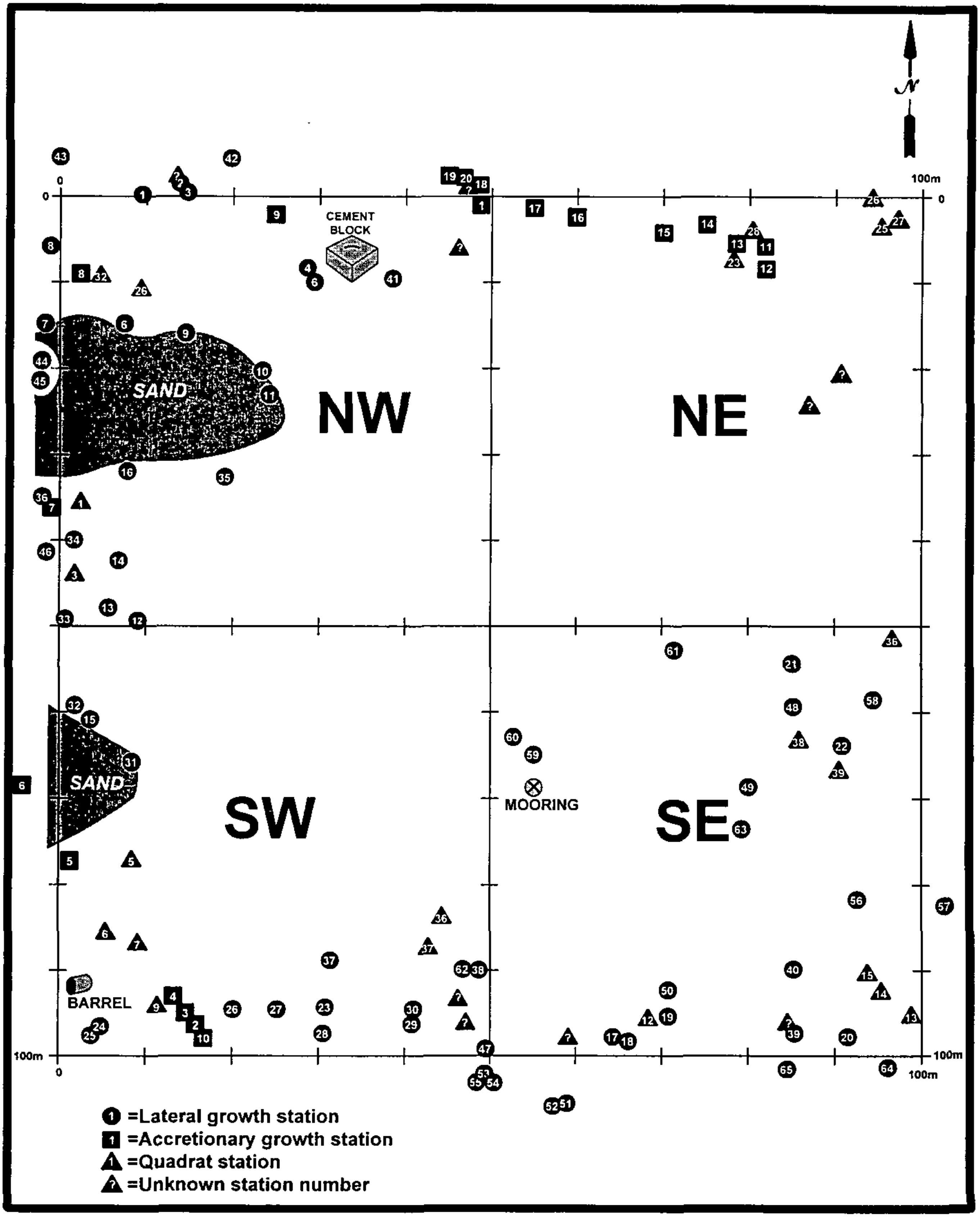


Figure 6. Map of the 100 m x 100 m study site at the East Flower Garden Bank, showing graduating boundary lines, relative positions of permanent stations, and conspicuous features.

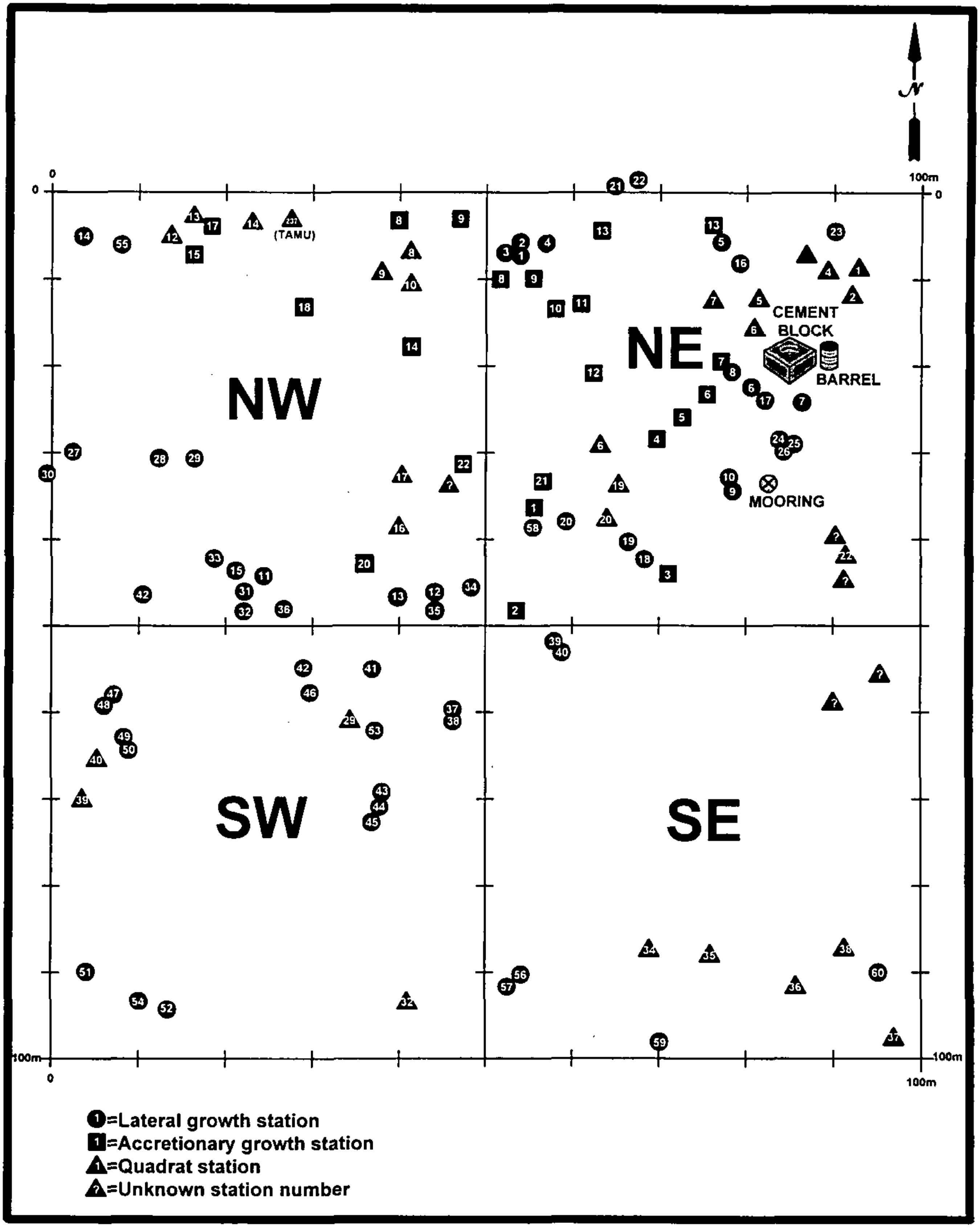


Figure 7. Map of the 100 m x 100 m study site at the West Flower Garden Bank, showing graduating boundary lines, relative positions of permanent stations, and conspicuous features.

and in proximity to the sites. The relative position of each station along a specific boundary line was drawn onto a form printed on underwater paper that showed the site boundary lines and distinctive features such as sand flats, mooring anchors, and various debris found within the site. Whenever possible, station positions were also referenced to a second perpendicular boundary line for improved accuracy.

2.3 RANDOM TRANSECTS

Population levels of reef coral communities within the two study sites were estimated using stratified random photographic transect techniques. During each field effort, fourteen, 10 m (33 ft) transects were photographed within each site. The photographs were obtained using a Nikonos V underwater camera with 28 mm lens and dual Ikelite 150 watt-second strobes, which were mounted on a rectangular stainless steel camera frame. The bottom tubes of the camera frame were covered with foam pipe insulation to minimize contact abrasion to corals during transect photography. Contact pressure on corals from the camera frame was minimized by reducing its underwater weight using small floats attached to the upper tubes (**Figure 8**).

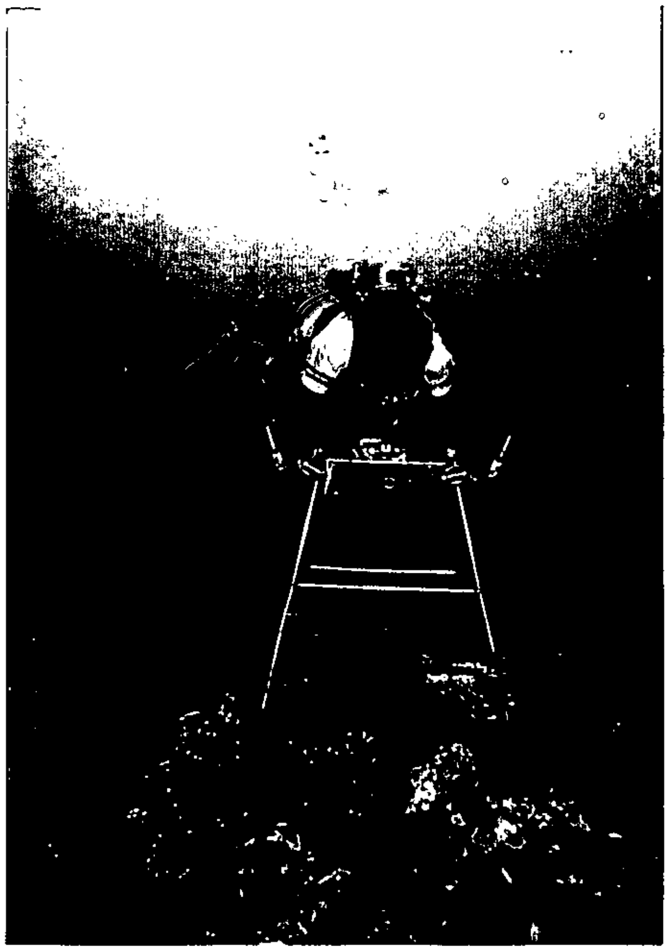


Figure 8. Diver using camera and stainless steel rectangular frame to photograph 10 m (33 ft) random transects. East-West study site boundary line is visible in the background.

Random numbers served as the prescribed compass direction and distance from the photographer's initial descent point within the study site (measured as number of flipperkicks) to the starting point of the first transect. The transect was then photographed along this same compass direction, producing a continuous swath of non-overlapping exposures. Seventeen exposures produced a transect swath of 10 m (33 ft) in length. Thus, the use of 36-exposure print film enabled each diver to complete two transects per dive. The end point of the first transect then served as a reference for the starting point of the second transect, using a second set of random direction and distance numbers. During all transects, areas of sandy bottom were bypassed or avoided to maximize the amount of coral and hard bottom community data collected.

Population levels of corals and other associated reef biota were determined by their areal coverage and abundance in transect photographs (**Figure 9**). Areal coverage of corals, sponges, leafy algae, and reef rock were determined in the lab using a Hi-Pad Plus electronic digitizing planimeter (Houston Instruments, Inc.) and EASYDIJ digitizer program (Geocomp, Ltd.). Each transect photograph was analyzed separately. The outlines of corals and reef biota within each transect photograph were traced on sheets of clear mylar and assigned corresponding identification codes. Coral species were identified to species level within transect photographs. The mylar traces provide a permanent record of all species identifications used in subsequent analyses. The outlines on the mylar traces were again traced using the calibrated planimeter and their areas automatically calculated. The sum of areas for each coral species, and all sponges, leafy algae, and reef rock traced on each set of transect photographs were converted to values of relative percent cover. The areas and numerical densities of each coral species were then used to calculate relative dominance (specific percent coral cover relative to total percent coral cover), species diversity (H') (the natural log variant of the Shannon Weaver Diversity Index), and species evenness (J) (species diversity divided by the maximum possible diversity, i.e., the natural log of the total number of species present).

The transect data were analyzed with a two-way factorial analysis of variance design. Treatments in the analysis were bank (East and West Flower Garden Banks) and year (1992, 1994, and 1995). Response variables in the analysis were percent cover of coral taxa, relative dominance of coral taxa, total coral cover, coral species diversity (based on cover and count) and coral evenness (based on cover and count). An arcsine-square root was used to transform data that were reported in percentages (cover and relative dominance). This transformation is commonly used to help normalize percentage data. Statistically significant main effects (bank and year) or interactions between the main effects were examined a posteriori with Tukey's honest significant difference test.

2.4 ACCRETIONARY GROWTH

Two methods were used for determination of accretionary growth rates in the coral *Montastrea annularis*. These included permanent growth stations and sclerochronological measurements from collected coral cores.

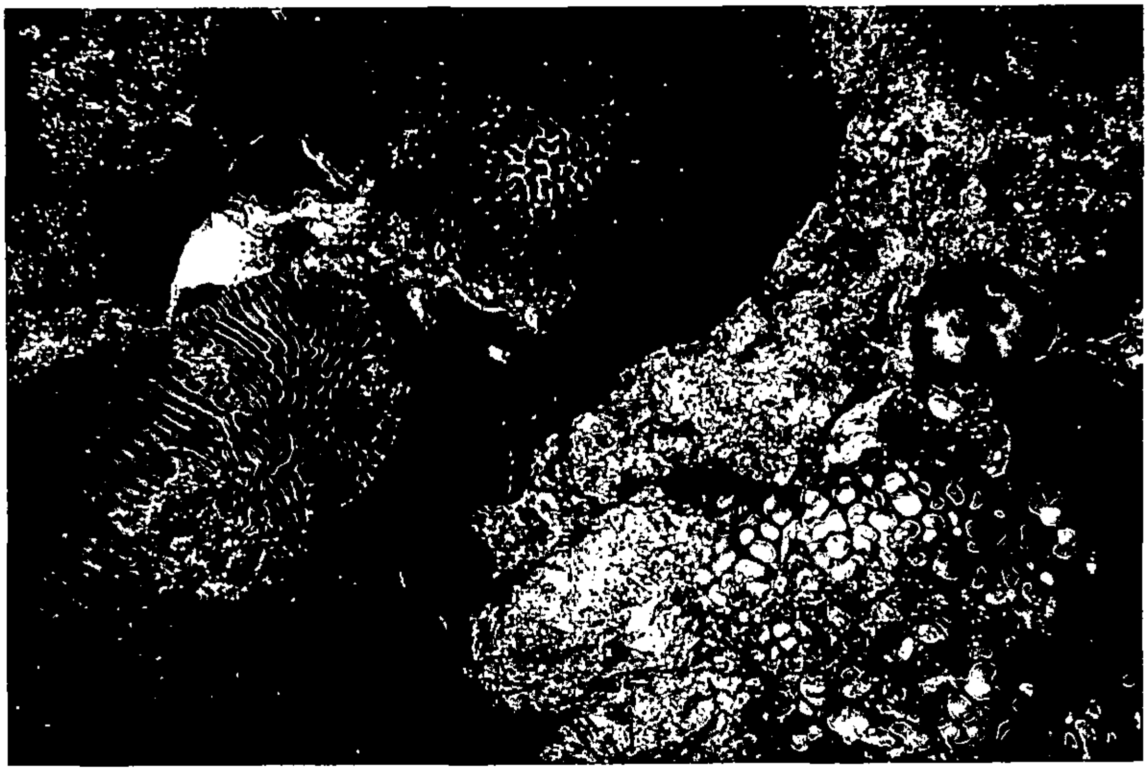


Figure 9. Example of a 10 m (33 ft) random transect photograph from the East Flower Garden Bank. Seventeen sequential photographs were equivalent to an overall transect length of 10 m (33 ft).

2.4.1 Permanent Growth Stations

Most accretionary growth stations used during the previous monitoring study were found to be unusable during the 1994 field effort due to the following:

- Sharpened stainless steel rods, or "growth spikes," had become loose within the coral, introducing the potential for substantial sample error during subsequent measurements.

- Coral tissue around the growth spikes had receded and negated further growth in the area.

- Placement of the growth spike had altered normal coral growth patterns, varying from a pronounced swelling, or hummock of growth around the base of the spike to a thin veneer of growth up the spike. In one case the coral had completely covered the spike and deposited fine streamers of growth in an outward or perpendicular direction.

- Spike was lost or previously removed.

- Station was not found in the area designated on site maps made during the previous monitoring study.

Therefore, a set of 20 new growth stations were established for the measurement of accretionary growth of the coral *M. annularis* (= *M. faveolata*) within both study sites during the 1994 field effort (**Figure 10**). Masonry expansion bolts (¼" X 2⅜") were used for both growth measurements and station markers instead of the smooth stainless spikes used during the previous study. This type of bolt is placed within a pre-drilled hole and secured by a slight expansion of its base using a mallet. This method permits accurate and reliable placement, with respect to both location and depth, and minimizes trauma to surrounding coral tissue. These types of fasteners are also very secure when properly set in reef rock. The holes for the expansion bolts were made using a ⅜ in. drive pneumatic drill attached to a compressed air (scuba) bottle. A single expansion bolt was set within the upper surface of each selected colony and measured to the nearest millimeter. As the coral continues to grow, calcium carbonate is deposited around the stationary growth spike. Accretionary growth rates are thus estimated by the measured decrease in the length of growth spikes over time. A second expansion bolt was then placed in proximity to the growth spike and marked with a small fluorescent numbered tag to serve as a station marker. The station marker bolts were placed in areas of the coral colony which would be easily visible to divers for relocation and, whenever possible, in areas of dead reef rock.

Figure 10. Permanent station for determination of accretionary growth in the coral *Montastrea annularis* (= *M. faveolata*). Note station marker tag and growth spike.

2.4.2 Sclerochronology

Determination of the accretionary growth of *M. annularis* via measurement of annual skeletal growth bands, or sclerochronology, was accomplished in 1995. This method involves the collection of intact coral cores from the tops of large, symmetrical colonies, which are later slabbed along the axis of the corallites and x-radiographed to illuminate banding (Hudson, 1981; Hudson et al., 1976). Two coral core samples were collected from separate colonies of *M. annularis* (= *M. faveolata*) within each site during the 1995 field effort using a 2.5 cm (1.0 in.) diamond-tipped coring bit and a 1.25 cm (0.5 in.) drive pneumatic drill (**Figure 11**). Core samples for sclerochronology must be taken from areas of the coral which have experienced relatively straight or planar growth. The core sample must be taken parallel to the plane of growth to obtain the most uninterrupted growth information. Breaks in the core sample, though common, must also be minimized to avoid loss of data. After removal of each intact core sample, the resultant holes in the coral colonies were sealed using tightly fitting, tapered rubber stoppers. The stoppers were positioned slightly below the level of the surrounding coral tissue to permit the subsequent lateral growth of coral over the affected area. Core samples were delivered to Mr. Harold Hudson (Reef Tech, Inc.), thin sectioned, x-ray photographed, and annual growth bands labelled and measured.

Figure 11. Diver using pneumatic drill and 2.5 cm (1 in.) coring bit to collect core sample from the coral *Montastrea annularis* (= *M. faveolata*) for determination of accretionary growth. Note application of padded drill guide.

2.5 ENCRUSTING GROWTH

Encrusting growth rates of 60 colonies of the coral *D. strigosa* were determined from permanent stations within each site. Each station was composed of a margin, or border, of coral which lay adjacent to dead reef rock. A pair of station marker spikes set into the reef rock and away from the actual coral border were used to align a Nikonos camera and close-up framer for repetitive photography. During the 1994 field effort it was found that lateral growth stations used during the previous monitoring study were no longer useable. This was due to the following:

- The coral border had shifted by either growth or recession beyond the area viewed in the repetitive photographs.

- The border had become three dimensional, or plateau-like, due to the bioerosion of the reef rock area and/or accretionary growth of the coral tissue. In this case, the growth border became perpendicular to the film plane and therefore very difficult to view and determine minute changes in growth and recession in station photographs.

- Spikes used during the previous study were missing or had become loose in the reef rock.

- The station was not located in the area designated on site maps made during the previous monitoring study.

Therefore, new stations were selected and photographed for the first time during the 1994 field effort. To maximize photograph repeatability, selected border areas were located on relatively planar surfaces. Coral borders exhibiting areas of apparent coral disease and intra- or inter-specific competition with other coral species for available space were avoided. Two expansion bolts were placed within dead reef rock adjacent to the selected coral border, using a Nikonos close-up framer as a guide for station position and dimension. After placement, a numbered marker tag was fastened to one of the bolts for station identification (**Figure 12**).

Photographic data were collected in 1992 for estimates of encrusting growth of both *D. strigosa* and *M. annularis*. These photographs were compared with those collected in 1991 during the 1989-1991 monitoring study for estimates of encrusting growth during the 1991-1992 period. The coral-reef rock borders in 1991 and 1994 encrusting growth station photographs were traced on mylar sheets, along with a series of corresponding and distinctive coral growth patterns to facilitate subsequent photograph alignment. The 1992 and 1995 coral-reef rock borders were also traced onto their corresponding mylar sheets, using a different color ink for clarity. The changes in area along the border length of each photograph were calculated using the electronic digitizing planimeter. In many cases, the 1995 border included sections of both growth and retreat, forming a number of border segments. Each border segment was traced and its area calculated separately. Growth and retreat rates for each station (expressed as cm/yr) were calculated by dividing areal measures of change (cm^2) by the total analyzed border length of the station (cm). Net growth was determined by pooling growth and retreat measurements. Each station provided a single estimate of each parameter (growth, retreat, and net growth rates) regardless of the total number of border segments present.

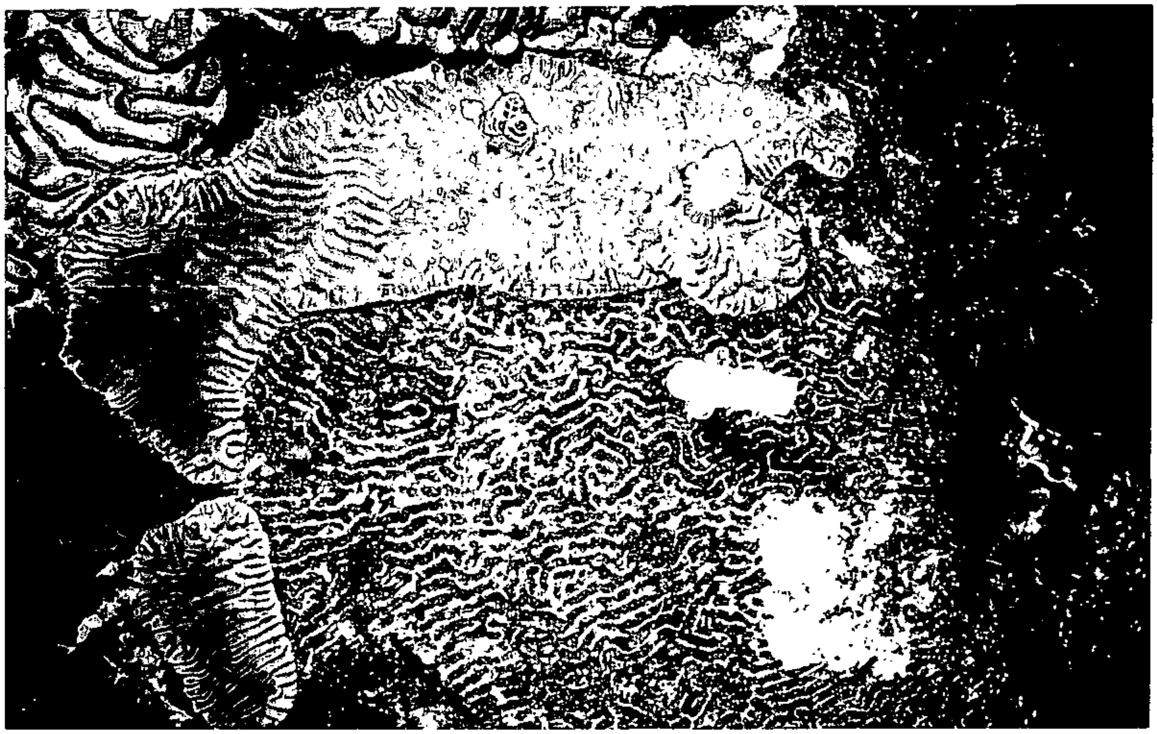


Figure 12. Permanent station for determination of encrusting growth in the coral *Diploria strigosa*. Note station marker tag on the right station spike and left station marker spike at colony break at left center of photograph.

2.6 REPETITIVE QUADRATS

Forty permanent quadrat stations established by either CSA or Texas A&M University during the previous monitoring studies were utilized during the 1994 and 1995 field efforts. Each station was marked with a single stainless steel rod set vertically into an area of reef rock (**Figure 13**). A plastic number tag was affixed to each post for station identification. Single photographs were taken at each station using a T-shaped camera frame equipped with a down-looking Nikonos V camera with 15 mm lens and two Ikelite 225 watt-second strobes mounted on the upper horizontal bar, or crossmember, and a 2 m (7 ft) vertical bar (**Figure 14**). The electronic strobes were attached to the ends of the frame's crossmember and oriented vertically. Precision in the orientation of subsequent photographs was ensured with the use of a compass and surveyor's bubblelevel mounted on the camera frame crossmember. The frame's vertical bar was placed directly against the station marker post, oriented to magnetic North, and positioned in a level attitude prior to each photograph.

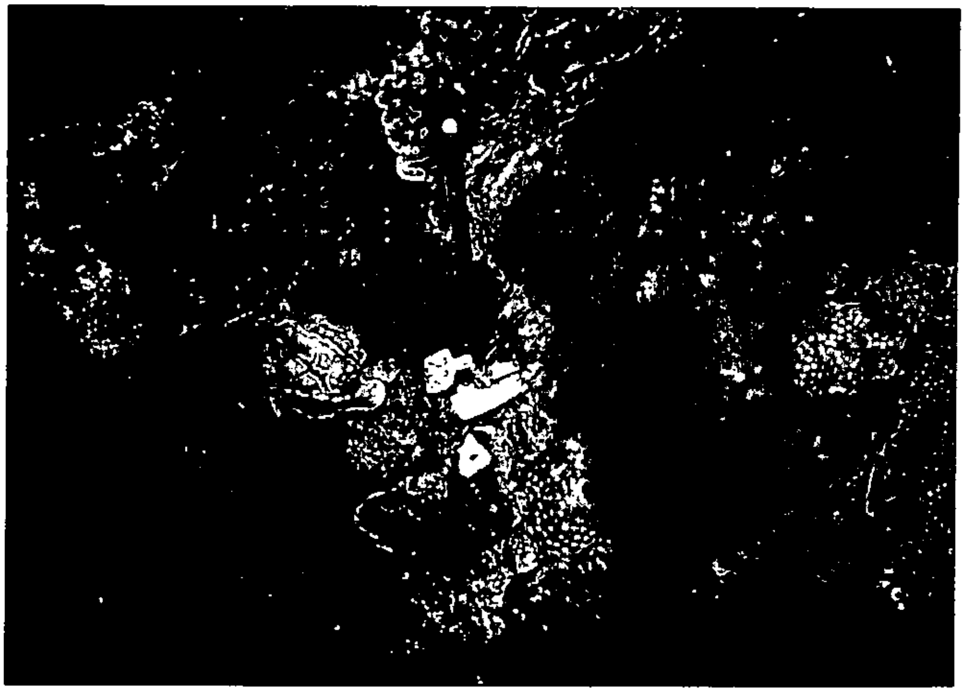


Figure 13. Permanent 8 m^2 quadrat station marker. Note marker post at center of photograph and station marker tag.

In the lab, the photographic transparency of each station was projected onto a table top and adjusted to produce images of 25.2 cm by 37.9 cm (**Figure 15**). Working templates of this size which were produced for each station during the previous study consisted of the outlines of living and dead portions of all visible colonies on large paper sheets. Temporal comparisons of each station were made by superimposing the current photographic image onto the template and comparing colony borders individually. Changes in borders were traced onto the templates using a different color pencil for each year. These changes were then categorized using the following categories: growth, algae-mediated or algae/sediment mat-mediated retreat, bleaching, and disease. Percent coral cover and percent bleached coral cover in each photograph were determined using identically sized paper templates containing 100 randomly located crosses. When superimposed on these overlays, the percent cover of live coral and bleached coral at each station were derived from the total number of crosses which were counted over live coral or bleached coral, respectively. One estimate of percent cover of live coral and bleached coral was made for each station.

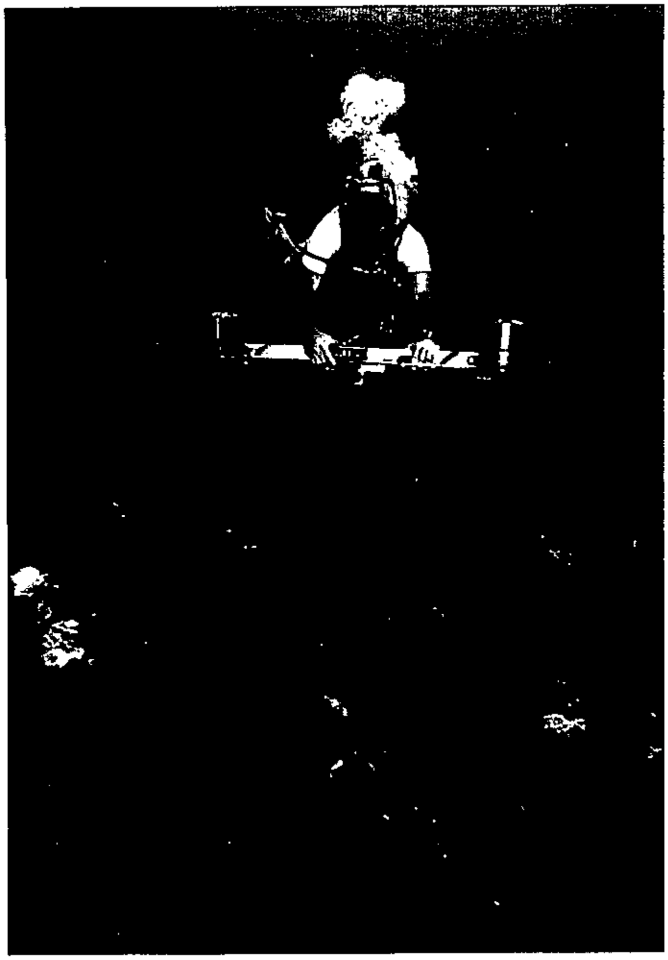


Figure 14. Diver using camera and aluminum T-frame to photograph 8 m^2 repetitive quadrats. Note that the lower end of the vertical frame member is positioned at the base of the station marker rod.

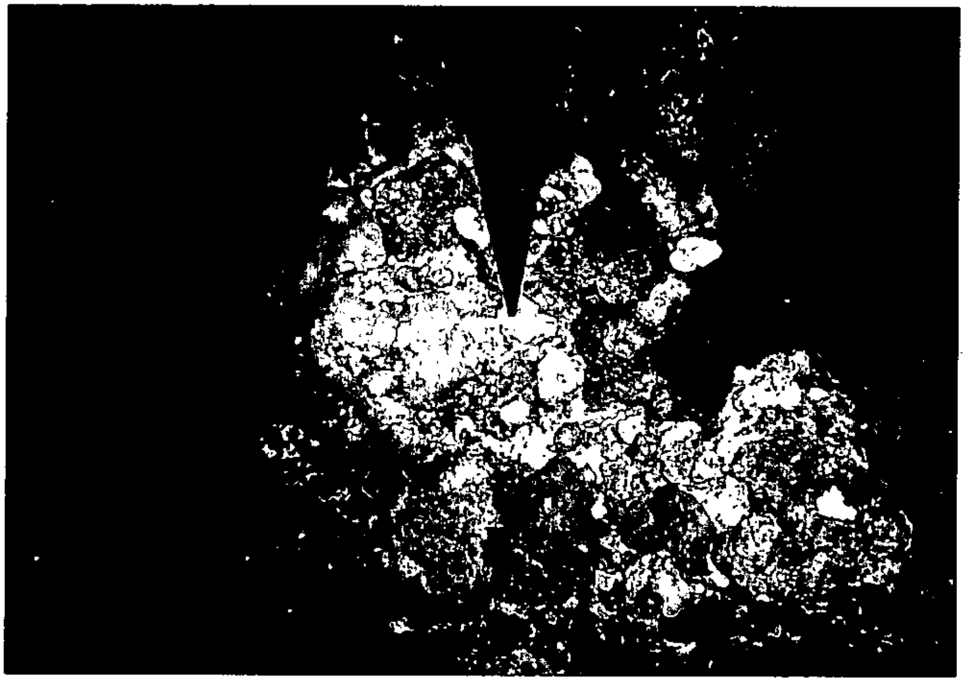


Figure 15. Example of a 8 m^2 repetitive quadrat photograph from the East Flower Garden Bank. Dark line in the photograph is the T-frame vertical member.

2.7 VIDEO TRANSECTS

Two diver-held, repetitive video transects were filmed at each site during the 1994 and 1995 field efforts. Each transect was 100 m (328 ft) in length and followed a specific boundary line for scale reference and to provide some degree of repetition between field sampling efforts. The general areas selected for video transects during the 1994 and 1995 field efforts duplicated those used during the previous monitoring study. At the East Flower Garden Bank site, these included the northern boundary line, run from west to east, and the eastern boundary line, run from north to south. At the West Flower Garden Bank site, these included the southern boundary line, run from east to west, and the western boundary line, run from south to north. Temporal comparability between each transect was possible only near the ends of each line, due to variability in positioning the line over rough topography of the reef top and displacement of the line by bottom currents. Each video transect was filmed from approximately 2 m (7 ft) above the bottom and at an angle of 45°. A 2 m (7 ft) weighted line suspended from the video camera housing provided a reference for camera altitude and angle during the filming of each transect. A baseline working map of each transect filmed during the 1994 field effort which depicts large or conspicuous coral colonies and areas of coral disease or bleaching, sand flats, sponges, etc., was constructed to provide a reference for changes observed in 1995 transects.

2.8 ANCILLARY MEASUREMENTS

2.8.1 Recording Thermometers

Hobotemp (Onset Instruments, Pocasset, Massachusetts) and Ryan TempMentor thermographs, deployed on both study sites during the previous monitoring study and presently owned by NOAA, were retrieved, their data downloaded onto computer, and redeployed during the 1994 and 1995 field efforts. These units are programmed to record water temperature every two hours. The units are affixed to the bottom in proximity to the mooring anchor at the EFG and in the northeast corner of the WFG study site.

2.8.2 Water Profiles

During each field effort, daily measurements of water temperature, salinity, dissolved oxygen, and ambient light were collected from near-surface (1 m [3 ft] depth) and near-bottom depths. A Hydrolab Surveyor III water quality probe was utilized for temperature, salinity, and dissolved oxygen parameters. A Licor 185B photometer was used to calculate ambient light. Both instruments were calibrated daily prior to each profile.

2.8.3 Light Recorders

Continuous recording light meters were installed during the 1995 field effort at underwater locations on the two sites and a surface location on the Mobil HI-384 A platform (East Flower Garden Bank). The light meters are designed to measure Photosynthetically Active Radiation (PAR) in the 400 to 700 nm waveband, and record data expressed in units of μmoles $s^{-1}m^{-2}$ (1μmol = 6.022×10^{17} photons). Data are then presented as total daily irradiance (mol $m^{-2}day^{-1}$) from each light meter and percent light transmission on each site, by dividing underwater irradiance values by the surface reference values collected by the above water meter on the HI-384 A platform. Each underwater unit consists of a Licor LI-193SA spherical (omnidirectional) quantum light sensor and LI-1000 datalogger (**Figure 16**). The dataloggers were placed in o-ring sealed, acrylic housings and secured within stainless steel cages which were coated with antifouling paint and equipped with zinc anodes (**Figure 17**). The underwater deployment sites were selected on relatively flat areas of solid reef rock located in proximity to the study site mooring buoys. The stainless steel cages were affixed to the bottom using four ⅜ in. masonry expansion bolts. 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 fastened over the sensors to prevent biofouling and the subsequent scoring of the 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. The surface reference light meter consists of a Licor LI-210 SA terrestrial quantum light sensor, 100 ft coaxial extension cable, and LI-1000 datalogger. The sensor was secured within a PVC bracket and fastened to a section of the safety guard fencing on the outer rim of the HI-384 A platform's helipad. This area will be least affected by daytime shading from the platform structure. The coaxial cable was fairleaded from the platform helipad to the living quarters below and fitted through an electrical penetrator in the outer wall to the main office quarters. The datalogger is equipped with a 110v AC adaptor; internal batteries thus provide auxiliary power only in the event of platform

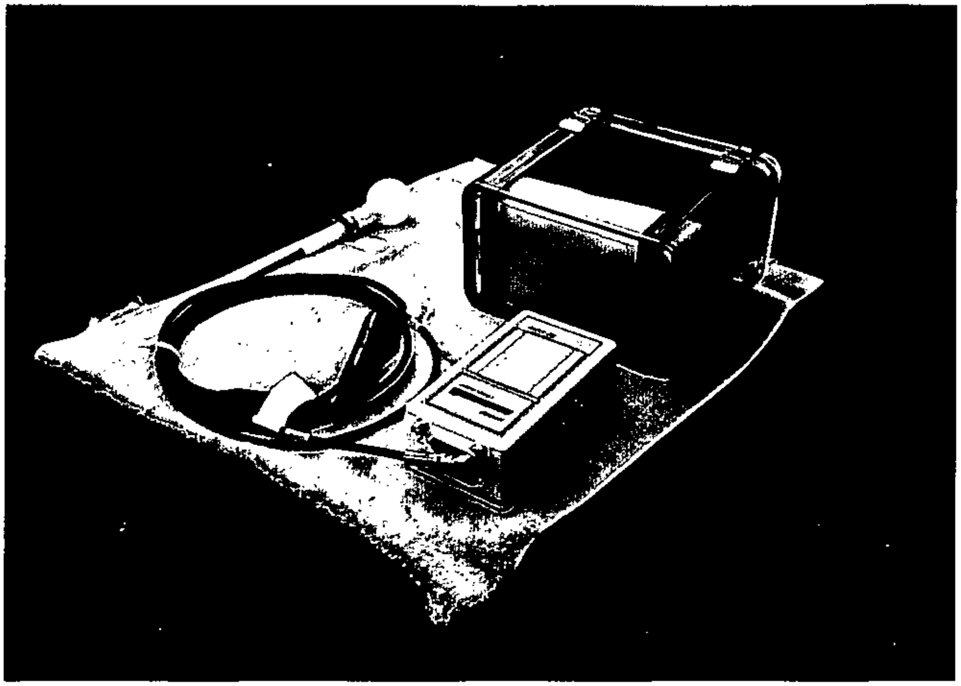


Figure 16. Layout of equipment used to record incident light at underwater sites on the East and West Flower Garden Banks study sites. These include a datalogger, spherical underwater sensor and coaxial cable, and sealed acrylic housing.

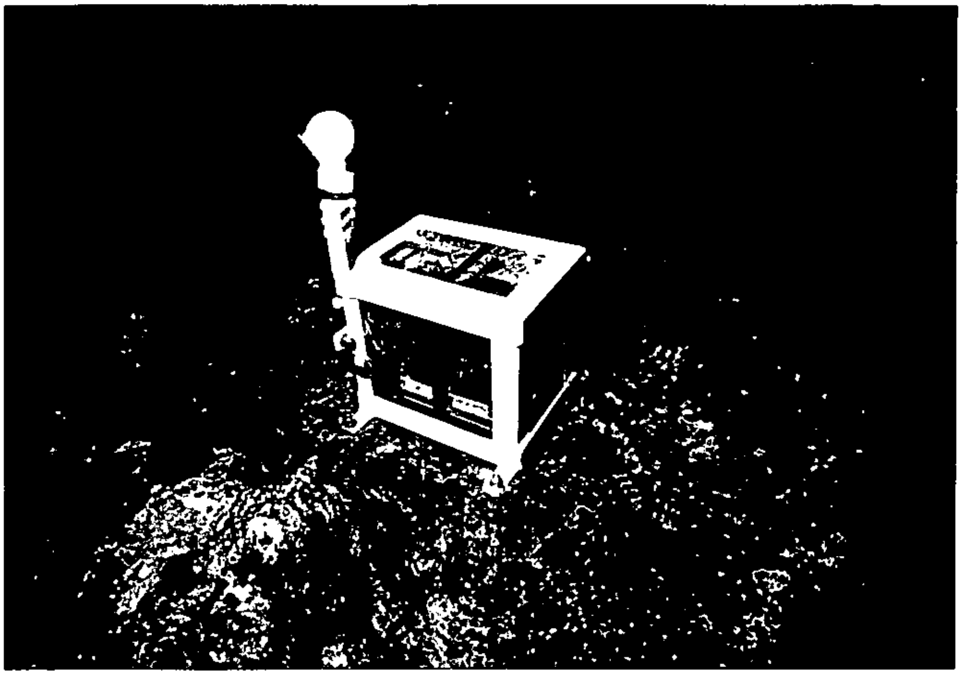


Figure 17. Recording underwater light meter in position at the East Flower Garden Bank study site. Note stainless steel containment cage bolted to reef rock and protective plastic bag over spherical sensor.

electrical power interruptions. Both underwater and surface reference light meters were programmed to record ambient light readings on an hourly basis. At this frequency, the internal memory of the dataloggers is filled in approximately three months, necessitating service on a quarterly basis. The three meters were serviced and their datasets collected during 15-16 November, 1995 and 2-3 March 1996. The service procedure included data collection from dataloggers, datalogger battery replacement and overall check, cleaning and servicing of acrylic housings, and the replacement of zinc anodes on the two underwater stainless steel cages.

2.9 SEDIMENT COLLECTIONS

Sediment samples were collected during each field effort to be archived for possible future hydrocarbon and trace metal analyses. Three replicate samples were collected for both trace metal and hydrocarbon analyses from each site during each field effort. At each site, pre-cleaned 250 ml glass jars filled with distilled water were carried by diver to a sand flat. Each jar was then opened and filled with sand, skimming only the upper 5 cm (2 in.). At the surface, approximately 5 cm (2 in.) of water and sand were poured from each jar to prevent breakage during freezing. The jars were then labelled and frozen. A separate jar filled with distilled water served as a trip blank during each field effort. These blanks have also been archived for future analysis.

3.0 RESULTS

3.1 RANDOM TRANSECTS

Percent coral cover (per taxa and total), relative dominance of coral species, and species diversity and evenness (calculated from both coral counts and coral cover) were determined through analysis of the stratified random photographic transects. Statistical comparisons were made between coral species, between the East and West Flower Garden Banks study sites, and between the 1992, 1994, and 1995 field efforts (years).

3.1.1 Coral Cover and Relative Dominance

The mean percent cover of coral taxa, reef rock, leafy algae, sponges, and sand at each study site for data collected during the 1992, 1994, and 1995 field efforts is graphically depicted in **Figure 18**. **Table A.1** in **Appendix A** lists mean percent cover estimates for coral taxa, combined coral taxa (total coral cover), reef rock, leafy algae, sponges, and sand on transects collected during the 1992, 1994, and 1995 field efforts on both banks. *M. annularis* was the dominant reef component on the East and West Flower Gardens Banks study sites, with estimates of 28.3% and 25.9% cover, respectively on the transects. The closest species in terms of percent cover to *M. annularis* was *D. strigosa*, with estimates of 6.9% and 7.5% cover at the East and West Flower Gardens Banks study sites. Estimated total coral cover at the East and West Flower Gardens Banks study sites was 48.2% and 44.1%, respectively.

Mean percent cover of reef rock over the 1992 to 1995 period on the East and West Flower Gardens Banks study sites was 48.0% and 44.1%, respectively. Since sand flats were avoided or bypassed during field data collection, its percent cover on transects was understandably extremely low. The percent cover of leafy algae and sponges on both banks was comparable to several coral species. Leafy algae comprised 1.88% and 2.52% of the transects on the East and West Flower Gardens Banks study sites. Percent cover of sponges at the East and West Flower Gardens Banks study sites were 0.88% and 1.13%, respectively.

Comparisons of percent cover for individual coral taxa were made for each year (with data from both study sites pooled) and bank (with data from all field efforts pooled) with the bank by year interaction also included in the analysis. A synopsis of these comparisons is displayed in **Table 1**. Among individual species, significant differences in cover between years for pooled banks were observed for three of the fourteen coral taxa. Cover of *M. annularis* and *Siderastrea siderea* was significantly higher on 1995 transects than on both 1994 and 1992 transects. Cover of *M. cavernosa* was significantly higher on 1994 transects than on 1992 transects. There were no significant differences in coral cover for specific corals (years pooled) between banks. Significant bank by year differences were observed in *P. astreoides*. Percent cover estimates for *P. astreoides* at the East Flower Garden Bank study site were significantly higher in 1992 than those on the West Flower Garden Bank study site in both 1992 and 1994. The 1994 East Flower Garden Bank study site estimates were significantly higher than at the West Flower Garden Bank site in 1992.

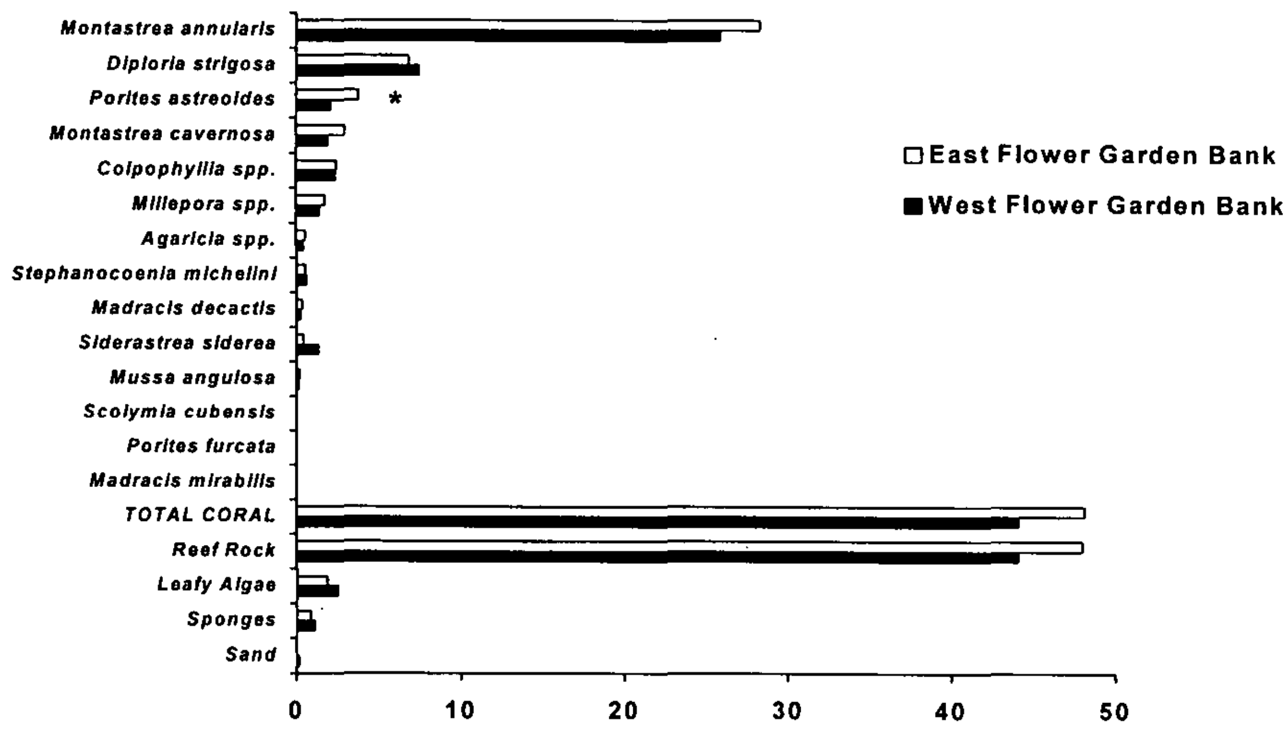


Figure 18. Comparison of percent cover of corals, reef rock, conspicuous biota, and sand between the East and West Flower Garden Banks study sites during the 1992 to 1995 period (* indicates coral cover estimates which are significantly different between banks at $\alpha = 0.05$).

Table 1. Summary of the results of the statistical analysis of percent coral cover from random transect data. Statistical analysis included year, bank, and bank by year interaction. Statistical tests were performed at a confidence level of 95% ($\alpha = 0.05$).

Species	Coral Cover		
	Year (banks pooled)	Bank (years pooled)	Bank by Year Interaction
Montastrea annularis	95 > 94, 92	NS	NS
Diploria strigosa	NS	NS	NS
Porites astreoides	*	*	EFG 92>WFG 92, WFG 94; EFG 94>WFG 92
Agaricia spp.	NS	NS	NS
Millepora spp.	NS	NS	NS
Colpophyllia spp.	NS	NS	NS
Montastrea cavernosa	94 > 92	NS	NS
Stephanocoenia michelini	NS	NS	NS
Siderastrea siderea	95 > 94, 92	NS	NS
Madracis decactis	NS	NS	NS
Madracis mirabilis	NS	NS	NS
Mussa angulosa	NS	NS	NS
Scolymia cubensis	NS	NS	NS
Porites furcata	NS	NS	NS
Total Coral Cover	95, 94 > 92	E > W	NS

NS = No significant difference.
* = Significant interaction of bank by year precludes interpretation of main effects (i.e., year and bank).

Total percent coral cover (with all species pooled) was significantly different between years and between banks. Mean percent coral cover was higher in both 1995 and 1994 than in 1992, and higher on the East Flower Garden Bank study site than the West Flower Garden Bank study site.

The relative dominance of each coral taxa on each bank for data collected during 1992, 1994, and 1995 is graphically depicted in **Figure 19**. Patterns in relative dominance of coral taxa were similar to those observed in percent cover. *M. annularis* was the dominant species observed in transects on both study sites, followed by *D. strigosa*. Ratios were slightly higher for both species at the West Flower Garden Bank study site.

Comparisons of relative dominance for each coral species were made for each year (with data from both study sites pooled), bank (with data from all field efforts pooled), and between bank by year. **Table A.2** in **Appendix A** lists relative dominance estimates, expressed in percent, for all coral taxa. A synopsis of these comparisons is displayed in **Table 2**. No significant differences in relative dominance of coral taxa between years (banks pooled) were observed. Significant differences in relative coral dominance between banks (years pooled) were observed in three species. Relative dominance of *M. cavernosa* was significantly higher in 1994 than 1992, *Stephanocoenia michelini* was higher in 1992 than 1995, and *S. siderea* was higher in 1995 than in both 1992 and 1994. As in the case of coral cover, *P. astreoides* showed significant differences in comparative bank by year interactions. The relative dominance of *P. astreoides* in 1992 at the East Flower Garden Bank study site was significantly higher than in 1994 and 1995, and higher than the West Flower Garden Bank study site during 1992, 1994, and 1995.

3.1.2 Species Diversity and Evenness

Estimates of coral species diversity and evenness from the random transects sampled during 1992, 1994, and 1995 at the East and West Flower Garden Banks study sites are listed in **Table A.3** in **Appendix A**. **Table 3** is a synopsis of comparisons between year (with data from both study sites pooled), bank (with data from all field efforts pooled), and between bank by year (interaction). With data from both banks pooled, values of species diversity and evenness based on coral counts were significantly higher in 1992 than 1995. No significant differences in diversity and evenness were observed between banks and the interaction between banks and years was not significant.

3.2 ACCRETIONARY GROWTH

3.2.1 Permanent Growth Stations

Accretionary growth rates were determined from 20 stations established at both the East and West Flower Garden Banks during the 1994 field effort. Data from 18 of the 20 stations at the East Flower Garden Bank and 15 of the 20 stations from the West Flower Garden Bank were used to derive these measurements (**Appendix B, Tables B.1** and **B.2**). Aberrant data, indicative of sampling error, were not included in the

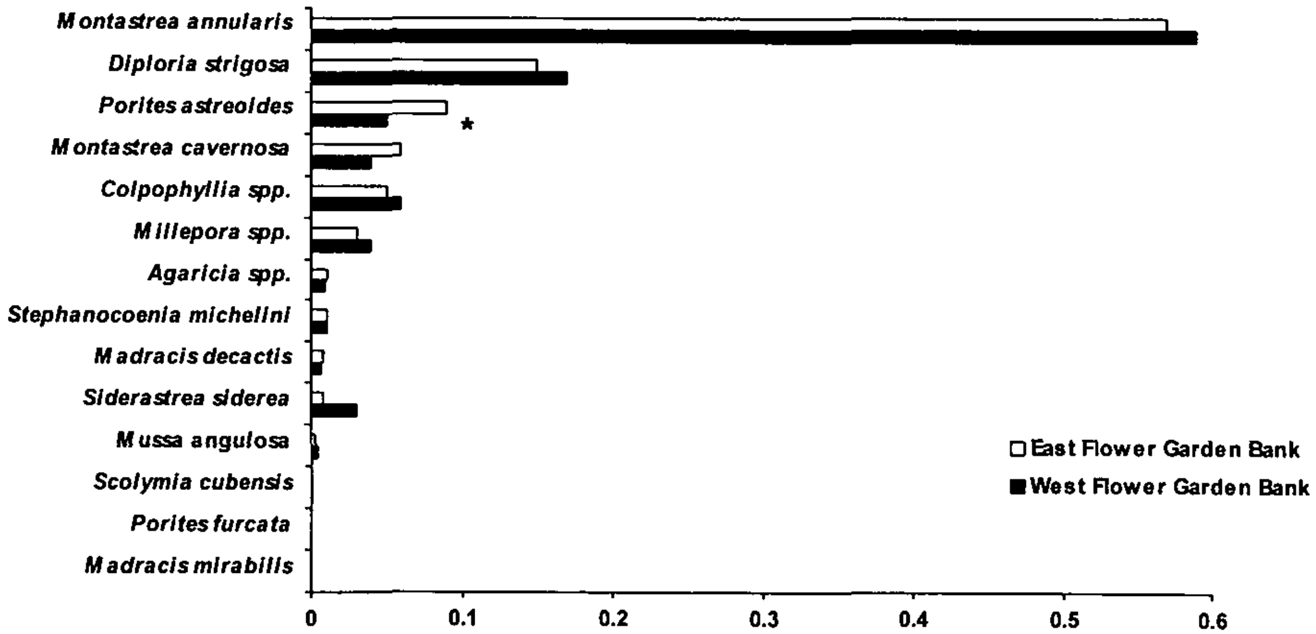


Figure 19. Comparison of relative dominance of corals between the East and West Flower Garden Banks study sites during the 1992 to 1995 period (* indicates relative dominance estimates which are significantly different between banks at $\alpha = 0.05$).

Table 2. Summary of the results of the statistical analysis of relative dominance of coral taxa from random transect data. Statistical analysis included year, bank, and bank by year interaction. Statistical tests were performed at a confidence level of 95% ($\alpha = 0.05$).

Species	Relative Dominance		
	Year (banks pooled)	Bank (years pooled)	Bank by Year Interaction
Montastrea annularis	NS	NS	NS
Diploria strigosa	NS	NS	NS
Porites astreoides	*	*	EFG 92>EFG 94, EFG 95, WFG 92, WFG 94, WFG 95
Agaricia spp.	NS	NS	NS
Millepora spp.	NS	NS	NS
Colpophyllia spp.	NS	NS	NS
Montastrea cavernosa	NS	94 > 92	NS
Stephanocoenia michelini	NS	92 > 95	NS
Siderastrea siderea	NS	95 > 94, 92	NS
Madracis decactis	NS	NS	NS
Madracis mirabilis	NS	NS	NS
Mussa angulosa	NS	NS	NS
Scolymia cubensis	NS	NS	NS
Porites furcata	NS	NS	NS

NS = No significant difference.
* = Significant interaction of bank by year precludes interpretation of main effects (i.e., year and bank).

Table 3. Summary of the results of the statistical analyses of coral species diversity (H') and species evenness (E) based on colony counts and percent cover. Statistical analyses included year, bank, and bank by year interaction. Statistical tests were performed at a confidence level of 95% ($\alpha = 0.05$).

	H' (counts)	E (counts)	H' (cover)	E (cover)
Year	1992 > 1995	1992 > 1995	NS	NS
Bank	NS	NS	NS	NS
Bank by Year	NS	NS	NS	NS

NS = No significant difference.

data set. **Table 4** is a synopsis of accretionary growth data collected during the 1994-95 period at both banks.

Table 4. Accretionary growth of *Montastrea annularis* from 1994-1995, measured from growth spikes installed at the East and West Flower Garden Banks study sites.

Bank	Mean (mm/yr)	Range (mm/yr)	Number	Standard Deviation
East	5.7	0-8	18	0.5
West	5.5	4-9	15	0.5

These data are also graphically depicted in **Figure 20**. Mean growth rates during this period were similar to those determined from the East and West Flower Garden Banks during the previous monitoring study (7.0 and 6.0 mm/yr, respectively) (Gittings et al., 1992).

3.2.2 Sclerochronology

The 1973 to 1995 accretionary growth records of two cores of *M. annularis* collected from each study site are listed in **Appendix B (Table B.3)** and graphically depicted in **Figures 20** and **21**. The mean accretionary growth rate during this period from cores collected from the East and West Flower Garden Banks was 6.8 and 8.1 mm/yr, respectively. Individual annual growth estimates ranged from 5.3 to 11.7 mm during this period. Mean accretionary growth of the cores during the 1994-1995 contract period was 8.0 mm (East Flower Garden Bank) and 8.5 mm (West Flower Garden Bank). These rates fall within the range of measurements derived from permanent growth station data during this period.

3.3 ENCRUSTING GROWTH

As discussed in **Section 2.5**, the physical condition of previously established, permanent encrusting growth stations at both East and West Flower Garden Bank study sites were determined to be unsuitable for continued use during the present contract period. Consequently, a new set of permanent stations for the measurement of encrusting growth of *D. strigosa* was established during the 1994 field effort. Estimates of encrusting growth rates for this species are availible for the periods between 1991-1992 and 1994-1995. Estimates of encrusting growth rates of *M. annularis* were measured from 1992 station photographs, representing growth from 1991-1992.

In the lab, it was found that approximately 60% of the encrusting growth station photographs of both *D. strigosa* and *M. annularis* taken in 1992 could not be analyzed. This was due in most cases to 1) the effects of natural changes observed along coral tissue-reef rock borders in certain stations (as described in **Section 2.5**), 2) the effects of inconsistent camera angle, or 3) different species selected for permanent stations (*M. cavernosa* or *Colpophyllia* spp.).

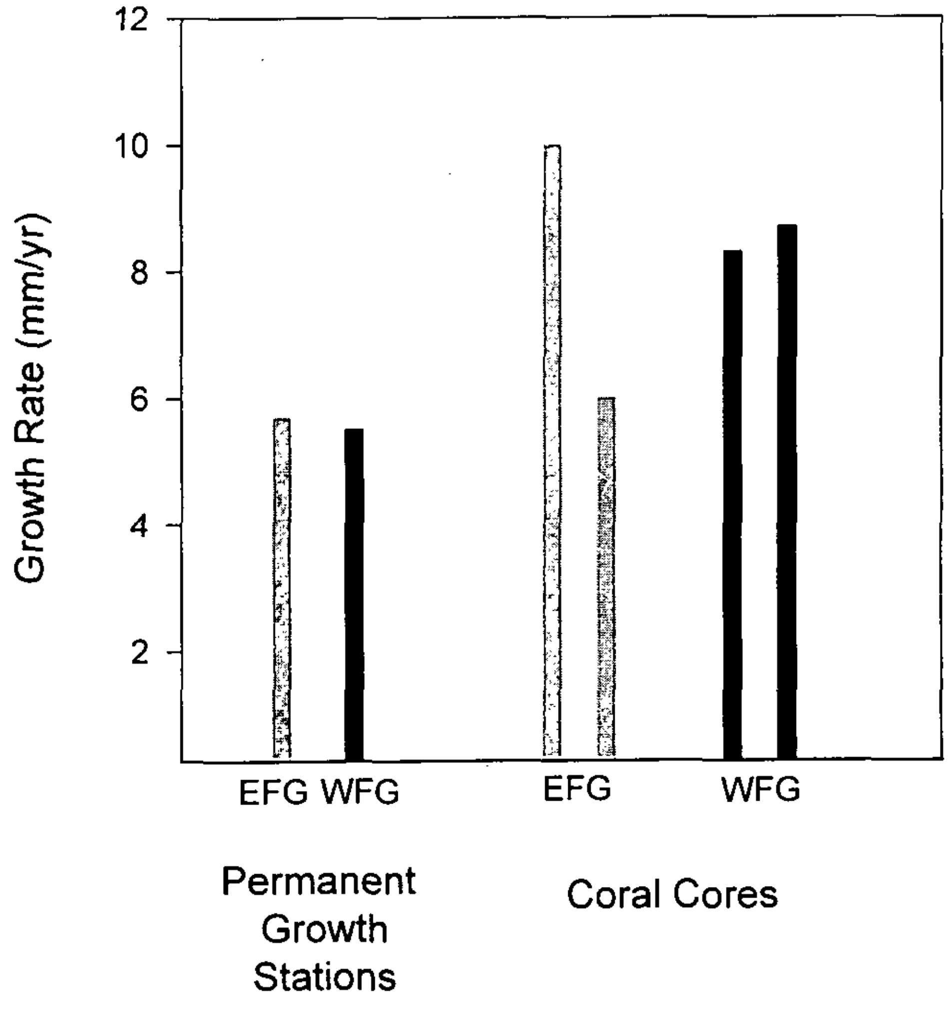


Figure 20. Comparison of accretionary growth rates of *Montastrea annularis* during 1994 - 1995 from *permanent growth stations and collected coral cores.*

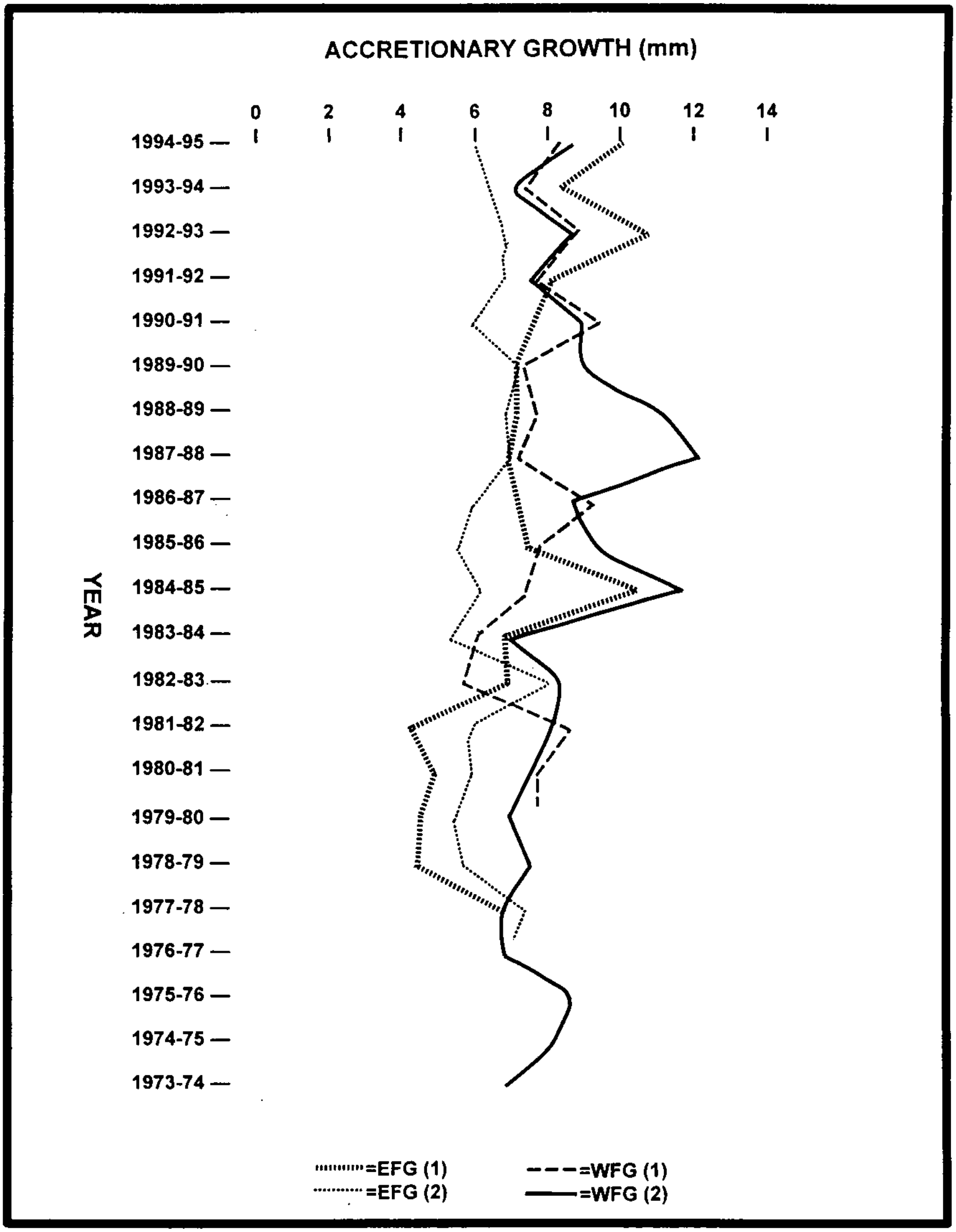


Figure 21. Accretionary growth rates of *Montastrea annularis* measured from cores collected at the East and West Flower Garden Banks.

Subsequent to the analysis of the acceptable 1992 photographs, it was discovered that the estimates of net encrusting growth rates of *D. strigosa* during the 1991-1992 period were substantially less than those estimated for the 1994-1995 period. Because of the problems with the 1992 data and the resultant low sample size, it is possible that the differences may be an artifact of sampling error. Therefore, they are compared only graphically and not statistically with the 1994-1995 data set.

3.3.1 Net Growth Rates

Net growth rates are defined as the mean rate of change of coral areas observed to advance (growth) or retreat, using pooled measurements from all stations. For *D. strigosa* (**Table 5**), net encrusting growth rates at the East and West Flower Garden Banks were positive during the 1991-1992 period and 1994-1995 period, and averaged 0.05 and 0.20 cm/yr, respectively. Comparisons between the banks showed comparable net growth rates within each sample period. The substantial differences in net growth rates between sample periods may be an artifact of sample error or may indicate that greater numbers of permanent stations in the 1994-1995 period had measureable growth than those selected for analysis from the 1991-1992 period.

Measurements of encrusting growth rates of *M. annularis* were determined from 1992 data (**Table 6**). Because the net growth rate estimated at the East Flower Garden Bank during this period was negative (-0.05 cm/yr), net growth for the combined banks during the 1991-1992 period was comparatively low (0.01 cm/yr). The net growth rate at the West Flower Garden Bank during this period was estimated at 0.07 cm/yr. As in the case of *D. strigosa*, the estimates for *M. annularis* may be an artifact of sampling error.

3.3.2 Advance and Retreat Rates

Separate mean advance and retreat rates and their corresponding standard deviations for *D. strigosa* are shown in **Table 7**. The mean advance rates for both banks during the 1991-1992 and 1994-1995 periods were 0.36 and 0.41 cm/yr, respectively. Mean retreat rates and their standard deviations were somewhat higher than advance rates during both sample periods. This may be explained by the fact that whereas encrusting growth of corals on the Flower Garden Banks proceeds at a relatively constant rate, their tissue retreat or death, which can be attributed to a variety of causes, may occur at a higher and more variable rate (Gittings et al., 1992). During the 1991-1992 period, both advance and retreat rates of encrusting growth in *D. strigosa* at the East Flower Garden Bank were greater than at the West Flower Garden Bank. Comparative advance and retreat rates for the combined banks during the 1994-1995 period were very close.

Mean advance and retreat rates for encrusting growth in *M. annularis* at the East and West Flower Garden Banks are shown in **Table 8**. The mean advance rate for the combined banks during the 1991-1992 period was 0.34 cm/yr. As in the case of *D. strigosa*, the mean retreat rate for the combined banks was somewhat greater for this period (-0.46 cm/yr). Differences in both advance and retreat rates between the two banks were small.

Table 5. Net growth rates of *Diploria strigosa*.

Area	Growth Rate (cm/yr)	Standard Deviation
East Flower Garden Bank 1991-1992	0.05	1.04
West Flower Garden Bank 1991-1992	0.05	0.33
Both Banks 1991-1992	0.05	0.71
East Flower Garden Bank 1994-1995	0.18	0.51
West Flower Garden Bank 1994-1995	0.21	0.50
Both Banks 1994-1995	0.20	0.51

Table 6. Net growth rates of *Montastrea annularis*.

Area	Growth Rate (cm/yr)	Standard Deviation
East Flower Garden Bank 1991-1992	-0.05	0.52
West Flower Garden Bank 1991-1992	0.07	0.68
Both Banks 1991-1992	0.01	0.60

Table 7. Mean advance and retreat rates of *Diploria strigosa*.

Area	Advance Rate (cm/yr)	Standard Deviation	Retreat Rate (cm/yr)	Standard Deviation
East Flower Garden Bank 1991-1992	0.45	0.27	-0.70	1.16
West Flower Garden Bank 1991-1992	0.30	0.19	-0.28	0.16
Both Banks 1991-1992	0.36	0.24	-0.42	0.68
East Flower Garden Bank 1994-1995	0.41	0.18	-0.58	0.69
West Flower Garden Bank 1994-1995	0.42	0.18	-0.55	0.82
Both Banks 1994-1995	0.41	0.18	-0.56	0.75

Table 8. Mean advance and retreat rates of *Montastrea annularis*.

Area	Advance Rate (cm/yr)	Standard Deviation	Retreat Rate (cm/yr)	Standard Deviation
East Flower Garden Bank 1991-1992	0.29	0.14	-0.53	0.44
West Flower Garden Bank 1991-1992	0.40	0.25	-0.38	0.74
Both Banks 1991-1992	0.34	0.21	-0.46	0.59

3.3.3 Retreat to Advance Ratios

Retreat to advance ratios are useful for the determination of net tissue gain or loss and are derived from mean retreat and advance rates. Values of retreat to advance ratios above 1.0 are indicative of net tissue loss; those below 1.0 indicate net tissue gain. **Figure 22** shows the ratios of tissue lost to tissue gained for *D. strigosa* during the 1991-1992 and 1994-1995 periods and for *M. annularis* during the 1991-1992 period.

Retreat to advance ratios for *D. strigosa* during the 1991-1992 and 1994-1995 periods were below 1.0 at both East and West Flower Garden Banks study sites, indicating net tissue gained for this species at all permanent stations. During the 1991-1992 period, the retreat to advance ratios for *M. annularis* at both sites were above 1.0, indicating net tissue loss at those stations selected for analyses. As mentioned in **Sections 2.5** and **3.3**, these data may be a result of sampling error.

3.4 REPETITIVE QUADRATS

3.4.1 1992 Survey

A total of 72 stations from the East and West Flower Garden Banks were analyzed in permanent 8 m^2 quadrat station images collected in 1992. Percent coral cover at the East Flower Garden Bank averaged 50.6% overall, and ranged from 14% to 82% (**Table 9**). Coral cover at the West Flower Garden Bank averaged 48.0% overall, and ranged from 24% to 68% (**Table 10**). Bleaching was observed on colonies at both banks. The mean percent cover of bleached corals at the East and West Flower Garden Banks during 1992 was 3.4% and 3.8%, respectively. Observations of growth in identified colonies far exceeded observations of retreat, bleaching, and disease (**Table 11** and **Appendix C, Tables C.1** and **C.2**).

3.4.2 1994 Survey

A total of 76 stations from the East and West Flower Garden Banks were analyzed in permanent 8 m^2 quadrat station images collected during the 1994 field effort. Percent coral cover at the East Flower Garden Bank coral cover averaged 49.3% overall, and ranged from 20% to 87% (**Table 9**). Coral cover at the West Flower Garden Bank averaged 45.1% overall, and ranged from 15% to 83% (**Table 10**). Average percent cover of bleached corals at the East and West Flower Garden Banks during 1994 was 3.0% and 3.4%, respectively. Observations of growth in identified colonies far exceeded observations of retreat, bleaching, and disease (**Table 12** and **Appendix C, Tables C.3** and **C.4**).

3.4.3 1995 Survey

A total of 75 stations from the East and West Flower Garden Banks were analyzed in permanent 8 m^2 quadrat station images collected during the 1995 field effort. Percent coral cover at the East Flower Garden Bank averaged 50.2% overall, and ranged from 10% to 84% (**Table 9**). Coral cover at the West Flower Garden Bank averaged 47.4% overall, and ranged from 19% to 75% (**Table 10**). Average percent cover of bleached corals at the East and West Flower Garden Banks during 1995 was 2.7% and

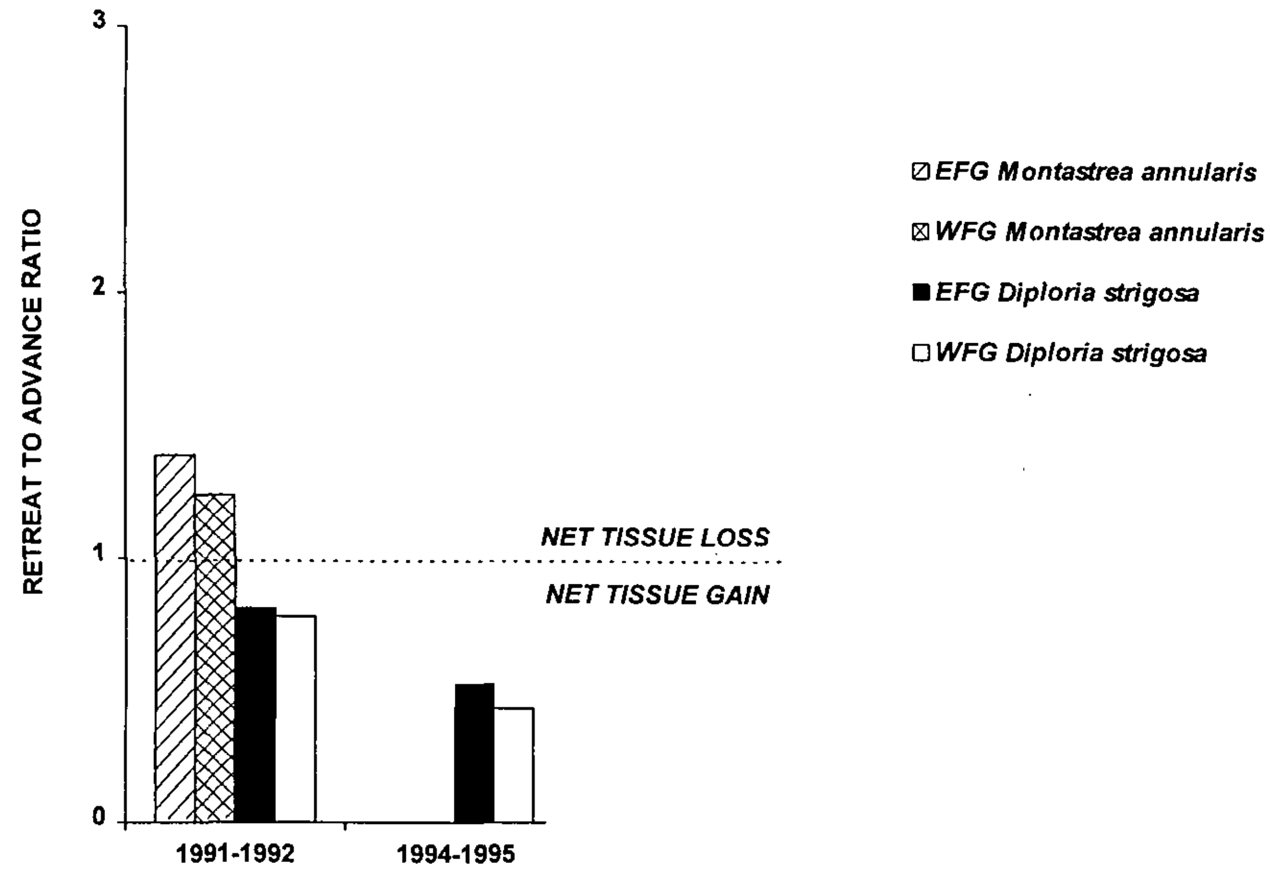


Figure 22. Retreat to advance ratios (total coral tissue lost divided by total tissue gained) of *Montastrea annularis* from 1991 - 1992 and *Diploria strigosa* from 1991 - 1992 and 1994 - 1995 at the East and West Flower Garden Banks study sites. Dotted line indicates ratio of one, where net tissue change between sample periods is zero.

Table 9. Percent coral cover at East Flower Garden Bank repetitive 8 m^2 stations during 1992, 1994, and 1995. Values were derived from one estimate per station per survey period. Shaded areas were not used in calculations of mean cover, standard deviation, etc., because slides were missing or not useful in one of the data sets. Also shown is the percent cover of bleached corals at repetitive stations during 1992, 1994, and 1995.

CSA Station No.	TAMU Station No.	% Coral Cover			Change in % Coral Cover (1992-1995)	% Bleached Coral Cover		
		1992	1994	1995		1992	1994	1995
1	173	76	20	51	-25	0	1	2
2	22		40	65			7	4
4	51	57	37	60	3	6	1	0
5	112	28	43	24	-4	2	5	1
6	61	53	54	50	-3	2	1	5
7	150	32	41	33	1	3	2	2
8	37	40	47	53	13	7	2	1
9	101		48	28				3
10	58	34	60	61	27	3	3	4
11	70	44	60	54	10	2	1	4
12	33	47	32	49	2	1	0	2
13	49	25	71	18	-7	9	2	1
14	43	49	35	63	14	7	5	4
15	21	39	46	50	11	8	1	2
16	39M	66	65	67	1	0	2	2
18	18	61	49	68	7	3	1	1
19	19	81	43	65	-16	0	2	2
20	7	82	24	84	2	2	1	1
21	155	76	77	59	-17	1	2	3
22	14	71	46	68	-3	2	3	1
23	5	74	35	81	7	3	5	1
24	52	54	77	64	10	7	1	1
27	36	39	50	18	-21	27	6	9
28	36M	44	87	45	1	2	1	3
29	50	14	40	10	-4	4	2	2
30	67	35	67	25	-10	2	1	2
31	41	59	45	58	-1	2	3	3
32	26	38	53	26	-12	2	4	0
33	8	71	32	75	4	5	0	2

Table 9. (continued).

CSA Station No.	TAMU Station No.	% Coral Cover			Change in % Coral Cover (1992-1995)	% Bleached Coral Cover		
		1992	1994	1995		1992	1994	1995
34	28	41	42	55	14	1	2	3
35	81	22	65	17	-5	2	12	7
36	82	44	57	43	-1	1	2	1
37	106	60	42	50	-10	0	11	9
38	134	50	42	58	8	3	6	2
39	151	50	41	40	-10	0	4	3
40	156	63	53	66	3	1	4	4
	31	48				1		
	4	62		65	3	4		2
	75	52				2		
	Mean	50.6	49.3	50.2	-0.3	3.4	3.0	2.7

Table 10. Percent coral cover at West Flower Garden Bank repetitive 8 m^2 stations during 1992, 1994, and 1995. Values were derived from one estimate per station per survey period. Shaded areas were not used in calculations of mean cover, standard deviation, etc., because slides were missing or not useful in one of the data sets. Also shown is the percent cover of bleached corals at repetitive stations during 1992, 1994, and 1995.

CSA Station No.	TAMU Station No.	% Coral Cover			Change in % Coral Cover (1992-1995)	% Bleached Coral Cover		
		1992	1994	1995		1992	1994	1995
1	149	55	60	44	-11	2	2	3
2	266	32	66	34	2	2	3	4
3	119	38	49	30	-8	6	11	2
4	31M	67	41	75	8	0	0	3
5	246		60	44			2	2
6	397	39	20	38	-1	2	5	1
7	247	26	78	20	-6	3	2	2
8	375	46	22	61	15	5	6	7
9	386	37	18	39	2	4	2	2
10	373	63	46	42	-21	3	3	0
11	341	55	32	58	3	4	4	4
12	329	47	23	51	4	3	7	8
13	332	36	38	36	0	9	8	6
14	32M	24	47	19	-5	7	5	2
15	232	38	36			8	2	
16	239	49	51	45	-4	6	3	4
17	240	53	47	54	1	7	1	2
18	185	51	40	63	12	2	4	1
19	350		64	48			3	3
20	346	47	44	51	4	4	4	1
21	279	48	80	42	-6	5	3	4
22	243	59	38	49	-10	3	2	2
23	310	57	47	54	-3	0	4	7
24	249	52	38	55	3	3	3	4
25	226	68	55	64	-4	1	3	6
26	285	43	83	43	0	4	1	6
27	366	61	66	55	-6	12	5	4
28	368		41	56			6	1
29	230	56	46	56	0	1	4	0

Table 10. (continued).

CSA Station No.	TAMU Station No.	% Coral Cover			Change in % Coral Cover (1992-1995)	% Bleached Coral Cover		
		1992	1994	1995		1992	1994	1995
30	311	46	44	60	14	1	1	1
31	229	30	15	33	3		1	3
32	189	58	40	46	-12	0	2	2
33	349	44	45	50	6	9	8	3
34	333	50	51	51	1	2	5	1
35	215	41	19	53	12	2	2	2
36	214	54	62	46	-8	3	4	0
37	NEW		44	40			2	11
38	NEW		49	46			1	0
39	NEW		26				1	
40	NEW		31				3	
*	231	55		51	-4	4		3
*	WFG NT	56				2		
	Mean	48.0	45.1	47.4	-47	3.8	3.4	3.4

* Stations not renumbered during the present study.

Table 11. Observations of growth, retreat, coral bleaching, and disease at permanent 8 m^2 quadrat stations photographed during the 1992 field effort at the East and West Flower Garden Banks. Data are in number of observations in all quadrat stations without regard to the sizes of areas affected. "New disease" occurrence is the number of colonies infected since the last sampling period. Mortality is the number of colonies exhibiting mortality since the last sampling period.

Change	Cause	Occurrence	Mortality
Growth	--	2,157	--
Retreat, Bleaching, and Disease	unknown cause	85	85
	algae mediated	692	0
	algae/sediment	28	0
	new disease	1	1
	bleaching	91	18

Table 12. Observations of growth, retreat, coral bleaching, and disease at permanent 8 m^2 *quadrat stations photographed during the 1994 field effort at the East and* West Flower Garden Banks. Data are in number of observations in all quadrat stations without regard to the sizes of areas affected. "New disease" occurrence is the number of colonies infected since the last sampling period. Mortality is the number of colonies exhibiting mortality since the last sampling period.

Change	Cause	Occurrence	Mortality
Growth	--	1,913	--
Retreat, Bleaching, and Disease	unknown cause	147	147
	algae mediated	729	729
	algae/sediment	28	28
	new disease	0	0
	bleaching	24	15

3.4%, respectively. Observations of growth in identified colonies far exceeded observations of retreat, bleaching, and disease (**Table 13** and **Appendix C, Tables C.5** and **C.6**).

Table 13. Observations of growth, retreat, coral bleaching, and disease at permanent 8 m^2 quadrat stations photographed during the 1995 field effort at the East and West Flower Garden Banks. Data are in number of observations in all quadrat stations without regard to the sizes of areas affected. "New disease" occurrence is the number of colonies infected since the last sampling period. Mortality is the number of colonies exhibiting mortality since the last sampling period.

Change	Cause	Occurrence	Mortality
Growth	--	2,138	--
Retreat, Bleaching, and Disease	unknown cause	19	19
	algae mediated	43	43
	algae/sediment	0	0
	new disease	317	234
	bleaching	429	111

3.4.4 1992 to 1995 Period

Coral growth was clearly identifiable in 8 m^2 quadrat station images collected during 1992, 1994, and 1995, and included examples of both unimpeded encrusting growth and interspecific competition between several species. Numbers of observations of coral growth far exceeded observations of coral bleaching, disease, and retreat during this period. Occurrences of coral colony retreat, bleaching, and disease were evident in quadrat images but causes were often difficult to conclusively identify due to the large scale of the overall quadrat images and the length of time between sample photographs. Occurrences of coral bleaching were much higher in quadrat images collected during the 1995 field effort than those from 1992 and 1994 (**Figure 23**). Mortality associated with bleaching observed in 1992 and 1994 quadrats was minimal. The hydrocoral, *Millepora alcicomis*, was the predominant species observed with bleached areas in 1992, 1994, and 1995 quadrat images. Occurrences of coral disease were significantly higher in 1995 quadrat images than in 1992 and 1994 (**Figure 24**). This may be due to differences in the interpretation of disease categories (**Table 13**) during analysis that were originally set up during the previous monitoring program. This ambiguity was exacerbated when examining very small colonies within the 8 m^2 quadrats.

3.5 VIDEO TRANSECTS

Video transects filmed during the 1994 and 1995 field efforts followed the same 100 m (328 ft) study site boundary lines and relative directions as those filmed during the previous monitoring study. Because of the displacement of the boundary lines, due to prevailing currents and the rough topography of the reef, it was estimated that only

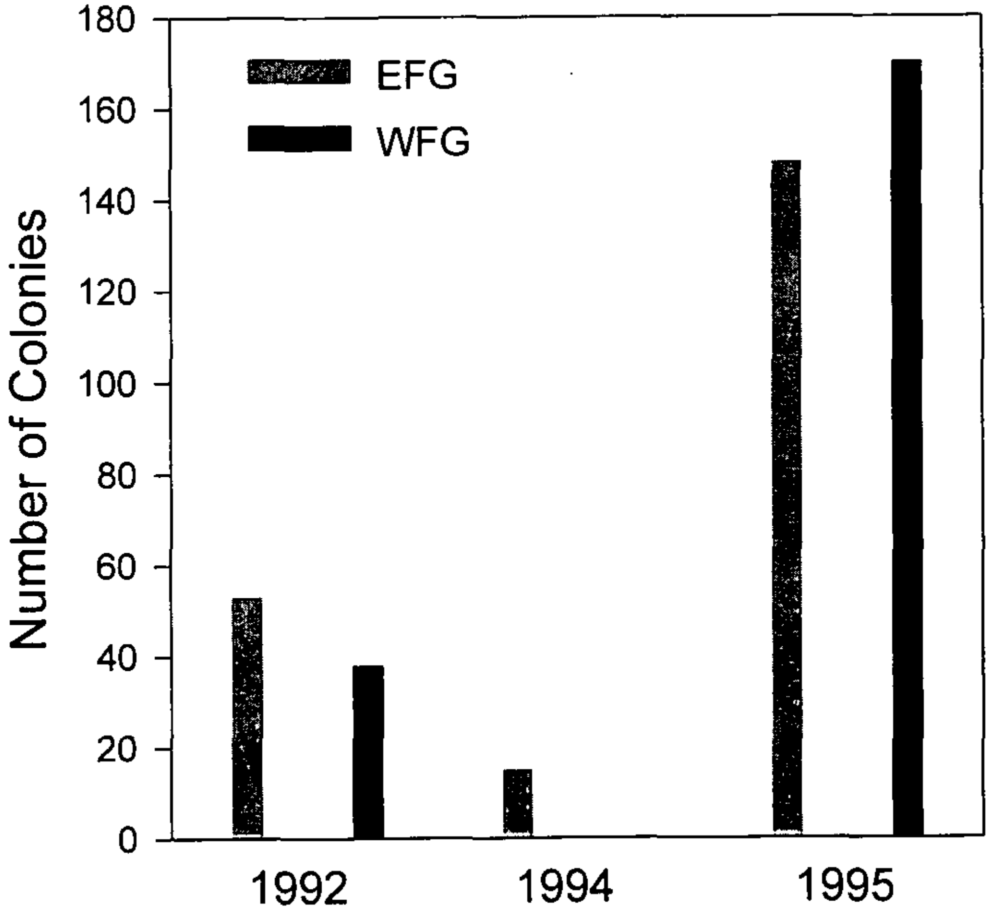


Figure 23. Coral bleaching observed in 8 m^2 quadrats, 1992, 1994, and 1995.

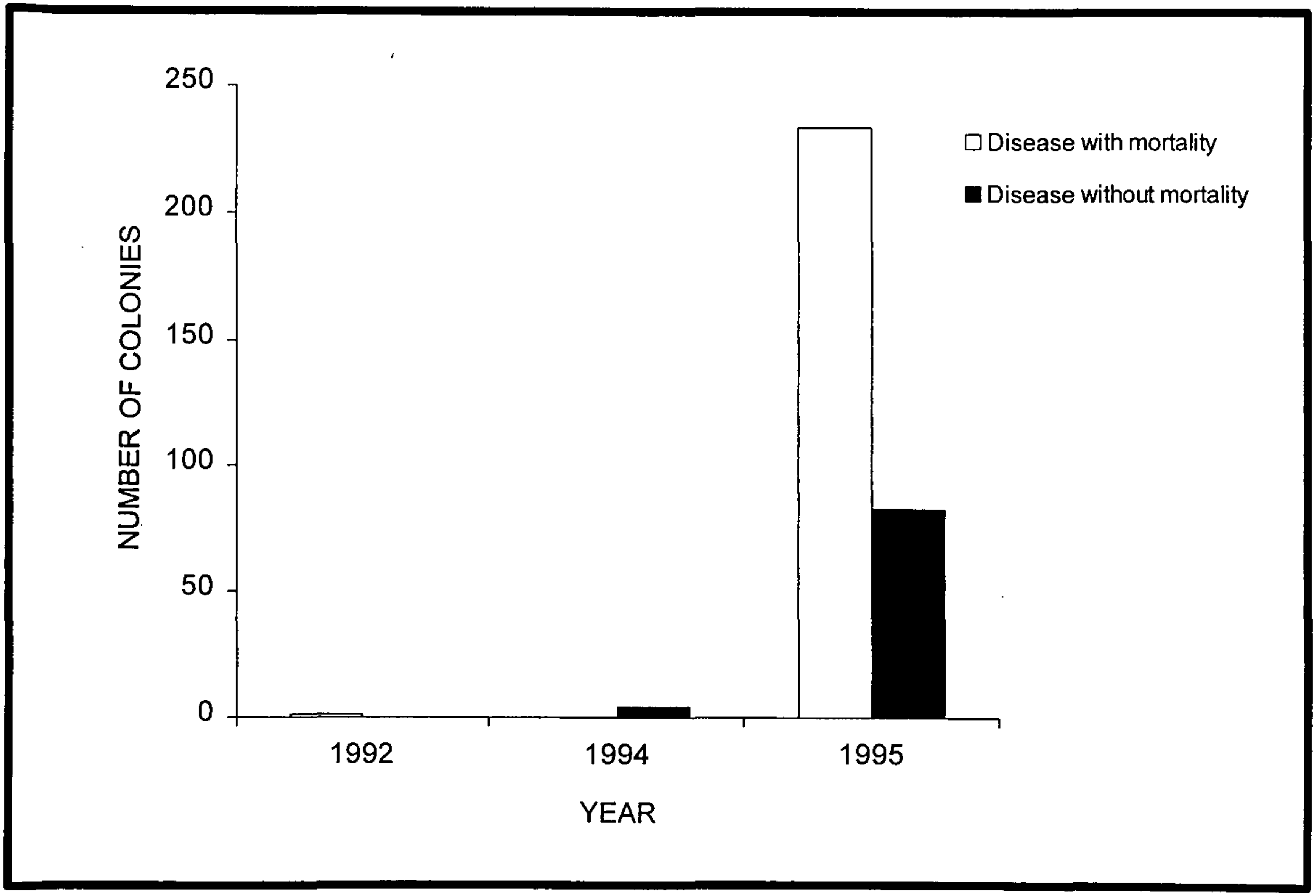


Figure 24. Numbers of colonies in permanent 8 m^2 quadrat stations with disease during the 1992, 1994, and 1995 field efforts. Data from both banks were combined.

20% (10 m [33 ft] at each end) of the 100 m (328 ft) transects were comparable between the 1994 and 1995 field efforts.

3.5.1 East Flower Garden Study Site

The relative condition of the reef observed within these transects was good, with no evidence of widespread coral disease or mechanical damage. Coral bleaching was observed in both 1994 and 1995 transects. During both years, small bleached areas on coral colonies were observed scattered throughout both transects. Some degree of temporal variability in the extent of bleaching observed on individual colonies was noted. **Sections 3.5.1.1** and **3.5.1.2** are descriptions of affected areas observed on the two video transects filmed during 1994 and 1995 field efforts.

3.5.1.1 Transect 1 - Northwest to Northeast Site Boundary Line

- 0 m: A *D. strigosa* colony had a central dead area in 1994; this area had infilling growth and formation of a colony of *P. astreoides* in 1995.

- 1 through 92 m (3.3 through 302 ft): No significant changes in the coral colonies were observed during 1994 and 1995. A bleached *M. alcicornis* colony was similar in appearance in both surveys.

- 93 m (305 ft) : A *D. strigosa* colony with a dead area and a bleached area was observed on a colony of *M. annularis.* These affected areas appeared to be similar in size in both 1994 and 1995.

- 94 through 100 m (308 through 328 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

3.5.1.2 Transect 2 - Northeast to Southeast Site Boundary Line

- 0 through 9 m (0 through 29 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

- 10 m (33 ft): A bleached area was observed on a colony of *M. annularis* in 1994. This affected area appeared to be very reduced in size in 1995.

- 11 through 15 m (36 through 49 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

- 16 m (52 ft): A paling area on a colony of *M. annularis* was observed in 1994. This affected area appeared to increase in size (bleaching) in 1995.

- 17 through 82 m (56 through 269 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

- 83 m (272 ft): A dead area in the center of a *D. strigosa* colony was observed in both 1994 and 1995.

- 84 through 86 m (276 through 282 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

- 87 m (285 ft): A round paling area was observed on top of a colony of *D. strigosa* in 1994. This area appeared to increase in size (bleaching) in 1995.

- 88 through 92 m (289 through 302 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

- 93 m (305 ft): Some bleaching and algae growth was observed on a colony of *M. annularis* in 1994. This affected area appeared to increase in size in 1995.

- 94 through 100 m (308 through 328 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

3.5.2 West Flower Garden Bank Study Site

Similar to the East Flower Garden Bank study site, the general condition of the reef observed within the two video transects was good. Only 10% (5 m at each end of the boundary lines) of the transects were comparable between 1994 and 1995. Scattered bleaching was observed in both transects during both field efforts. From comparable sections of the transects, both increased and decreased bleaching was observed between 1994 and 1995.

3.5.2.1 Transect 1 - Southeast to Southwest Site Boundary Line

- 100 through 95 m (328 through 312 ft): No significant changes in coral colonies were observed during 1994 and 1995.

- 94 through 6 m (308 through 20 ft): Areas were not comparable between 1994 and 1995.

- 5 through 0 m (16 through 0 ft): No significant changes in coral colonies were observed during 1994 and 1995.

3.5.2.2 Transect 2 - Southwest to Northwest Site Boundary Line

- 100 through 14 m (328 through 46 ft): No significant changes in coral colonies were observed during 1994 and 1995.

- 13 m (43 ft): A bleached area was observed on a colony of *M. alcicornis*. This affected area appeared to be similar in appearance and size in 1995.

- 10 m (33 ft): A dead area was observed on top of a colony of *M. alcicornis* in 1994. This affected area increased in size along with complete bleaching of the colony in 1995.

- 8 m (26 ft): A bleached area was observed on top of a colony of *D. strigosa* in 1994. In 1995, the bleached area appeared to moderate to a pale area in 1995.

- 6 m (20 ft): A colony of *M. alcicornis* was completely bleached in 1995.

- 5 through 0 m (16 through 0 ft): No significant changes in the coral colonies were observed during 1994 and 1995.

3.6 ANCILLARY MEASUREMENTS

3.6.1 Water Profiles

Discrete measurements of temperature, salinity, dissolved oxygen, and light made from near surface (1 m [3.3 ft]) and near bottom depths during the 1994 and 1995 field efforts are listed in **Appendix D, Tables D.1** and **D.2**. In 1994, near surface and near bottom temperatures were rather homogeneous and ranged from 28.8°C to 29.3°C. Temperatures were slightly higher in 1995, ranging from 28.9°C to 30.3°C. Salinity and dissolved oxygen measurements were relatively homogeneous during both field efforts.

3.6.2 Recording Thermometers

Water temperature profiles collected by recording thermometers at the East and West Flower Garden Bank study sites are shown in **Figure 25**. Due to equipment failure, data sets were incomplete at both sites. Minimum and maximum temperatures recorded at both study sites are listed in **Table 14**.

Table 14. Minimum and maximum temperatures recorded on the East and West Flower Garden Banks during 1993 - 1995.

Year	Temperatures (°C)			
	East Flower Garden Bank		West Flower Garden Bank	
	Minimum	Maximum	Minimum	Maximum
1993[a]	18.7	29.11	n/a	n/a
1994[b]	19.0	29.5	22.1	28.9
1995[c]	18.1	30.0	18.0	22.3

a = East Flower Garden Bank data collected after 1 September 1993.
b = West Flower Garden Bank data collected after 28 February 1994.
c = West Flower Garden Bank data collected from January-March, 1995.

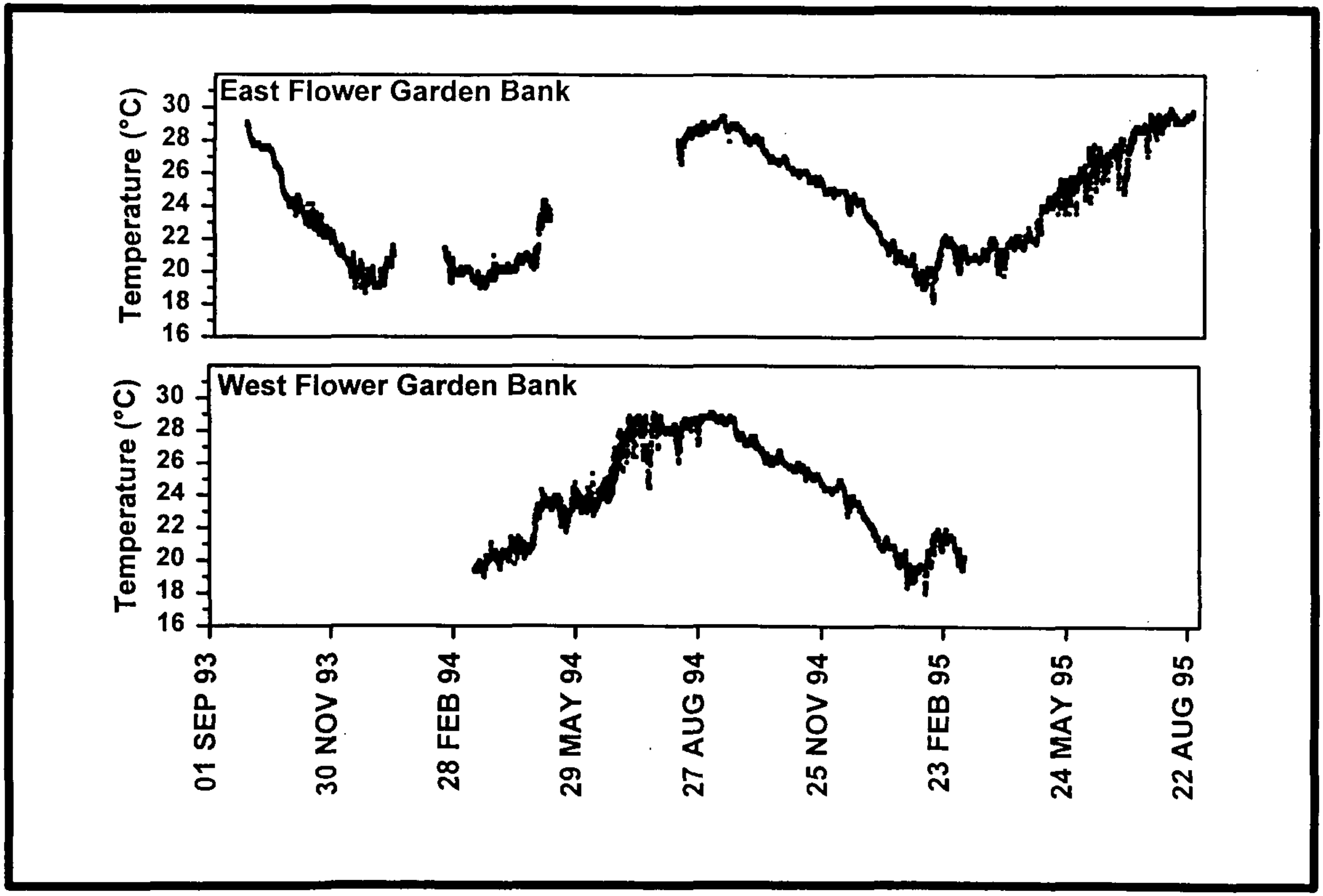


Figure 25. Seafloor temperature data on the Flower Garden Banks, September 1993 to August 1995.

3.6.3 Recording Light Meters

Total daily irradiance (expressed in mol m^{-2} day^{-1}) at the two study sites and the surface reference station (HI 389) during the period from 24 August to 12 November 1995 (Period 1) is graphically shown in **Figure 26** and 17 November 1995 to 2 March 1996 (Period 2) in **Figure 27**. Temporal trends between the 3 m (10 ft) are quite similar, with slightly lower irradiance values collected at the deeper West Flower Garden Bank site. Mean percent transmission during Period 1 was 17.7% (East Flower Garden Bank) and 12.7% (West Flower Garden Bank) (**Figure 28**). Data were not collected from the West Flower Garden Bank site during Period 2 due to equipment failure. Mean percent transmission for the East Flower Garden Bank site during this period was 8.7% (**Figure 29**).

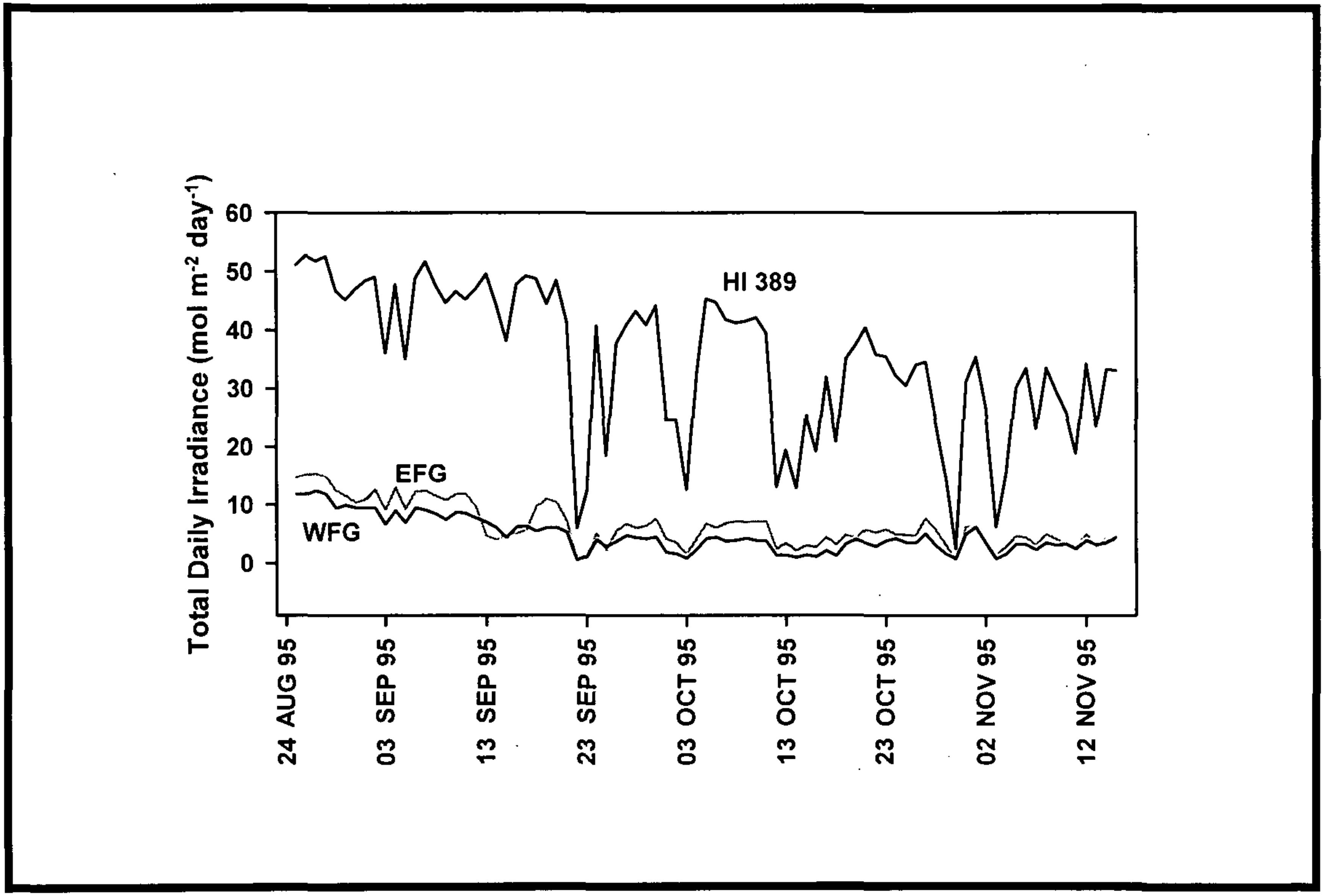


Figure 26. Total daily irradiance on the East and West Flower Garden Banks from August to November 1995 (Period 1).

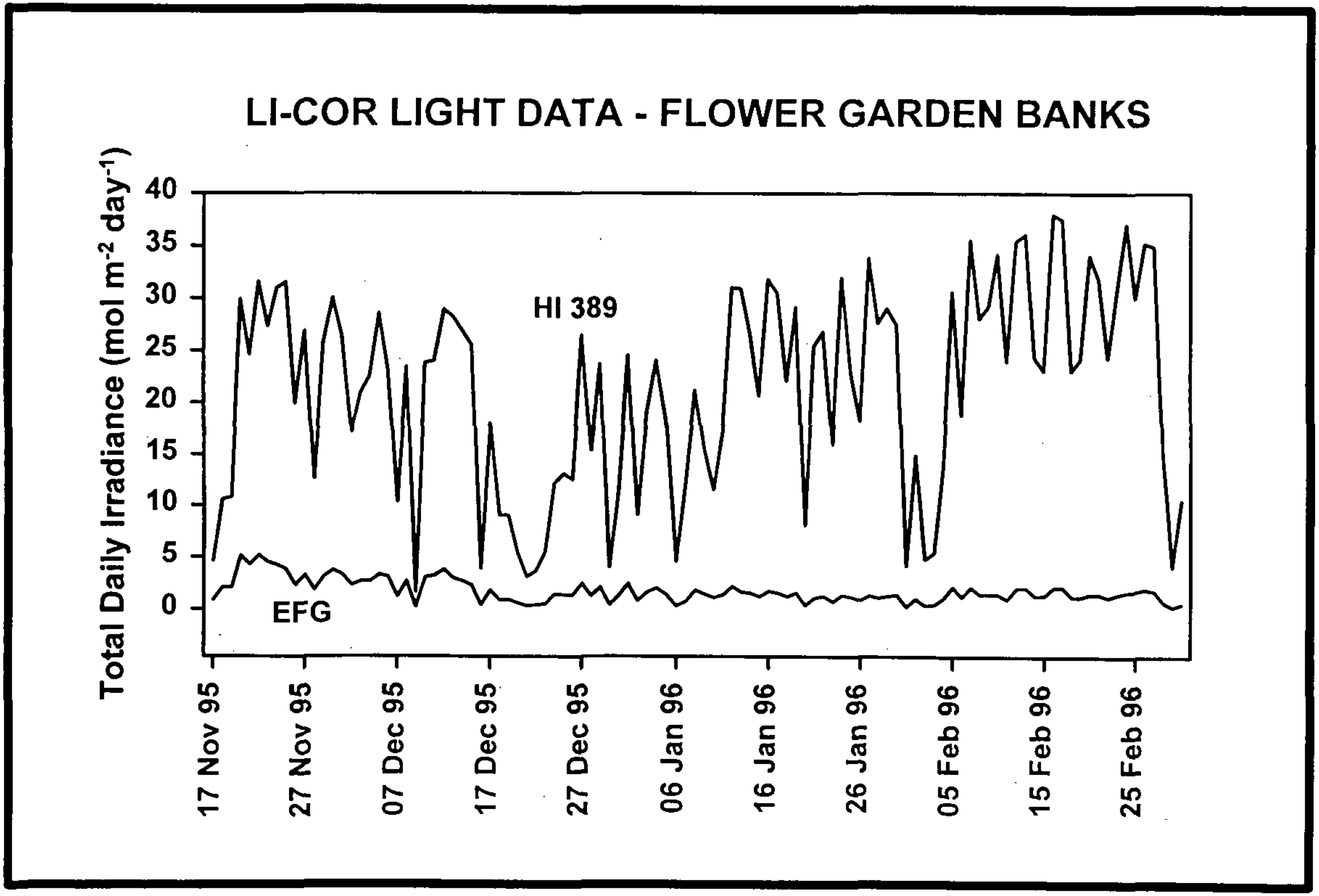


Figure 27. Total daily irradiance on the East Flower Garden Bank from November 1995 to February 1996.

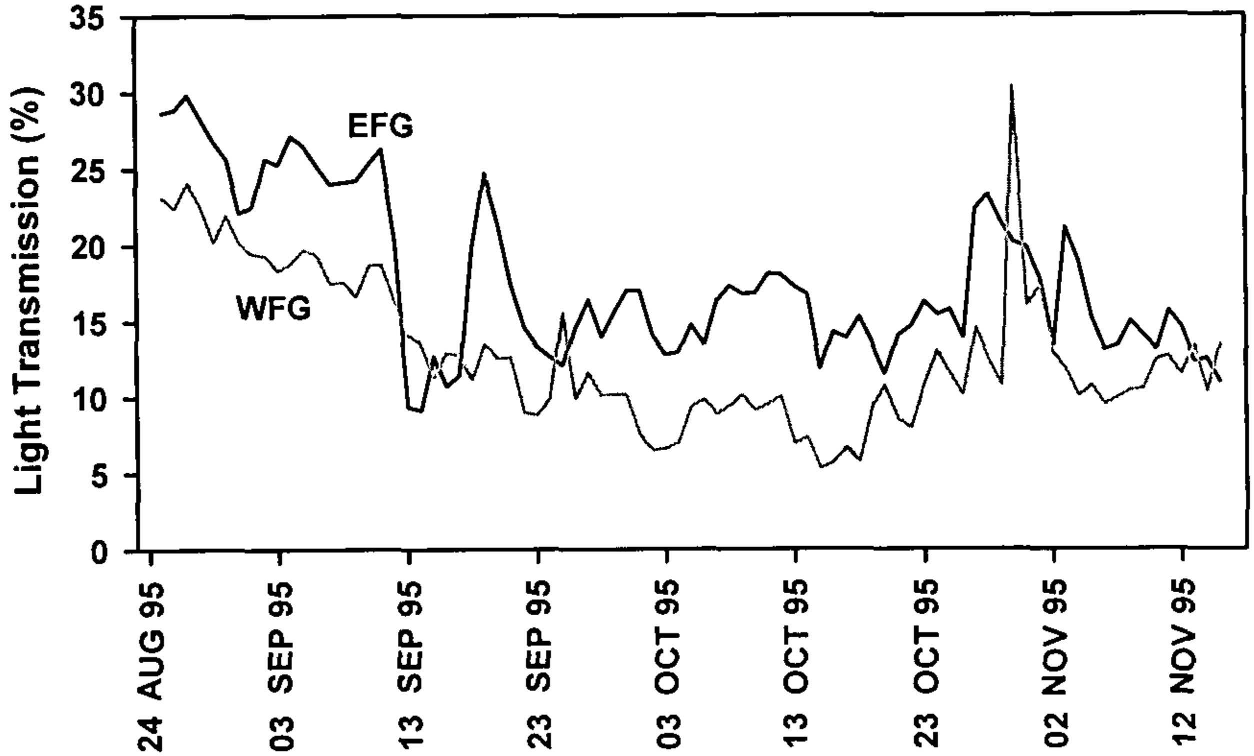


Figure 28. Percent of surface light transmission to the East and West Flower Garden Banks from August - November 1995.

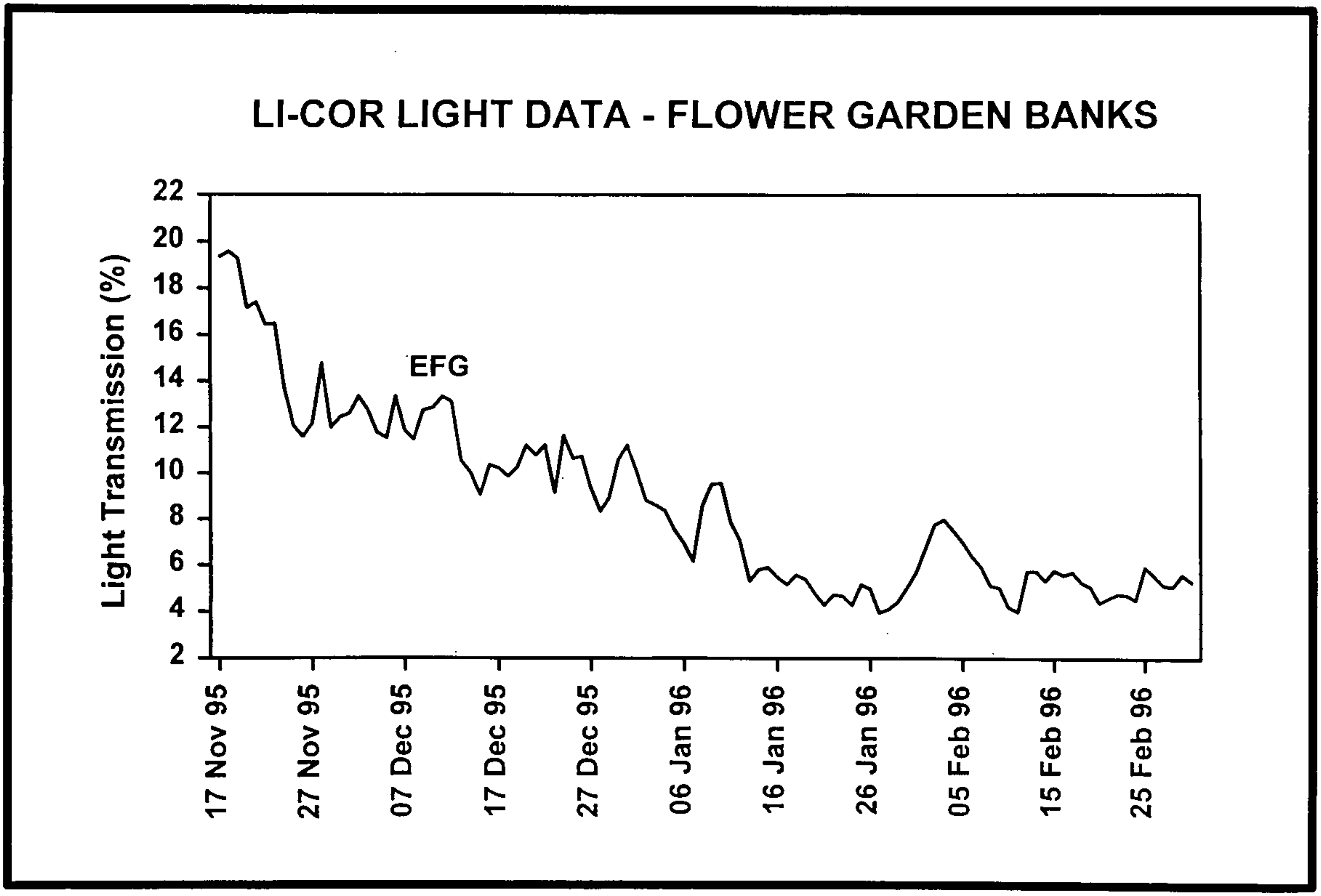


Figure 29. Percent of surface light transmission to the East Flower Garden Bank from November 1995 to February 1996.

4.0 DISCUSSION

The following section includes a discussion of results obtained during this study and comparisons of these results with data collected during previous monitoring studies on the Flower Garden Banks. Specific topics include coral reef community structure and coral growth rates and patterns, loss of coral pigmentation (bleaching), coral diseases, and present environmental threats to the banks from offshore oil and gas activities, and recreational diving. Based on these impact producing factors, a recommendation for a more extensive and effective water quality monitoring plan for the Flower Garden Banks is included.

4.1 CORAL COMMUNITY STRUCTURE - STATUS AND TRENDS

Total percent coral cover, as estimated from stratified random photographic transects at the East and West Flower Garden Banks study sites, was 48.2% and 44.1%, respectively. These estimates are very similar to those from the 1989-1991 monitoring study (46.0% on the East Flower Garden Bank and 46.5% on the West Flower Garden Bank) (Gittings et al., 1992). Significant spatial and temporal differences in percent coral cover were not measured in the 1989-1991 study. In the present study, total percent coral cover was significantly greater at the East Flower Garden Bank compared to the West Flower Garden Bank during 1992, 1994, and 1995. Total coral cover at both banks combined was greater in 1994 and 1995 than in 1992.

Differences in results from the two studies were also observed in comparisons of percent cover among individual coral taxa. For example, from the 1989-1991 study, percent cover estimates of *D. strigosa* and *S. siderea* were greater at the West Flower Garden Bank study site than the East Flower Garden Bank study site, and percent cover estimates of *P. astreoides* and *Agaricia* spp. were greater at the East Flower Garden Bank than the West Flower Garden Bank. From the present study, percent cover estimates of only *P. astreoides* were shown to be significantly greater between banks during various years (**Table 1**). Overall, the pattern of annual differences in percent cover and relative dominance of corals on the Flower Garden Banks do not suggest significant spatial or temporal changes in their population levels.

Coral species diversity and evenness based on colony counts were statistically similar between banks. Mean coral species diversity and evenness were statistically greater in 1992 compared to 1995. Diversity and evenness values collected during the present study were generally similar to those collected during the 1989-1991 study (Gittings et al., 1992). Coral species diversity and evenness based on coral cover were not statistically different between banks and years. Diversity and evenness values collected during the present study were also generally similar to those collected during the 1989-1991 study. These results indicated that there were no temporal trends within the two study sites.

4.2 CORAL GROWTH - STATUS AND TRENDS

Mean accretionary growth rates of *M. annularis*, measured by growth spikes within permanent stations, were very similar between the East and West Flower Garden

Banks (5.7 and 5.5 mm/yr, respectfully) during the 1994-1995 survey period. Mean estimates of accretionary growth rates of this species during the 1989-1991 monitoring study (East Flower Garden, 7 mm/yr; West Flower Garden, 6 mm/yr) fell within the range of values determined during the 1994-1995 survey period.

Accretionary growth rates of *M. annularis*, as measured by linear growth measurements of sectioned coral core samples collected during the 1995 field effort, were comparable between the East and West Flower Garden Banks during the period between 1973 and 1995 (6.8 and 8.1 mm/yr, respectfully). These data also fell with the range of values determined from similar core samples collected during previous studies on the banks (**Table 15**).

Table 15. A comparison of accretionary growth rates of *Montastrea annularis* estimated from sectioned core samples collected during recent studies of the East and West Flower Garden Banks.

Investigator	Growth Period	Mean Growth Rate	# Cores
CSA (present study)	1973-1995	7.4 mm/yr	4
Gittings et al. (1992)	1910-1989	6.6 mm/yr*	4
Kraemer (1982)	1964-1980	7.6 mm/yr	4
Hudson and Robbin (1980)	1910-1979	8.3 mm/yr	12

* Measurements in this study were made by integrating annual growth increments using planimetry rather than the standard linear measurement of single polyps along growth axes.

During the 1994 field effort, it was discovered that the majority of permanent growth stations which had been established during previous studies within both study sites were unsuitable for further use. The rejection of encrusting growth stations was primarily due to the dynamic nature of the coral-reef rock margins. In accretionary growth stations, it was found that the growth spike had loosened within the corallum, the surrounding coral tissue had died around the spike or encrusted over the spike. These examples suggest that there may be a limit to the length of time that permanent stations may be used for studies which involve either direct measurements or repetitive photography.

Since all permanent encrusting growth stations were re-established during the 1994 field effort, encrusting growth data were not available for the 1992-1994 period. In addition, approximately 60% of the photographs of these stations collected during 1992 could not be analyzed. Because of the high variability in these data and their relative small sample size, no statistical comparisons of encrusting growth between the 1991-1992 and 1994-1995 periods were attempted.

Net encrusting growth rates of *M. annularis* during the 1991-1992 period and *D. strigosa* during both 1991-1992 and 1994-1995 survey periods fell within the range of measurements estimated during the 1989-1991 monitoring study for the combined East and West Flower Garden Banks (Gittings et al., 1992). Substantial differences in net growth rates of *D. strigosa* were observed between 1991-1992 and 1994-1995 survey periods at both East and West Flower Garden Banks. Because individual advance and retreat rates were comparable, these data indicate that there were greater numbers of coral borders within these growth stations which demonstrated retreat instead of advance during the 1991-1992 period. These differences may be attributed to sampling error caused by incorrect camera angle at the time of data collection and/or physical problems with the growth station's coral tissue-reef rock border. Net growth rates were positive for *D. strigosa* at the East and West Flower Garden Banks during the 1991-1992 and 1994-1995 survey periods. Net growth rates for *M. annularis* were negative at the East Flower Garden Bank and positive at the West Flower Garden Bank during the 1991-1992 period.

Individual coral advance and retreat rates were comparable between the two survey periods and similar to rates estimated during the 1989-1991 monitoring study (Gittings et al., 1992). From these data, it was found that coral retreat rates often exceeded advance rates. This was also determined in previous studies on the Flower Garden Banks and Florida Keys (Abbott, 1979; Gittings, 1988; Gittings et al., 1992).

Retreat to advance ratios for *D. strigosa* during this study were also comparable to those observed during the 1989-1991 monitoring study. Since all permanent encrusting growth stations were re-established during the 1994 field effort, the similar ratios calculated from the 1994-1995 survey period indicate that encrusting growth patterns for this species at both study sites have remained consistent. Retreat to advance ratios for *M. annularis* were above 1.0 during the 1991-1992 period, indicating net tissue loss. Ratios calculated for this species during the 1989-1991 monitoring study were below 1.0. Since encrusting growth measurements for this species were only required for data collected during 1992, it is not possible to ascertain whether these data are correct or in error as a result of the condition of the permanent stations or incorrect camera angle during the time of data collection.

4.3 CORAL BLEACHING

Coral bleaching is the localized or widespread loss of pigmentation in coral tissues and is considered a stress response to one or more abnormal environmental conditions (**Figure 30**). The loss of pigmentation is due to the loss of symbiotic algae (zooxanthellae) by expulsion or migration of the algae out of the coral tissue, degradation of the algae in situ, or by the loss of pigmentation of the algae itself. Conditions reported to cause bleaching in corals include high/low temperatures, high/low light levels, high levels of ultraviolet radiation, high/low salinity, sub-aerial exposure, excessive sedimentation, storm shock, and anthropogenic sources such as petroleum hydrocarbons and oil dispersants (Hagman and Gittings, 1992). The effects of bleaching on corals may include loss of reproductive activity, significantly reduced growth rate, and tissue loss.

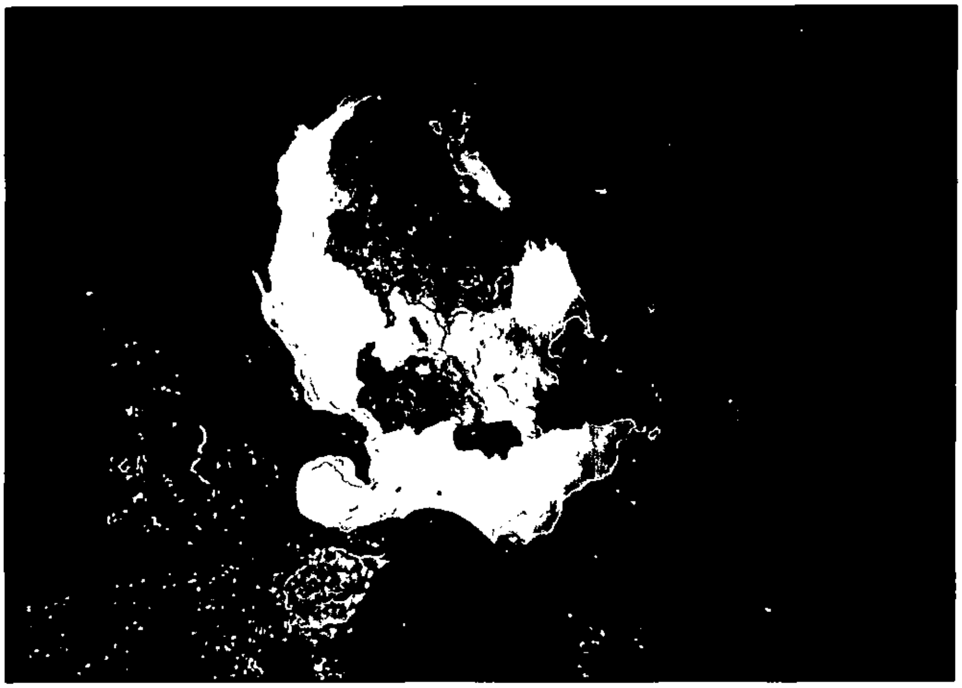


Figure 30. Coral bleaching in *Montastrea annularis* observed during the 1995 monitoring survey at the Flower Garden Banks.

Coral bleaching was observed in repetitive quadrat photographs taken in 1992, 1994, and to a much greater extent during 1995. The extent of bleaching within the study sites was even more pronounced in November 1995, when the two sites were visited to conduct periodic maintenance of recording light meters. Bleaching during these periods coincided with periods of elevated bottom temperatures (above 30°C) which are not uncommon during late summer. As observed in November 1995, the effects of bleaching may appear to persist long after temperatures drop below 30°C. Coral bleaching events have been documented on the Flower Garden Banks on numerous occasions. Data collected during the 1989-1991 monitoring study showed that coral bleaching events occurred following summer water temperature maxima when bottom temperatures exceeded 30°C (Hagman and Gittings, 1992; Gittings et al., 1992). Temperature data collected during the 1994 and 1995 field efforts also showed temperatures in excess of 30°C. This threshold temperature is also considered representative for reefs within the tropical western Atlantic and tropical eastern Pacific. As in historical observations at the Flower Garden Banks, the species most affected by the phenomenon were *M. alcicornis* and *M. cavernosa*. Other bleached species included *M. annularis*, *Agaricia* spp., *P. astreoides*, and *S. siderea*.

Coral mortality associated with coral bleaching at the Flower Garden Banks is low. Colonies that exhibited bleaching usually sustained only minor tissue loss (1992 - 0.5%; 1994 - 0.2%; 1995 - 2.8%). Hagman and Gittings (1992) found that bleaching often recurred in certain colonies in similar patterns or areas within the colonies. Mortality, however, appeared to be no higher in colonies which exhibited recurrent bleaching than in other colonies.

4.4 DISEASES IN REEF BIOTA

Coral "disease", usually resulting in necrosis of the affected coral tissue, remains the most serious natural threat to corals at the Flower Garden Banks. Data collected from repetitive 8 m^2 quadrat stations showed evidence of coral tissue necrosis attributed to "ridge mortality" (Abbott, 1979), a progressive disease that first spreads along the tops of ridges on brain corals, especially *D. strigosa*, and unidentified diseases. No evidence of "black-band" or "white-band" diseases (Antonius, 1981), caused by the spread of bacteria or viruses, were observed on corals during the contract period. This was also noted during the previous monitoring study (Gittings et al., 1992). The percentage of coral colonies observed on repetitive quadrat stations affected by diseases were significantly higher in 1995 than 1994 and 1992. Similarly, numbers of colonies affected in 1995 photographs were also appreciably higher than during the previous monitoring study, which ranged from approximately 10 to 25 colonies per bank per survey. It is not known whether the increased numbers of coral colonies affected by diseases can be attributed to the same environmental conditions on the banks (e.g., elevated water temperatures during the summer and early autumn) which led to significant coral bleaching during this period. Despite the marked increase observed in 1995, the number of colonies exhibiting disease was low when compared to the 3,902 colonies analyzed in quadrat photographs (6.0% occurrence).

4.5 PRESENT ENVIRONMENTAL THREATS

The Flower Garden Banks were officially designated as a National Marine Sanctuary in January 1992. Regulations associated with National Marine Sanctuary status have been designed to protect the banks from many impact producing factors. Despite these regulations, certain environmental threats to the banks remain. These include negative impacts resulting from accidental oil spills and chronic, low-level impacts associated with increases in the numbers of recreational divers who visit the banks each year.

4.5.1 Oil Spills

Oil and gas exploration and production continues in the vicinity of the Flower Garden Banks. Potential sources of petroleum input to the offshore marine environment of the Flower Garden Banks include natural seeps, marine transportation, and offshore operations for the exploration and production of hydrocarbons. Accidents related to offshore operations that result in the release of oil include well blowouts and transportation incidents.

Blowouts are defined as the accidental and uncontrolled release of petroleum hydrocarbons resulting from improperly balanced well pressures. Blowouts can occur during any phase of oil development. Accidental oil spills can also occur during any stage of exploration, development, or production, and can be attributed to many causes in both the oil extraction process and support activities necessary for recovery and transportation of the resource. In addition to crude oil spills, chemical, fuel oil, and other oil-product spills can also occur (USDOI, MMS, 1995). Most field studies concerning the effects of petroleum hydrocarbons on coral reef communities conclude that oil imparts significant negative impacts on shallow-water reef biota (Lewis, 1971; Johannes et al., 1972; Reimer, 1975; Loya, 1976; Birkeland et al., 1976; Rinkevich and Loya, 1977, 1979;

Loya and Rinkevich, 1980; Peters et al., 1981; Bak, 1987; Jackson et al., 1989; Guzma'n and Jackson, 1991; Keller and Jackson, 1991). Laboratory studies show some variability in results with respect to effects of petroleum hydrocarbons and oil dispersants on corals (Lewis, 1971; Reimer, 1975; Birkeland et al., 1976; Elgershuizen and de Kruijf, 1976; Neff, 1979; Peters et al., 1981; Cook and Knap, 1983; LeGore et al., 1983; Dodge et al., 1984; Knap et al., 1985; Wyers et al., 1986). Stress responses exhibited by corals to direct exposure to oil are difficult to assess at sublethal levels, especially when measured in the field (Fucik et al., 1984). In some cases, the effects or impacts are not evident for some length of time subsequent to exposure. In general, corals exposed to oil may reveal elevated susceptibility to mortality, bleaching and infection, and reduced growth rates and fecundity (Brown and Howard, 1985).

Methods, or options, for responding to offshore spills include mechanical containment and collection (e.g., skimmers and sorbents), the use of chemical oil dispersants, and natural removal (involving no cleanup action). Other countermeasures include burning, sinking, gelling, and enhanced biodegradation (bioremediation).

Generally, oil spills at the Flower Garden Banks and their vicinity could originate either at the surface or on the seafloor. Because of the depth of the Flower Garden Banks, surface spills and resultant slicks would produce minimal to negligible impacts to major reef constituents, such as scleractinian corals, other invertebrates, and reef fishes. Surface winds and currents would carry spilled oil or fuel away from the vicinity of the banks in a relatively short time period. Surface slicks could, however, impact marine mammals, sea turtles, seabirds, certain pelagic fish, and floating marine plants. An oil spill occurring during the annual coral reproductive spawning period could also severely impact or entirely destroy the floating spawn. Continental Shelf Associates, Inc. (1992) conducted an analysis to evaluate potential effects of subsurface oil spilled from a proposed pipeline in the vicinity of the Flower Garden Banks. Assumptions were made based upon worst case scenarios from oil spills at three separate locations and depths. Times chosen for the spill to reach the sensitive areas of the Banks were selected to predict reasonable arrival times from corresponding current velocities for the area. A comparison of the estimated water column oil concentrations to acute and chronic toxicity data summarized in the literature indicated that the effects of an untreated oil spill from a pipeline would have minimal to non-existent effects on the sensitive benthic biota of the Flower Garden Banks.

4.5.2 Oil Spill Dispersants

Chemical dispersants are agents designed for reducing the surface tension of spilled oil on the water surface. Surface oil treated with a dispersant mixes within the water column as fine droplets and is dispersed by currents. Rationale for treating spilled oil with chemical dispersants includes the prevention of a concentrated surface slick from moving into biologically sensitive environments; a reduction of direct impacts of surface oil to offshore natural resources such as marine birds, marine mammals, sea turtles, and pelagic fish; or the prevention of surface oil from stranding onshore, thus reducing or eliminating impacts to important coastal habitats, biological communities, or coastal facilities.

The key constituents of oil spill dispersants are one or more surface-active agents termed surfactants (or detergents), which contain both water-compatible and oil-compatible fractions, and in most cases a solvent to reduce viscosity and facilitate application and dispersal. The surfactants are also classed by chemical charge type, including anionic, cationic, nonionic, and zwitterionic (containing both positively and negatively charged groups). Generally, the addition of a dispersant to a slick greatly reduces the natural energy required to break a surface oil slick apart into droplets. The size distribution of dispersed droplets within the water column is an important measure of dispersant effectiveness. Larger droplets tend to resurface, whereas smaller droplets tend to remain suspended in the water column as a result of turbulent diffusion. Suspended droplets are transported horizontally by subsurface currents and can diffuse or be transported into deeper depths. They are eventually removed from the water column by combining with suspended sediment and other abiotic particles, or becoming bound to or ingested by biota such as plankton.

Because of the uncertainties associated with vertical transport of oil and dispersant, the MMS has historically banned their use within the 1-Mile Exclusion Zone of the Flower Garden Banks. This was felt to be an adequate mitigative measure for unknown and unquantifiable impacts of the dispersed oil and dispersant to reef biota on the banks.

Recent studies have reported that dispersed oil was not more toxic to species found in the Gulf of Mexico than undispersed oil (Fucik et al., 1994; National Research Council, 1989). Furthermore, studies on the behavior of dispersed oil within the water column showed that oil was diluted to concentrations of approximately 0.1 ppm at depths of 10 m (33 ft). At this dilution, the plume was not considered acutely toxic (Mackay and Wells, 1983).

These data have led to a decision by the Flower Garden Banks National Marine Sanctuary Office that the application of dispersants may be advantageous to Sanctuary resources in the event of a surface oil spill (S.R. Gittings, 1995, personal communication, NOAA). It is felt that an untreated surface spill would be more harmful than dispersed oil to certain pelagic fish, marine mammals, and sea turtles, due to elevated concentrations of hydrocarbon vapors associated with a surface spill, consumption of spilled oil through respiration or ingestion, and direct oiling of animals and plants. Therefore, the Sanctuary Office approves of the use of oil dispersants on the Flower Garden Banks when deemed appropriate and conducive by the Federal On Scene Coordinator. When applied, all efforts must be made to apply the dispersants in water as deep as possible and as far from the Sanctuary as possible to promote dilution of dispersed oil and to minimize effects on shallow-water biota. Other factors to be considered include prevailing weather and sea state, water temperature, characteristics of the spilled oil, history of the spill, and the risk of spill contact for particular biota. In some cases, the use of oil dispersants may be avoided, such as during mass spawning periods for corals and other species.

4.5.3 Operational Wastes

The major operational wastes of concern generated in quantity by offshore oil and gas exploration and development include produced waters and drilling fluids and cuttings. Other wastes generated during these activities include drilling waste chemicals, fracturing and acidifying fluids, and well completion and workover fluids produced during drilling operations; produced sand, deck drainage, and miscellaneous well fluids generated during production operations; and miscellaneous minor discharges (USDOI, MMS, 1995).

4.5.3.1 Produced Waters

Produced water is defined as the water discharged from the oil and gas extraction process. It is primarily composed of formation waters (those located in the permeable sedimentary rock strata), injection water (when used), and various chemicals added during the oil and water separation process. Because these waters are mixed with petroleum, they contain variable concentrations of petroleum hydrocarbons, Naturally Occurring Radioactive Material (NORM), and other toxic chemicals. Current NPDES permits limit allowable oil and grease levels in produced waters, restrict flow rates, require chronic, static, aquatic toxicity analyses of produced water effluents, and require monitoring of produced water discharges (USDOI, MMS, 1995).

Currently, there are no oil and gas production platforms close enough to the Flower Garden Banks to pose a risk of impact from the discharge of produced waters. Historic monitoring studies of the effects of a platform in the vicinity of the East Flower Garden Bank showed no detectable effects on the shallow, high-diversity reef. Other platforms in the area are in relatively deep water, where strong shelf edge currents serve to disperse discharges. Platforms within the MMS 4-Mile Zone are required to shunt all discharges to within 10 m (33 ft) of the seafloor as a means to further reduce potential impacts.

4.5.3.2 Drilling Fluids and Cuttings

The major source of environmental contamination from drilling operations is the discharge of drilling fluids and cuttings. Drilling fluids are defined as the suspensions of solids and dissolved materials in a water or oil base which are used in rotary drilling to remove cuttings from beneath the drill bit, to control well pressure, to cool and lubricate the drill string, and to seal the well. Drill cuttings are fragments of rock that are generated during drilling operations and carried to the surface with drilling fluid.

According to MMS and National Marine Sanctuary requirements, persons engaged in oil and gas exploration, development, and production in areas outside of the established no-activity zones and within Sanctuary boundaries must shunt all drill cuttings and drilling fluids through a downpipe which terminates at a distance of no more than 10 m (33 ft) from the seafloor (15 CFR, Part 922, Subpart L). Due to these regulations, negative impacts to the Flower Garden Banks resulting from the discharges of offshore oil and gas operational discharges have not been detected and do not pose a threat to the bank's biotic communities.

4.5.4 Recreational Diving

Historically, all recreational diving activities on the Flower Garden Banks were unregulated. Their distance from shore has made visitation to the banks somewhat difficult and costly for recreational divers. Negative impacts on the banks were associated with activities such as the anchoring of boats on the live coral reef, spearfishing, collecting reef biota, and physical damage to living corals by divers themselves.

Historically, the greatest physical impacts to the Flower Garden Banks associated with recreational diving were due to the anchoring of vessels on live coral areas of the banks. Permanent mooring lines with surface floats were installed in 1990 at several locations on the high diversity reef areas of both banks in an effort to reduce anchor damage. Current Sanctuary regulations prohibit anchoring or otherwise mooring a vessel greater than 100 ft in length within the Sanctuary boundaries. Vessels less than 100 ft in length are prohibited from anchoring in areas where mooring lines are available. In areas where there are no mooring lines, these vessels must minimize physical impacts to the reef by reducing the length of chain or wire rope on ground tackle (15 CFR, Part 922, Subpart L).

Activities such as spearfishing, collections of reef biota, and destruction, additions, or modifications to the seabed of the Sanctuary are also prohibited. Despite the protection afforded to the Flower Garden Banks from regulations associated with Sanctuary status, negative impacts resulting from physical contact between recreational divers and sensitive reef biota remain an issue of concern. The Flower Garden Banks have received a marked increase in publicity as a result of their Sanctuary status. This in turn has brought about an increase in the number of recreational divers that visit the banks each year. The use of mooring lines tends to focus the numbers of divers within repetitively used areas and thus increases the probability of localized damage caused by physical contact with corals and other reef biota, and displacement of certain fish species. To date, no studies have been conducted to assess the impacts of recreational diving pressures within the area. Utilization of several alternative mooring line sites for divers during alternate years may serve to reduce localized pressure on recreational dive sites on the banks.

4.6 WATER QUALITY PLAN

The physical location of the Flower Garden Banks poses logistical difficulties for the systematic collection of water quality data. Historical water quality data at the Flower Garden Banks typically involved discrete collections of water samples or hydrocast profiles in different locations on the banks. Because of the continental shelf edge location of the banks, measured concentrations of hydrocarbons, pesticides, and trace metals from historic collections were typically very low to undetectable. These samples have provided baseline data of water quality in the area but do not reveal temporal trends in contaminant concentrations or show evidence of acute events such as spills. Collections of the American thorny oyster (*Spondylus americanus*) were made during the 1970's from the high diversity coral reef and the algal-sponge zones of the banks for determination of biological accumulation of hydrocarbons and trace metals in bivalve tissues. These bivalves are irregularly distributed within these zones and were at times difficult to locate in sufficient numbers for analyses. Typically, collections were made using Texas A&M University's submersible DIAPHUS in the deeper waters of the algal-sponge zone.

The design of a water quality monitoring plan for the Flower Garden Banks will be limited by the budgetary constraints of the monitoring study contract. Field sampling, as specified in the existing contract, is limited to annual visits. Plans involving extensive water quality sampling at this frequency are ineffective and collections of live corals or other reef fauna within the sanctuary boundaries for tissue analyses are not recommended for long-term studies.

The recent installation of recording light meters on the Flower Garden Banks has necessitated quarterly visitation to both study sites in order to download data and service the instruments. This service schedule, conducted from a sport diving charter vessel during a 2-day trip, could also permit cost effective, quarterly collections of water samples for analyses of hydrocarbons, trace metals, pesticides, and nutrients. Uncontaminated water samples could be collected using the charter vessel's inflatable boat during dive operations on each bank. Also, a device for passive in-situ monitoring of organic contaminants in water is available and suitable for use at the Flower Garden Banks. This semi-permeable membrane device (SPMD) consists of a thin film of neutral lipid which is enclosed in thin-walled layflat tubing made of low-density polyethylene. Lipophilic chemicals such as petroleum hydrocarbons permeate the thin wall of the tubing and partition into the lipid where they are concentrated. In this manner the SPMDs function, or uptake contaminants, as an "artificial bivalve" with the exception that accumulated chemicals are not metabolized. These devices have been successfully used in studies within both coastal and offshore waters (Prest et al., 1992; Huckins et al., 1993; Peven et al., 1996). For application at the Flower Garden Banks, a single SPMD would be contained within a fabricated stainless steel rack at each study site. The racks would be affixed to the reef rock with masonry bolts in proximity to the recording light meters. The SPMD's could be collected and replaced at the same time that the recording light meters are serviced, and thus provide quarterly qualitative records of organic hydrocarbons (and pesticides) present on the Flower Garden Banks. Collected water samples would provide single point collection data of concentrations of hydrocarbons and pesticides to compare to those collected by the SPMD's. A one year feasibility study of the SPMD's on the banks would determine their practicality and provide a year of uninterrupted baseline data.

5.0 CONCLUSIONS

The results of the analysis of the random transect data collected in 1992, 1994, and 1995 do not suggest significant long-term changes in coral cover or diversity parameters. Overall estimates of total coral cover, cover of individual species, relative dominance of individual coral species, and species diversity and evenness are generally comparable with previous studies within the same study sites. Specific differences in the estimates made during the present study and previous studies on the banks appear to result from spatial variability in coral communities and are not considered to represent trends or deterioration of habitat quality.

Estimates of the growth rates of *M. annularis* and *D. strigosa* made on the Flower Garden Banks indicate favorable conditions for both accretionary and encrusting growth during the study period. Accretionary growth rates of *M. annularis* during 1994-1995 were comparable with estimates from previous studies. The poor physical condition of all permanent growth stations located during the 1994 field effort necessitated their re-establishment during this period. Growth estimates, therefore, are only available for the 1991-1992 and 1994-1995 periods. In addition, a large percentage (over 60%) of photographic data from permanent growth stations collected during the 1992 field effort were not analyzed because of the condition of individual stations, sampling error caused by inconsistent camera angle, and inconsistent species selection. As a result, statistical comparisons of encrusting growth between data representative of the 1991-1992 period and the 1994-1995 period were not made. Overall, these observations indicate that permanent growth stations typically have a finite useable lifespan and must be abandoned and re-established as necessary to maximize accuracy of growth rate estimates. Encrusting growth estimates made from re-established stations during the 1994-1995 period were comparable to those of previous studies, and showed relatively high rates of tissue advance and net tissue gain during this period.

Coral growth was also clearly identifiable in 8 m^2 photographic quadrat stations during the study period. The number of observations of coral growth far exceeded observations of retreat at both study sites during this period.

Coral bleaching was observed on 8 m^2 photographic quadrats collected during 1992, 1994, and 1995. The extent of bleaching observed at the two study sites was most pronounced during the 1995 field effort. Minor coral bleaching events have been documented on the Flower Garden Banks on numerous occasions. Both historic and present documentation of bleaching events appear to coincide with periods of elevated sea water temperatures of 30°C or above, which may be common during late summer. Susceptibility to bleaching in corals also appears to be somewhat species-specific and perhaps colony-specific. Data from 8 m^2 photographic quadrats suggest that coral bleaching may not necessarily result in coral tissue mortality. Colonies that exhibited bleaching during the present study usually sustained only minor tissue loss (1992, 0.5%; 1994, 0.2%; 1995, 2.8%).

Potential threats to the Flower Garden Banks associated with offshore petroleum hydrocarbon exploration and development remain. These include oil spills from tankers, platforms, and pipelines, associated spill clean-up efforts, and chronic effects from the discharge of produced waters and drilling fluids. Accidents involving the release of oil in the vicinity of the Flower Garden Banks represent the most serious threat. Presently, it is the opinion of the Flower Garden National Marine Sanctuary management that surface oil spills in the vicinity of the banks should be, under proper conditions, treated with oil dispersants to promote the dilution of surface oil in order to mitigate harmful effects to certain pelagic fish, marine mammals, and sea turtles. Public awareness of the Flower Garden Banks, associated with their designation as a National Marine Sanctuary, has increased the public demand for visitation and access by means of recreational diving. Present threats associated with recreational diving on the Flower Garden Banks include small boat anchor damage to corals and other reef biota, and physical damage to the coral community by divers themselves. The maintenance of mooring buoys for small vessels may reduce overall anchor damage to the banks but tends to focus the number of divers within specific locations. Alternation of mooring buoy availability may be the best solution for minimizing damage associated with recreational diving.

6.0 LITERATURE CITED

Abbott, R.E. 1975. The faunal composition of the algal-sponge zone of the Flower Garden Banks, northwest Gulf of Mexico. M.S. thesis, Texas A&M University, Department of Oceanography. 205 pp.

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 University, College Station, TX. 154 pp.

Antonius, A. 1981. The "band" diseases in coral reefs. Proceedings - 4th International Coral Reef Symposium. (Manila) 2:7-14.

Bak, R.P.M. 1987. Effects of chronic oil pollution on a Caribbean coral reef. Mar. Poll. Bull. 18:534-539.

Birkeland, C., A.A. Reimer, and J.R. Young. 1976. Survey of marine communities in Panama and experiments with oil. EPA 60013-76-028.

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

Bright, T.J. and R. Rezak. 1976. A biological and geological reconnaissance of selected topographical features on the Texas continental shelf. Final Report to the U.S. Department of the Interior, Bureau of Land Management. Contract No. 08550-CT5-4. 377 pp.

Bright, T.J., S.T. Viada, C. Combs, G. Dennis, E. Powell, and G. Denoux. 1981. East Flower Garden Bank monitoring study - Vol. III, pp. 27-35. In: R. Rezak and T.J. Bright (eds.), Northern Gulf of Mexico Topographic Features Study. Final Report to the U.S. Department of the Interior, Bureau of Land Management. Gulf of Mexico OCS Office, New Orleans, LA. Contract No. AA551-CT8-35. Texas A&M Department of Oceanography Technical Report 81-2-T.

Bright, T.J., C. Combs, G. Kraemer, and G. Minnery. 1982. Biological monitoring at the Flower Garden Banks, pp. 88-102. In: Environmental studies at the Flower Gardens and selected banks: Northwestern Gulf of Mexico, 1979-1981. Final Report to the U.S. Department of the Interior, Minerals Management Service. Gulf of Mexico OCS Office, New Orleans, LA. Contract No. AA851-CT0-25.

Bright, T.J., G.P. Kraemer, G.A. Minnery, and S.T. Viada. 1984. Hermatypes of the Flower Garden Banks, northwestern Gulf of Mexico: A comparison to other Western Atlantic Reefs. Bull. Mar. Sci. 34(3):461-476.

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

Bright, T.J., S.R. Gittings, and R. Zingula. 1991. Occurrence of Atlantic reef corals on offshore platforms in the northwestern Gulf of Mexico. Northeast Gulf Sci. 12(1):55-60.

Brown, B.E. and L.S. Howard. 1985. Assessing the effects of "stress" on reef corals. Adv. Mar. Biol. 22:1-63.

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

Continental Shelf Associates, Inc. 1985. Environmental monitoring program for Platform "A", Lease OCS-G-2759, High Island Area, South Extension, East Addition, Block A-389, near the East Flower Garden Bank. Report to Mobil Producing Texas and New Mexico, Inc., The Woodlands, TX. 353 pp. + app.

Continental Shelf Associates, Inc. 1990. Environmental monitoring program for Exploratory Well #1, Lease OCS-G-6264, High Island Area, South Extension, East Addition, Block A-401, near the West Flower Garden Bank. Report to Union Oil Company of California, Houston, TX. 35 pp. + app.

Continental Shelf Associates, Inc. 1992. Analysis of potential effects of oil spilled from Texaco's proposed pipeline on the biota of the East Flower Garden, West Flower Garden, Rankin, and MacNeil Banks. Report to Texaco, New Orleans, LA. 27 pp.

Cook, C.B. and A.H. Knap. 1983. Effects of crude oil and chemical dispersant on photosynthesis in the brain coral *Diploria strigosa*. Mar. Biol. 78:21-27.

Dodge, R.E., S.C. Wyers, H.R. Frith, A.H. Knap, S.R. Smith, and T.D. Sleeter. 1984. The effects of oil and oil dispersants on the skeletal growth of the hermatypic coral Diploria strigosa. Coral Reefs 3:191-198.

Elgershuizen, J.H.B.W. and H.A.M. de Kruijf. 1976. Toxicity of crude oils and dispersant to the stony coral *Madracis mirabilis*. Mar. Poll. Bull. 7(2):22-25.

Fucik, K.W., T.J. Bright, and K.S. Goodman. 1984. Measurements of damage, recovery, and rehabilitation of coral reefs exposed to oil, pp. 115-134. In: J. Cairns, Jr. and A.L. Buikema, Jr. (eds.), Restoration of Habitats Impacted by Oil Spills. Butterworth Publishers, Boston. 182 pp.

Fucik, K.W., K.A. Carr, and B.J. Balcom. 1994. Dispersed oil toxicity tests with biological species indigenous to the Gulf of Mexico. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, MMS 94-0021. 97 pp. + app.

Gittings, S.R. 1988. The recovery process in a mechanically damaged coral reef community. Ph.D. dissertation. Texas A&M University, Department of Oceanography, College Station, TX. 228 pp.

Gittings, S.R. and T.J. Bright. 1986. Assessment of coral recovery following an incident of anchoring damage at the East Flower Garden Bank, northwest Gulf of Mexico. Final Report to NOAA National Marine Sanctuaries Division. Contract No. NA85AA-H-CZ015. 45 pp.

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, LA. OCS Study MMS 92-0006. 206 pp.

Gittings, S.R., T.J. Bright, and D.K. Hagman. 1993. Protection and monitoring of reefs on the Flower Garden Banks, 1972-1992, pp. F29-F35. Proc. Coll. on Global Aspects of Coral Reefs: Health Hazards and History. Miami, FL.

Guzma'n, H.M. and J.B.C. Jackson. 1991. Short-term ecological consequences of a major oil spill on Panamanian subtidal reef corals. Coral Reefs 10:1-12.

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

Holland, B.S. 1991. Mitochondrial DNA sequence variation of the 16s RRNA gene from five western Atlantic populations of the coral *Montastrea annularis*. M.S. thesis, Texas A&M University. 56 pp.

Huckins, J.N., G.K. Manuweera, J.D. Petty, D. Mackay, and J.A. Lebo. 1993. Lipid-containing semipermeable membrane devices for monitoring organic contaminants in water. Environ. Sci. Technol. 27:2,489-2,496.

Hudson, J.H. 1981. Growth rates of Montastrea 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, *Montastrea annularis*, pp. 455-470. In: R.A. Geyer (ed.), Marine Environmental Pollution, Volume 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.

Jackson, J.B.C., J.D. Cubit, B.D. Keller, V. Batista, K. Burns, H.M. Caffey, R.L. Caldwell, S.D. Garrity, C.D. Getter, C. Gonzalez, H.M. Guzma'n, K.W. Kaufmann, A.H. Knap, S.C. Levings, M.J. Marshall, R. Steger, R.C. Thompson, and E. Weil. 1989. Ecological effects of a major oil spill on Panamanian coastal marine communities. Science 243:37-44.

Johannes, R.E., J. Maragos, and S.L. Coles. 1972. Oil damages corals exposed to air. Mar. Poll. Bull. 3:29-30.

Keller, B.D. and J.B.C. Jackson (eds.). 1991. Long-term assessment of the oil spill at Bahia Las Minas, Panama. Interim Report. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. OCS Study MMS-90-0031. 450 pp.

Knap, A.H., S.C. Wyers, R.E. Dodge, T.D. Sleeter, H.R. Frith, S.R. Smith, and C.B. Cook. 1985. The effects of chemically and physically dispersed oil on the brain coral *Diploria strigosa*, pp. 547-551. In: Proceedings - 1985 Oil Spill Conference, American Petroleum Institute, Washington, DC.

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

LeGore, R.S., D.S. Marszalek, J.E. Hoffman, and J.E. Cuddebak. 1983. A field experiment to assess the impact of chemically dispersed oil on Arabian Gulf corals. Society of Petroleum Engineers 11444:51-60.

Lewis, J.B. 1971. Effects of crude oil and oil spill dispersants on reef corals. Mar. Poll. Bull. 2:59-62.

Loya, Y. 1976. Recolonization of Red Sea corals affected by natural catastrophes and man-made perturbations. Ecology 57:278-289.

Loya, Y. and B. Rinkevich. 1980. Effects of oil pollution on coral reef communities. Mar. Ecol. Prog. Ser. Vol. 3:167-180.

Mackay, D. and P.G. Wells. 1983. Effectiveness, behavior, and toxicity of (oil spill) dispersants, pp. 65-71. In: Proceedings - 1983 Oil Spill Conference, American Petroleum Institute, Washington, DC.

McGrail, D., 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: Rezak, R. et al. (eds.), Environmental Studies at the Flower Gardens and Selected Banks: Northwestern Gulf of Mexico, 1979-1981. Texas A&M Research Foundation Technical Report No. 82-7-T.

National Research Council. 1989. Using Oil Spill Dispersant on the Sea. National Academy Press, Washington, DC. 335 pp.

Neff, J.M. 1979. Polycyclic Aromatic Hydrocarbons in the Aquatic Environment: Sources, Fates, and Biological Effects. Applied Science Publishers. Essex, England.

Nettleton, L.L. 1957. Gravity survey over a Gulf coast continental shelf mount. Geophys. 22:630.

Peters, E.C., P.A. Meyers, P.P. Yevich, and N.J. Blake. 1981. Bioaccumulation and histopathological effects of oil on a stony coral. Mar. Poll. Bull. 12(10):333-339.

Peven, C.S., A.D. Uhler, and F.J. Querzoli. 1996. Caged mussels and semi-permeable membrane devices as indicators of organic contaminant uptake in Dorchester and Duxbury Bays, Massachusetts. Environ. Tox. and Chem. 15(2): 144-149.

Prest, H.F., W.M. Jarman, S.A. Burns, T. Weismuller, M. Martin, and J.N. Huckins. 1992. Passive water sampling via semipermeable membrane devices (SPMDS) in concert with bivalves in the Sacramento/San Joaquin River delta. Chemosphere 25(12):1,811-1,823.

Pulley, T.E. 1963. Texas to the tropics. Houston Geol. Soc. Bull. 6:13-19.

Reimer, A.A. 1975. Effects of crude oil on corals. Mar. Poll. Bull. 6:39-43.

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., S.R. Gittings, and T.J. Bright. 1990. Biotic assemblages and ecological controls on reefs and banks of the northwest Gulf of Mexico. Amer. Zool. 30:23-35.

Rinkevich, B. and Y. Loya. 1977. Harmful effects of chronic oil pollution on a Red Sea coral population. Proceedings - 3rd International Coral Reef Symposium, Miami, FL 2:585-591.

Rinkevich, B. and Y. Loya. 1979. Laboratory experiments on the effects of crude oil on the Red Sea coral *Stylophora pistillata*. Mar. Poll. Bull. 10:328-330.

Stetson, H.C. 1953. The sediments of the western Gulf of Mexico, Part I - The continental terraces of the western Gulf of Mexico: Its surface sediments, origin, and development. Papers in Physical Oceanography and Meteorology, M.I.T./W.H.O.I. 12(4):1-45.

U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region. 1995. Final Environmental Impact Statement for Proposed Central Gulf of Mexico OCS Lease Sale 157 (March 1996) and Proposed Western Gulf of Mexico OCS Lease Sale 161 (August 1996). OCS EIS/EA MMS 95-0058. 2 vol., 832 pp. + app.

Wyers, S.C., H.R. Frith, R.E. Dodge, S.R. Smith, A.H. Knap, and T.D. Sleeter. 1986. Behavioral effects of chemically dispersed oil and subsequent recovery in *Diploria strigosa*. Mar. Ecol. 7(1):23-42.

APPENDICES

APPENDIX A

STRATIFIED RANDOM TRANSECT DATA

Table A.1. Mean percent cover estimates of corals, reef rock, conspicuous biota, and sand on random transects sampled during 1992, 1994, and 1995 field efforts at the East and West Flower Garden Banks study sites.

Analyzed Reef Component	Percent Cover							
	East Flower Garden Bank				West Flower Garden Bank			
	1992	1994	1995	All	1992	1994	1995	All
Montastrea annularis	24.12	26.93	35.65	28.30	23.02	24.95	31.00	25.89
Diploria strigosa	4.69	8.92	7.92	6.86	6.15	10.15	6.66	7.52
Porites astreoides	4.57	3.89	2.71	3.83	1.49	2.55	2.44	2.09
Montastrea cavernosa	1.49	4.80	3.20	2.96	0.87	3.15	2.33	1.98
Colpophyllia spp.	2.14	1.59	3.78	2.46	3.11	2.82	0.97	2.41
Millepora spp.	1.30	2.49	1.66	1.75	0.80	1.91	1.87	1.44
Agaricia spp.	0.50	0.89	0.32	0.57	0.36	0.42	0.46	0.40
Stephanocoenia michelini	0.52	0.97	0.14	0.54	0.63	0.37	0.75	0.59
Madracis decactis	0.53	0.37	0.05	0.34	0.19	0.25	0.34	0.25
Siderastrea siderea	0.22	0.07	1.07	0.42	0.39	0.00	4.13	1.34
Mussa angulosa	0.05	0.17	0.08	0.09	0.16	0.14	0.18	0.16
Scolymia cubensis	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01
Porites furcata	0.00	0.07	0.01	0.02	0.01	0.02	0.00	0.01
Madracis mirabilis	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
TOTAL CORAL	40.15	51.17	56.61	48.16	37.20	46.74	51.14	44.10
Reefrock	54.46	47.31	42.15	47.97	56.56	51.08	45.85	51.16
Leafy algae	4.78	0.29	0.57	1.88	4.45	0.42	2.70	2.52
Sponges	0.74	1.23	0.67	0.88	1.53	1.58	0.27	1.13
Sand	0.00	0.00	0.00	0.00	0.26	0.17	0.03	0.15

Table A.2. Relative dominance estimates, expressed in percent, of all coral taxa on *random transects sampled during 1992, 1994, and 1995 field efforts at the* East and West Flower Garden Banks study sites.

Taxa	Relative Dominance							
	East Flower Garden Bank				West Flower Garden Bank			
	1992	1994	1995	All	1992	1994	1995	All
Montastrea annularis	57.33	51.69	61.36	56.86	61.93	53.96	60.05	58.95
Diploria strigosa	12.06	18.17	14.81	14.64	16.15	21.27	12.68	16.72
Porites astreoides	12.77	8.37	5.14	9.26	4.07	6.13	4.81	4.91
Montastrea cavernosa	3.38	8.63	5.82	5.62	2.44	5.89	5.09	4.26
Colpophyllia spp.	6.41	2.94	6.65	5.47	8.12	5.71	1.92	5.61
Millepora spp.	3.23	4.81	3.10	3.65	2.38	4.09	4.01	3.37
Agaricia spp.	1.38	1.85	0.58	1.28	0.87	1.06	0.92	0.94
Stephanocoenia michelini	1.41	2.04	0.24	1.25	1.97	0.85	1.60	1.52
Madracis decactis	1.41	0.76	0.09	0.84	0.55	0.64	0.63	0.60
Siderastrea siderea	0.47	0.13	2.02	0.82	1.04	0.00	7.90	2.68
Mussa angulosa	0.14	0.39	0.13	0.21	0.44	0.34	0.39	0.39
Scolymia cubensis	0.02	0.28	0.02	0.02	0.02	0.01	0.01	0.01
Porites furcata	0.00	0.17	0.02	0.06	0.02	0.05	0.00	0.02
Madracis mirabilis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A.3. Species diversity (H') and species evenness (E) of corals observed on random transects collected during 1992, 1994, and 1995 field efforts at the East and West Flower Garden Banks study sites. Shannon-Weaver diversity and species evenness estimates are based on both colony counts and percent cover.

Bank	Year	H' (count)	E (count)	H' (cover)	E (cover)
EFG	1992	1.835	0.861	1.216	0.568
WFG	1992	1.866	0.844	1.113	0.501
EFG	1994	1.841	0.839	1.340	0.608
WFG	1994	1.758	0.812	1.200	0.554
EFG	1995	1.672	0.815	1.118	0.538
WFG	1995	1.724	0.829	1.136	0.540
EFG	All	1.789	0.841	1.224	0.571
WFG	All	1.792	0.830	1.146	0.529

APPENDIX B

ACCRETIONARY GROWTH DATA

Table B.1. *Montastrea annularis* accretionary growth data (spike length in mm) and growth rates (mm/yr) measured on growth spikes at the East Flower Garden Bank study site. Data are shown only for stations and time periods that were used for analysis of growth rates.

CSA Station Number	1994		1995	
	Length (mm)	Growth (mm/yr)	Length (mm)	Growth (mm/yr)
1	31		28.5	2.5
2	80		*	
3	75		70	5
4	71		63	8
5	35		30	5
6	24		19	5
7	35		29	6
8	38		31	7
9	33		26	7
10	30		22	8
11	33		25	8
12	27		22	5
13	55		*	
14	33		26	7
15	34		28	6
16	30		30	0
17	34		27	7
18	25		20	5
19	27		20	7
20	26		21	5
21				
22				
Mean Growth (mm/yr)			5.7	
Standard Deviation			0.5	
Number			18	

* Stations destroyed between 1994-1995 field efforts.

Table B.2. *Montastrea annularis* accretionary growth data (spike length in mm) and growth rates (mm/yr) measured on growth spikes at the West Flower Garden Bank study site. Data are shown only for stations and time periods that were used for analysis of growth rates. Shaded areas were not used in calculation of accretionary growth due to incorrect field measurement.

CSA Station Number	1994		1995	
	Length (mm)	Growth (mm/yr)	Length (mm)	Growth (mm/yr)
1	32			
2	24.5		15.5	9
3	27		21	6
4	75		68	7
5	27		23	4
6	27		23	4
7	31		26	5
8	27		21	6
9	30		28	2
10	31		27	4
11	30.5			
12	29.5		24	5.5
13	28		19	9
14	31			
15	30		23.5	6.5
16	28			
17	31		26	5
18	25		20	5
19	30			
20	35		30	5
21			24.5	
22			21	
Mean Growth (mm/yr)			5.5	
Standard Deviation			0.5	
Number			15	

Table B.3. Accretionary growth rates of *Montastrea annularis* measured from cores collected at the East and West Flower Garden Banks.

Years	Annual Growth Rates (mm)			
	EFG(1)	EFG(2)	WFG(1)	WFG(2)
1994-1995	10.0	6.0	8.3	8.7
1993-1994	8.4	6.4	7.4	7.0
1992-1993	10.7	6.8	8.9	8.7
1991-1992	8.1	6.8	7.7	7.5
1990-1991	7.5	5.9	9.4	8.9
1989-1990	7.1	7.2	7.3	8.9
1988-1989	7.1	6.9	7.7	11.1
1987-1988	6.9	7.0	7.2	12.1
1986-1987	7.2	6.0	9.3	8.6
1985-1986	7.5	5.5	7.8	9.3
1984-1985	10.4	6.2	7.4	11.7
1983-1984	6.8	5.3	6.1	6.9
1982-1983	6.9	7.9	5.7	8.4
1981-1982	4.2	5.8	8.6	8.1
1980-1981	4.9	5.9	7.7	7.5
1979-1980	4.5	5.4	7.7	6.9
1978-1979	4.4	5.7		7.5
1977-1978	6.8	7.4		6.6
1976-1977		6.8		6.8
1975-1976				8.7
1974-1975				8.1
1973-1974				6.8

EFG(1): Collected 8/24/95 East Flower Gardens Bank.
EFG(2): Collected 8/24/95 East Flower Gardens Bank.
WFG(1): Collected 8/22/95 West Flower Gardens Bank.
WFG(2): Collected 8/22/95 West Flower Gardens Bank.

APPENDIX C

REPETITIVE QUADRAT DATA

Table C.1. Repetitive 8 m^2 stations, East Flower Garden Bank, 1992.

Change	Cause	Occurrence	Mortality
Growth	--	1,202	--
Retreat, Bleaching, and Disease	*unknown cause*	80	80
	algae mediated	382	382
	algae/sediment	5	5
	new disease	0	0
	bleaching	53	9

Table C.2. Repetitive 8 m^2 stations, West Flower Garden Bank, 1992.

Change	Cause	Occurrence	Mortality
Growth	--	955	--
Retreat, Bleaching, and Disease	unknown cause	5	5
	algae mediated	310	310
	algae/sediment	23	23
	new disease	1	1
	bleaching	38	9

Table C.3. Repetitive 8 m^2 stations, East Flower Garden Bank, 1994.

Change	Cause	Occurrence	Mortality
Growth	--	995	--
Retreat, Bleaching, and Disease	unknown cause	78	78
	algae mediated	330	330
	algae/sediment	28	28
	new disease	0	0
	bleaching	16	15

Table C.4. Repetitive 8 m^2 stations, West Flower Garden Bank, 1994.

Change	Cause	Occurrence	Mortality
Growth	--	918	--
Retreat, Bleaching, and Disease	unknown cause	69	69
	algae mediated	399	399
	algae/sediment	0	0
	new disease	0	0
	bleaching	8	0

Table C.5. Repetitive 8 m^2 stations, East Flower Garden Bank, 1995.

Change	Cause	Occurrence	Mortality
Growth	--	1,195	--
Retreat, Bleaching, and Disease	unknown cause	17	17
	algae mediated	26	26
	algae/sediment	0	0
	new disease	165	97
	bleaching	200	52

Table C.6. Repetitive 8 m^2 stations, West Flower Garden Bank, 1995.

Change	Cause	Occurrence	Mortality
Growth	--	943	--
Retreat, Bleaching, and Disease	unknown cause	2	2
	algae mediated	17	17
	algae/sediment	0	0
	new disease	152	137
	bleaching	229	59

APPENDIX D

ANCILLARY DATA

Table D.1. Ancillary measurements: temperature, salinity, dissolved oxygen, and ambient light data collected at near surface and near bottom depths during the 1994 field effort.

Bank	Date	Local Time	Near Surface (1 m)				Near Bottom (within 1 m)			
			Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/l)	Ambient Light (μmol sec^{-1} m^{-2})	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/l)	Ambient Light (μmol sec^{-1} m^{-2})
EFG	14 Sept. 1994	1540	29.1	34.9	6.2	NA	29.0	35.2	6.2	NA
EFG	15 Sept. 1994	1135	28.8	34.9	6.2	400	28.9	35.2	6.1	120
EFG	16 Sept. 1994	0900	28.8	34.8	6.1	300	28.9	35.0	5.6	50
WFG	12 Sept. 1994	1344	29.1	35.0	6.4	120	29.2	35.0	6.3	50
WFG	13 Sept. 1994	1057	29.0	34.9	6.1	800	29.3	36.3	6.1	180
WFG	14 Sept. 1994	0940	29.0	34.6	6.2	700	29.2	35.1	6.1	150

NA = Data not available.

Table D.2. Ancillary measurements: temperature, salinity, dissolved oxygen, and ambient light data collected at near surface and near bottom depths during the 1995 field effort.

Bank	Date	Local Time	Near Surface (1 m)				Near Bottom (within 1 m)			
			Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/l)	Ambient Light (μmol sec^{-1} m^{-2})	Temperature (°C)	Salinity (ppt)	Dissolved Oxygen (mg/l)	Ambient Light (μmol sec^{-1} m^{-2})
EFG	23 Aug. 1995	--	30.1	37.6	6.3	150	29.7	38.0	6.2	50
EFG	24 Aug. 1995	1042	30.3	37.3	6.2	800	29.5	37.4	6.3	180
WFG	21 Aug. 1995	1618	30.0	36.3	6.0	NA	29.4	36.3	5.7	NA
WFG	22 Aug. 1995	0900	29.9	33.2	6.2	NA	29.8	33.4	6.2	NA

NA = Data not available.

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 **Royalty Management Program** 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.