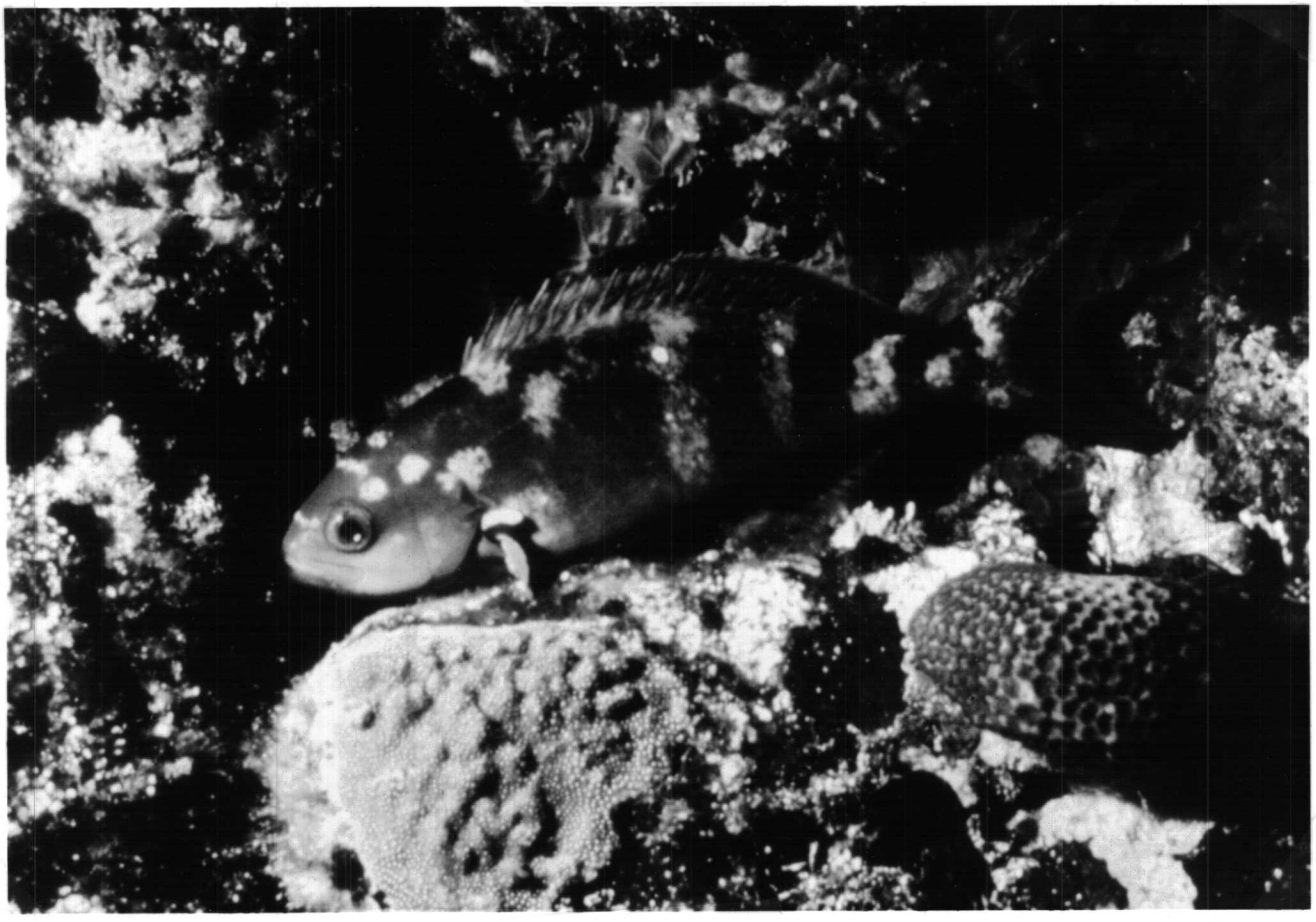
OCS Study
MMS 92-0006

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



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U.S. Department of the Interior
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Acknowledgments

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Abstract

Study sites designed for long-term monitoring of the condition of coral populations and water quality were established on the East and West Flower Garden Banks (northwest Gulf of Mexico) in 1988 and 1989. Coral cover, relative dominance, diversity, evenness, and accretionary and encrusting growth rates were monitored semi-annually through 1991. Several differences existed between study sites, particularly with respect to diversity and evenness, but these do not necessarily imply differences between the banks. No significant trends were observed in any parameters during the study. Comparison with data from population and growth studies conducted between 1978 and 1982 suggest no significant long-term trends. Monitoring of the occurrence and effects of coral bleaching (the expulsion of symbiotic algae essential to vigorous growth) and diseases suggests that disease was the more important cause of coral mortality even though more coral cover was affected by bleaching than by disease. Late summer bleaching followed temperature maxima that exceeded 30°C. The conditions for coral growth on the banks appear to be favorable, as suggested by relatively high growth rates, net tissue gain over the study period, and a high proportion of advancing margins on *Montastrea annularis* and *Diploria strigosa*, the two dominant corals on the banks. An episode of mass spawning (synchronous gamete release) by three coral species on the banks, the first documented occurrence in the Atlantic basin, as well as data on coral recruitment and reef coral occurrence on hydrocarbon platforms in the region, suggest that the Flower Gardens harbor ecosystems that may be fully capable of repopulation following natural or man-induced disturbance (i.e., without dependence on gene flow from outside sources). A review of the potential effects of industrial activities on the reefs indicated that tanker spills and spills resulting from platform accidents, as well as the application of dispersants during clean-up operations, pose the most realistic threats to reef corals at the Flower Gardens. Discharges of produced waters and drilling fluids were not considered to pose substantial threats because of existing regulations in the vicinity of the banks and dilution by intervening water masses.

1.0 Executive Summary

Introduction

Under normal conditions, change on coral reefs occurs slowly. Under altered conditions, deterioration of coral reef communities can be a rapid process, especially when caused by catastrophic natural or man-induced mechanical impact (e.g. hurricanes, blasting, dredging, mining, and ship groundings). Impacts that alter predator/prey relationships, or cause thermal, oil, chemical, or nutrient pollution can result in gradual deterioration of coral reefs. Similarly, chronic low level mechanical stresses imposed by coral collection, intensive fishing, high levels of diver visitation or boat and ship activities may also cause the gradual decline of coral populations or coral viability.

Environmental threats posed by substantial hydrocarbon development and other human activities on the outer continental shelf (OCS) in the northwest Gulf of Mexico, and the sensitivity of coral reefs to unusual environmental change prompted the Minerals Management Service to initiate a long-term monitoring program at the Flower Garden Banks, two OCS banks harboring coral reefs. The East (EFG) and West (WFG) Flower Garden Banks are located on the edge of the continental shelf, slightly over 175 km SSE of Galveston, Texas. The banks are topographic expressions of uplift caused by underlying salt domes originating from Jurassic, Louann evaporite deposits 15 km below the seafloor. The crests of these isolated banks, which are 19 km apart, are occupied by submerged coral reefs which rise to within 15 m of the surface. Together, the bank zones containing high diversity coral reefs cover roughly 350 acres.

The Flower Garden Banks are unique in many respects, not the least of which is the fact that these isolated environments harbor coral reefs very near the northern physiological limits for tropical reef-building corals. The northerly location of the Flower Garden Banks has resulted in reduced community diversity; only 18 of the 65 Western Atlantic reef-building coral species occur. Nevertheless, abundance and growth rates compare favorably with those in more tropical locales at similar depths.

A monitoring program should address concerns regarding both gradual and catastrophic deterioration. This is critical in light of the Flower Garden Banks National Marine Sanctuary designation in January 1992. Recreational use of underwater areas has historically increased following the establishment of such areas as marine parks, preserves, sanctuaries, etc. A long-term data base incorporating standardized data collection and analysis techniques may allow for the identification of impacts caused by the expected increase in recreational use as well as those caused by escalating industrial activity in the vicinity.

The first objective of the monitoring study at the Flower Garden banks was to provide relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and development in the vicinity of these sensitive ecosystems. The second objective was to document long-term changes in coral and associated communities at the Flower Garden Banks caused either by impacts of petroleum exploration and development or other human activities. The third objective was to document long-term natural variation in reef-building and associated communities on the banks.

Quantitative studies of community characteristics on the Flower Gardens were funded by MMS as early as the mid-1970's. Studies in the late 1970's and 1980's were funded by oil companies in conjuction with development of leases in regulated areas in the vicinity of each bank. Data collected in these studies allow long-term comparisons (nearly 14 years) with data collected during the 1988-1991 study period reported here.

Methods

The establishment of monitoring stations at the East Flower Garden Bank involved first delimiting a 100 m by 100 m area containing reef communities considered representative of those inhabiting the high diversity zone of the bank. This was followed by establishing and mapping one hundred twenty (120) permanent stations for monitoring encrusting (lateral) growth of *Montastrea annularis* (mountainous star coral) and *Diploria strigosa* (brain coral; 60 stations for each species), forty (40) permanent posts to mark 8 m^2 repetitive sampling stations for monitoring individual coral colonies, and thirty (30) permanent accretionary growth

spikes in coral colonies. The East Flower Garden site was established in such a manner to insure continuity with an MMS-required monitoring study conducted by Union Oil Co., and carried out by Continental Shelf Associates, Inc. in at the West Flower Garden Bank in the summer of 1988. Sites were at similar depths, were the same size, and contained the same number of stations. Following study site establishment, photographic and video field work was conducted at both banks at roughly six month intervals.

During each sampling effort, twenty (20), 10-meter random transects were photographed at each study site. Percent cover data were acquired planimetrically for all coral species, leafy algae, sponges, and reefrock on the photographs. Also calculated was the number of colonies of each species, relative dominance of each coral species (percent cover relative to total coral cover), species diversity (from the natural log form of the Shannon-Weaver Diversity Index), and evenness (species diversity divided by the maximum possible diversity; i.e., the natural log of the number of species present). For species diversity and evenness based on coral cover, p_i in the diversity formula $H'=-\Sigma\ p_i \ln p_i$ was relative dominance.

At each site thirty (30) spikes implanted in the tops of colonies of *M. annularis* were repeatedly measured to monitor accretionary growth. In addition, sclerochronology was used to determine accretionary growth rates. Cores were taken in May of 1990 from four *M. annularis* colonies, two from each bank. Growth rates from 1910 to 1989 were determined by measurement of annual corallum density changes (analogous to tree rings).

Core samples were also analyzed for their trace metal content by Instrumental Neutron Activation Analysis. A preliminary study of barium incorporation rates in coral skeletons was conducted to assess the possibility of using barium to document long-term water quality changes resulting from industrial oil and gas activity.

Each permanent station for monitoring the encrusting growth of *M. annularis* or *D. strigosa* was established by implanting two nails 23 cm apart near colony borders. A diopter framer (Plus 5) attached to an underwater camera and placed directly over the nails allowed photography of a repeatable 13.3 by 19.7 cm area. Growth and retreat were analyzed by projecting sequential margins onto the same surface, followed by planimetric measurement of areas of growth and retreat, and the border lengths over which these changes occurred.

Permanent posts were installed to mark repetitively photographed 8 m^2 areas for monitoring changes in individual colonies. Single slides were produced for each station during each sampling effort using a T-shaped camera frame equipped with a down-looking camera, 15-mm wide angle lens, two strobes, a compass, and a bubble level. The height of the camera above the bottom was maintained at 2.0 m by a single aluminum angle post. The photos were taken at a compass heading of 000° and the bubble level centered above the station post. Laboratory tests showed that, over five sampling periods, we could expect to cover over 90% of each station in 100% of the photographs. Tests also showed that minor variations caused by camera frame twist or tilt did not affect estimates of colony size.

Comparisons of slides between cruises were made by overlaying baseline templates (Cruise 2 colony borders) on projected images, and comparing colonies one by one. Growth, disease, bleaching, algae-mediated or algae/sediment mat-mediated retreat, unexplained mortality, and mechanical damage were quantified, as were their effects (mortality, recovery, or no effect).

Two videotaped transects of 100 m length were acquired at each study site during each cruise to record the general conditions of the coral community at the sites. The video was taken from approximately two meters above the bottom at an angle of 45°. Video transects were taken along two of the four 100-m boundary lines that were tautly strung along the sides of each survey area. At the East Flower Garden Bank, transects were taken from the southeast corner northward along the east line, then westward on the north line. At the West Bank, transects were taken from the southeast corner westward along the south line, then northward along the west line.

Ancillary measurements included dissolved oxygen, salinity, temperature, and light intensity. Samples and measurements were made at one meter depth and one meter above the bottom. Light was also measured above the surface (on the ship deck). Sea surface temperature data between 1979 and 1990 were collected from records of AVHRR satellite transits. In addition, Ryan TempMentor thermographs were installed in 1990 on the banks to record bottom temperature every two hours.

Coral Community - Status and Trends

Total coral cover did not differ significantly between study sites (46.0% on the EFG and 46.5% on the WFG), or between sites during any cruise. Species diversity and evenness based on coral counts (standard Shannon-Weaver species diversity) were significantly higher at the WFG study site. Species diversity and evenness based on coral cover showed the opposite pattern, being significantly higher at the EFG study site. The contrasting data are a result of the fact that coral numerical population levels differed significantly between sites (114.8 colonies per transect at the EFG vs. 84.6 per transect at the WFG), and the fact that mean colony area (size) of *Siderastrea siderea* (the largest of all species) and *Porites astreoides* (the most abundant of all species) differed significantly between study sites. Nevertheless, results were consistent within indices, and future monitoring efforts require clearly stating whether diversity indices are based on colony counts or percent cover.

Data collected from 1978-1982 reported cover of 50.4% ($45.1<\mu<55.7$) and 55.2% ($23.8<\mu<86.5$) for the EFG and WFG, respectively, but used a different method of analysis (line-intercept method rather than planimetry). Nevertheless, confidence intervals of cover estimates overlapped between the two studies, as did those for measures of diversity and evenness. In addition, cover for individual species reported in the 1978-1982 period were all close to those found in this study.

Thus, virtually no significant changes have been detected in coral reef populations, cover, or diversity at the Flower Garden Banks in the time since quantitative surveys of the reefs began. Thus, there was no evidence of downward trends or deterioration of habitat quality. Furthermore, differences between study sites of similar depths should not, without further study, be considered as representative of differences between the banks in general.

Coral Growth - Status and Trends

Virtually all encrusting growth data suggest favorable conditions for coral growth at the Flower Garden Banks. Accretionary growth rates of *M. annularis* measured between 1989 and 1991 using growth spikes averaged

6.8 mm/yr. Accretionary growth rates measured from 1910 to 1989 in coral cores were 6.6 mm/yr. An interesting feature noted in cores was an unexplained, yet distinctive decrease in growth rates and concurrent increase in year-to-year variability between 1957 and 1980.

Net growth rates along coral margins (average rate of change; i.e., taking into account areas of advance and areas of retreat) of *M. annularis* and *D. strigosa* were positive for nearly all semi-annual periods from 1989 through 1991. Positive net encrusting growth rates contrast data collected from Molasses Reef, in the Florida Keys, which indicated net encrusting growth rates of essentially zero on apparently healthy, adult *M. annularis* colonies.

Where tissue retreat did take place, the average rate was not significantly different from that of areas of tissue growth. This was an unexpected finding since, where mortality occurs, coral tissue generally dies at a faster rate than it is capable of growing.

Measurements of areas of advance and retreat showed that for every square centimeter of *D. strigosa* tissue that died, approximately 1.5 cm^2 grew. For *M. annularis*, for every square centimeter lost, approximately 1.8 cm^2 grew. A similar study of *M. annularis* at 10 m depth the Florida Keys found substantially more tissue loss relative to tissue gain (during all seasons of the year).

Analyses of the proportions of margins advancing, retreating, and remaining stable between cruises showed that over half of the marginal tissue on *M. annularis* and *D. strigosa* was undergoing advance between cruises (averaging 63% for *M. annularis* and 56% for *D. strigosa*). By contrast, the proportions of retreating margins averaged only 22% for *M. annularis* and 26% for *D. strigosa*. In the Florida Keys study, data indicated roughly equal proportions of advance, retreat, and stable margins.

All these data suggest a condition at the Flower Gardens whereby retreat and advance are dictated by natural factors, such as competition for space, rather than man-induced stress, and/or a situation wherein vectors which cause considerable tissue loss, such as disease, are acting on limited scales.

Historical Water Quality

Barium/Calcium molar ratios were obtained from 16 annual bands between 1910 and 1989. Barium levels the Flower Gardens were generally higher than those reported from the Florida Straits. No significant trends were found based on these preliminary data. However, post-1970 samples showed consistently higher ratios than those prior to 1970. This coincides with a significant increase in drilling activity on the outer continental shelf in the vicinity of the Flower Garden Banks. The relationship between Ba/Ca molar ratios and drilling activity has not been shown to be statistically significant. Also, increases in Ba/Ca molar ratios at the level observed are not thought to affect coral growth or other essential functions. Nevertheless, the preliminary findings suggest the need for continued study of the potential for corals to record long-term water quality changes.

Reproductive Viability

Information concerning the reproductive viability of most coral species at the Flower Gardens is limited. Reproductive viability is of consequence to the potential for repopulation after mass mortality caused, for example, by extreme environmental perturbations, pathogens, or man-induced catastrophes. Moreover, reproductive viability controls the success of colonization and the development of coral communities on other topographic highs, artificial reefs, and hydrocarbon production platforms in the region. The potential for repopulation of the Flower Garden Banks is of particular concern because of their isolation. Such geographically isolated reefs may rely on larval retention (self-seeding) for reef coral community maintenance and recovery. If the reproductive potential of local corals is low, the reefs would be forced to depend on long-distance dispersal from other locations following a disturbance, resulting in prolonged recovery.

The first mass spawning of reef corals documented in the Atlantic basin occurred in September 1991 at the East Flower Garden Bank. Mass spawning is the synchronous release of gametes by multiple species. It has been widely reported in the Pacific Ocean, but observations on Atlantic reefs have been limited to single species and a small number of colonies. Most mass spawners reproduce by broadcasting eggs and sperm, often packed

together into gamete bundles, into the water column for external fertilization and larval development. This behavior has received considerable attention because it is visually impressive, predictably related to lunar cycles, and because it has important evolutionary implications.

Peak spawning activity at the EFG occurred between 2115 and 2300 hours, in calm conditions, eight evenings after the August full moon. Release by one *Diploria strigosa* colony, in which nearly all polyps contained gametes, was estimated at 34,000 gamete bundles m^{-2} over a three-minute period. In addition, minor spawning activity was noted just prior to sunset on the same day (sperm release by one colony of *Montastrea cavernosa*, a dioecious species), on the day following the mass spawning (one *D. strigosa* was observed to spawn), and seven days following the July full moon (sperm release by *M. cavernosa* a month earlier). A dense slick of gamete bundles and sperm streamed from the reef until 2300 hours, after which all spawning activity appeared to cease.

Data from these observations, from studies of coral recruitment, and observations of reef corals on petroleum platforms suggest that the Flower Garden Banks harbor wholly functional coral communities. This suggests that the reefs are capable of self-seeding, and could persist for some time without gene flow originating from outside sources. In addition, it would appear that there is high potential for repopulation following substantial disturbance. Monitoring and research should be conducted to elucidate the persistence of mass spawning on a year-by-year basis.

Coral Bleaching

Coral bleaching, the expulsion of symbiotic algae by corals under stress, was observed to some extent every summer during the study. The most significant episodes were associated with sea water temperatures that exceeded 30°C, generally in early to mid-August. In 1991, thermographs installed on both banks revealed that water temperature on the West Bank did not exceed 30°C at any time. On the East Bank, temperatures exceeding 30°C persisted for over a week. Following that period, significantly more bleaching was observed on the East Bank. Nevertheless, bleaching was never observed to affect more than 2.4% of the coral cover on the banks.

Mortality was seldom associated with bleaching; only 7% of bleached colonies exhibited any tissue loss. Where it did occur, tissue loss was limited to small portions of the bleached colonies.

Coral bleaching has been shown to affect calcification rates and other metabolic functions, and may cause substantial mortality when severe. Data collected so far at the Flower Gardens suggest either considerable resilience of corals there, or more likely, a lack of high temperature excursions of sufficient intensity or duration to induce mortality. In addition, factors which are known to exacerbate the effects of bleaching, such as concurrent low tides, stagnant conditions, high levels of ultraviolet light, or pollutants, seldom, if ever, affect the Flower Garden Banks.

Diseases

At present, diseases may be the most serious natural threat to corals at the Flower Garden Banks. Though they occurred on less then 2% (67) of corals analyzed at repetitive stations, relatively high levels of tissue mortality occurred; 69% (46) of diseased colonies exhibited measurable tissue loss.

Unfortunately, rates of occurrence of disease and bleaching were not obtained in early surveys of reef corals on the Flower Garden Banks. It is thought that coral disease incidence increases with deteriorating environmental conditions. Therefore, continued monitoring of disease frequency and effects should be considered an important component of any long-term monitoring program. In addition, research on identification of diseases should be conducted so that the occurrence of "exotic" infestations can be identified. These might include "black band" and "white band" diseases, which are common elsewhere, but have never been observed at the Flower Gardens.

Reef Fish

Reef fish populations exhibited considerable seasonal variation. Differences between banks for one species (the creolefish, *Paranthias furcifer*) may be a result of behavioral variations related to feeding and the locations of study sites relative to the banks' peripheries. Creolefish are plankton feeders and are commonly observed to form large feeding

aggregations on the up-current edges of reefs. The EFG study site was located very near the drop-off on the eastern margin of the bank. The WFG study site was more centrally located with respect to the edges of the coral reef zone. Seasonal variations in currents could therefore account for differences in abundances of creolefish in the study areas.

Parrotfish abundances appeared to have increased since the early 1980's. This may be a result of the 1983-1984 mass mortality of the long-spine sea urchin, *Diadema antillarum*, and consequent changes in benthic algae availability on the banks. *D. antillarum* populations have not recovered measurably since the mass mortality.

Industrial Threats to the Flower Garden Banks

Potential threats to communities on the Flower Garden Banks from hydrocarbon exploration and development include tanker spills, accidental spills from platforms and pipelines, spill clean-up efforts, and the discharge of produced waters and drilling fluids. Accidents on platforms, and those occurring during tanker transport of oil through the Gulf may pose the most realistic threats to the Flower Gardens, since platforms occur in the vicinity and heavily-used tanker traffic routes are nearby. Clean-up efforts near the Flower Gardens would probably not involve the use of dispersants, which would otherwise pose a threat to reef corals, since they cause oil to mix into the water column. Material discharge is largely regulated by shunting in areas close enough to the Flower Gardens to otherwise preclude effective dilution.

Of the 10 Gulf of Mexico platform accidents between 1974 and 1990 resulting in spills in excess of 1,000 bbl, all causes including blowouts, ship collisions, storage tank spills, and weather related accidents could occur in the vicinity of the Flower Garden Banks.

Pipeline ruptures have historically been caused mainly by anchor dragging. However, since the depths surrounding the Flower Garden Banks generally exceed practical anchoring and trawling depths, the largest potential threat with respect to pipeline and platform activities in the region may be that of leaks caused by equipment deterioration and failure.

At present there are no production platforms near enough to the Flower Garden Banks to have an expected impact due to the discharge of

produced waters or drilling fluids. Required shunting to within 10 m of the bottom, and negligible upward transport by currents minimize the potential for discharged contaminants to reach the reef communities of the Flower Garden Banks.

Recreational Threats

Increasing use of the Flower Garden Banks by recreational divers poses an uncertain threat to the reefs. The damage is likely to come primarily from anchoring by recreaional vessels. However, the installation of mooring buoys on the banks in 1990 should limit this problem. It is unlikely that damage caused by careless divers will be as evident as that in other heavily-used coral reefs, mainly because the Flower Gardens are dominated by massive, head-forming corals, and lack the more fragile branching forms and gorgonian corals.

Conclusions

The remote location of the Flower Garden Banks has left them, for the most part, undisturbed by man. Demonstrable human impacts have been limited to mechanical destruction caused by anchors, and the occurrence of debris on the reefs (primarily anchors, chains, and cables). Resource monitoring of long-term changes in reef coral populations or growth rates has indicated no substantial changes attributable to human activities. Potential industrial effects caused by offshore development in the northwest Gulf have been monitored, but have never been detected, nor have long-term water quality changes. It is anticipated that the January 1992 designation of the Flower Garden Banks National Marine Sanctuary will foster continued resource protection and monitoring, and encourage increased research on important functional attributes of these unique and pristine coral reefs.

2.0 INTRODUCTION

2.1 Program Relevance and Direction

Tropical coral reefs are complex biogenic structures on the sea bed which support the most highly diverse communities of organisms in the marine environment. The framework of coral reefs is produced primarily by hermatypic corals and coralline algae, which are the dominant components of the benthic assemblage. The integrity and nature of coral reef communities are dependent on both the continued existence of a substantial cover of living coral to produce new reef rock, continual cementation by coralline algae, and the maintenance of the framework in the configuration in which it was produced. In general, the form and structure of reefs are highly influenced by, and adjusted to, the physical conditions of their environment. Some of the most important physical parameters involved in controlling development include prevailing currents, water clarity, thermal cycles, salinity, and the frequency of storms.

Man has repeatedly caused the destruction of reef framework and reef populations. Reef rock is mined for use as building stone in the Indo-West Pacific. Swaths of Red Sea reef flats have been severely damaged by explosions used in geophysical surveys. Reefs have been buried beneath causeways, trampled upon, broken piecemeal by tourists, crushed beneath shipwrecks, subjected to damage by anchors and ground tackle from boats and ships of all sizes, and silted over or destroyed by dredging activities (see reviews by Johannes, 1975, Endean, 1976, and Pearson, 1981). More subtle, but important stresses, such as the eutrophication (or nutrification) of waters around tropical reefs have more recently become evident, particularly in the Florida Keys (LaPointe and Clark, 1990; Olsen, 1991) and in Hawaii (e.g., Marszalek, 1987).

Although such impacts are most intense on coastal emergent reefs, submerged reefs far offshore are not immune. In 1985, a portion of Bright Bank, a reef at 37 m depth near the Flower Garden Banks, was blown apart by treasure hunters (Bright, 1986). The Flower Garden reefs, adjacent to commercial shipping lanes, have been used as offshore anchoring sites by large vessels for decades, and it became evident in the 1980's that anchoring on these reefs was increasing with escalating ship traffic. Prior to

the installation of permanent moorings in 1990, it also became evident that small vessel anchoring was increasing on the banks. Concern over the fate of the Flower Garden reefs in relation to these impacts has been an important factor leading to their designation as a National Marine Sanctuary.

Under normal conditions, change on coral reefs occurs slowly. Under altered conditions, deterioration of coral reef communities can be a rapid process, especially when caused by catastrophic natural or man-induced mechanical impact (e.g., hurricanes, blasting, dredging, mining, and ship groundings). Under such conditions, change is perceived as acute coral tissue loss. Such impacts as thermal, oil, chemical, or nutrient pollution can cause gradual deterioration of coral reefs. In these cases, change is perceived as gradual, but consistent net tissue loss. Similarly, chronic low level mechanical stresses imposed by coral collection, destructive fishing techniques, or high levels of recreational diving and boating may also cause gradual decline of coral populations or coral viability (e.g., Tilmant and Schmahl, 1983, and papers in Salvat, 1987).

Potential environmental threats posed by substantial hydrocarbon development and other human activities on the outer continental shelf in the northwest Gulf of Mexico, and the sensitivity of coral reefs to unfamiliar environmental change prompted the Minerals Management Service to initiate a long-term monitoring program at the Flower Garden Banks. Such a program serves to address concerns regarding both gradual and catastrophic deterioration of these unique offshore ecosystems. It also provides for the augmentation of a data base relating to coral community viability dating from the early 1970's. Techniques for coral community assessments, and baseline data on coral populations, cover, and diversity were collected during the 70's during MMS-funded studies of the coral reefs of the Flower Garden Banks (Bright et al., 1981, 1982) and later used in damage assessment (CSA, 1984; Gittings and Bright, 1986) and monitoring studies on the East (CSA, 1985) and West (CSA, 1990) banks.

A long-term database is extremely valuable, particularly in light of the January 1992 Flower Garden Banks National Marine Sanctuary designation. Recreational use of underwater areas tends to increase following the establishment of an area as a marine park, preserve, sanctuary, or reef authority (Tilmant, 1987). A long-term data base and standardized data collection and analysis techniques may allow for the identification of impacts

caused by the expected increase in recreational use. Furthermore, due to differences in the nature of recreational activities and petroleum exploration and production activities, and the nature of the damage potentially caused by these operations, it may be possible to determine the principal factors leading to any community changes observed in future years at the Flower Gardens.

2.2 Study Objectives

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

(1) to provide relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and development in the vicinity of sensitive ecosystems,

(2) to document long-term changes in reef-building and associated communities at the Flower Garden Banks caused either by impacts of petroleum exploration and development or other human activities, and

(3) to document long-term natural variation in reef-building and associated communities on the banks.

In addition to these primary objectives, a preliminary study on trace metals in corals was conducted in order to evaluate the potential for determining long-term changes in water quality by skeletal analysis. Trace metals are found in annual growth bands of reef-building corals (Livingston and Thompson, 1971; Shen and Boyle, 1988). Elemental characteristics of coral skeleton within these growth bands may reflect temporal changes in seawater composition. Thus, seawater composition changes resulting from dissolved materials discarded during industrial activities in the northern Gulf of Mexico may be reflected in coral skeletons on the Flower Garden Banks.

The saturation concentration of barium (as barite) in the surface ocean is approximately 35 parts per billion (ppb) (Church and Wolgemuth, 1972). Dissolved barium concentrations in Gulf of Mexico surface waters

are in the range of 5-15 ppb. (substantially undersaturated). Consequently the dissolution of barite is possible under these conditions.

More than two million metric tons of barite have been discharged on the Gulf of Mexico Outer Continental Shelf since 1978 (10,000 new wells; P. Boothe, pers. comm.). There is growing evidence that a significant portion (50% or more) of the barite dissolves, releasing contaminant trace metals, or is rapidly advected to the shelf/slope break (P. Boothe, pers. comm.). These processes could be altering trace element and organic levels in the fauna of the Flower Garden Banks. Coral skeletal material is particularly well-suited for studies of barium (Ba) because Ba substitutes for calcium during calcification at a fairly high rate (ppb range). We chose, therefore, to analyze reef-building corals at the Flower Gardens to determine whether they have incorporated increased amounts of Ba following increases in industrial activity. Preliminary results of Ba incorporation from 1910 to 1989 are presented.

2.3 Overview of the Study Area

The East (EFG) and West (WFG) Flower Garden Banks are located near the edge of the continental shelf, slightly over 175 km SSE of Galveston, Texas (Figure 2-1). The banks are topographic expressions of uplift caused by underlying salt domes originating from Jurassic, Louann evaporite deposits 15 km below the seafloor (Rezak, 1981). The crests of these isolated banks, which are 19 km apart, are occupied by submerged coral reefs which rise to within 15 m of the surface. Total coral cover on the reefs averages over 46%. The reefs are dominated by *Montastrea annularis* (~25.5% cover), *Diploria strigosa* (~8%), *Porites astreoides* (~3.5%), *M. cavernosa* (~3%), *Colpophyllia* spp. (~2.5%), and the hydrozoan *Millepora* spp. (~2%) (Bright et al., 1984; and data from this study). These six species comprise over 95% of the total coral cover. An additional 11 reef-building species total approximately two percent cover. No acroporid scleractinians (elkhorn or staghorn corals) or shallow-water octocorals (sea fans, sea whips, and other gorgonian corals) exist on the banks. Together, the bank zones containing high diversity coral reefs cover roughly 1.4 km^2 (almost 350 acres) Figures 2-2 and 2-3 show the relative amounts of high diversity reef and other habitats at the EFG and WFG.

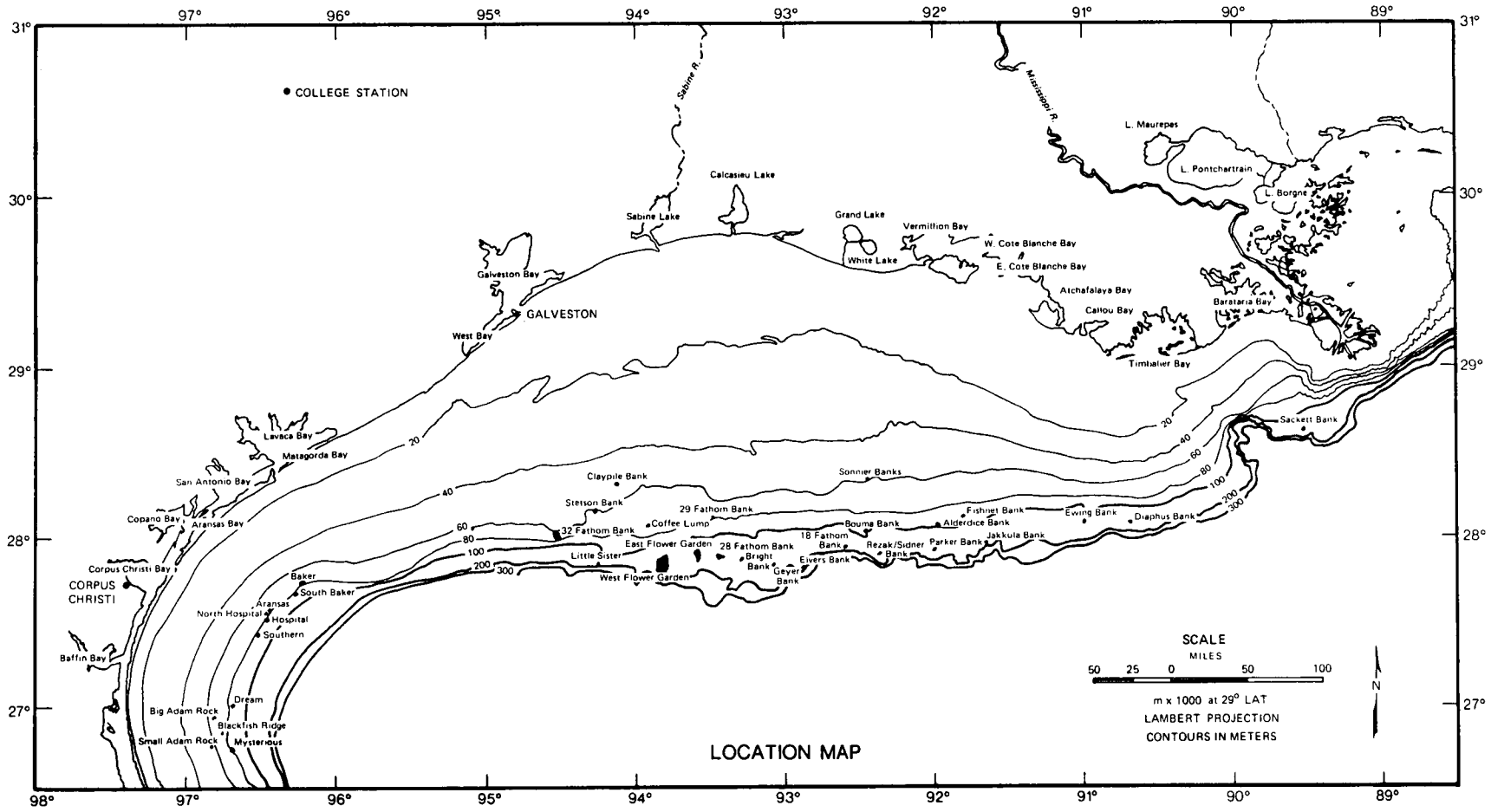


Figure 2-1. Location of the Flower Garden Banks and other topographic prominences in the northwestern Gulf of Mexico. Little Sister Bank is also known as Applebaum Bank. 28 Fathom Bank is also known as Rankin Bank.

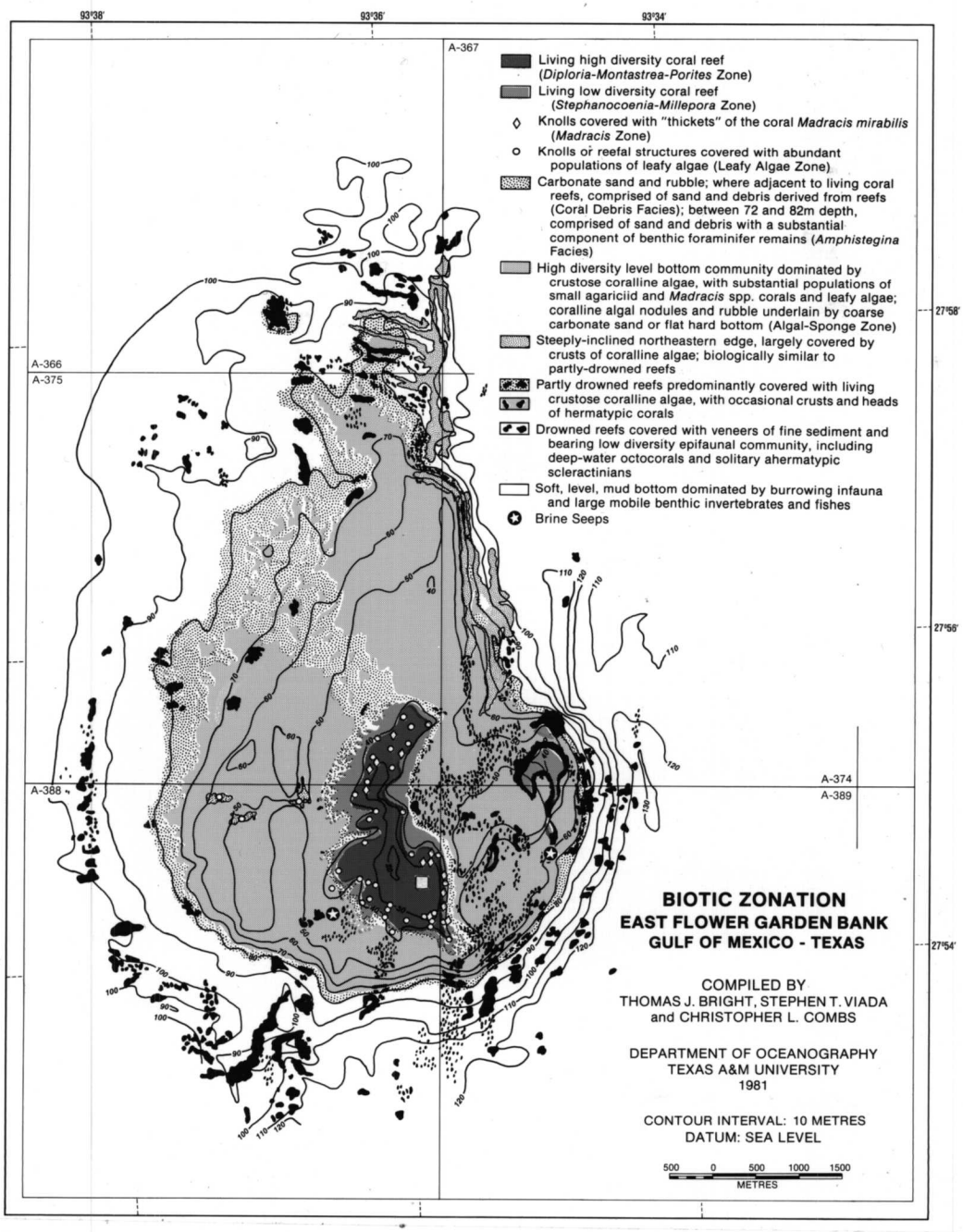


Figure 2-2. Biotic zonation of the East Flower Garden Bank. The darkest portion of the figure indicates the living high diversity reef. White box indicates approximate study site location and size. (from Rezak et al., 1985).

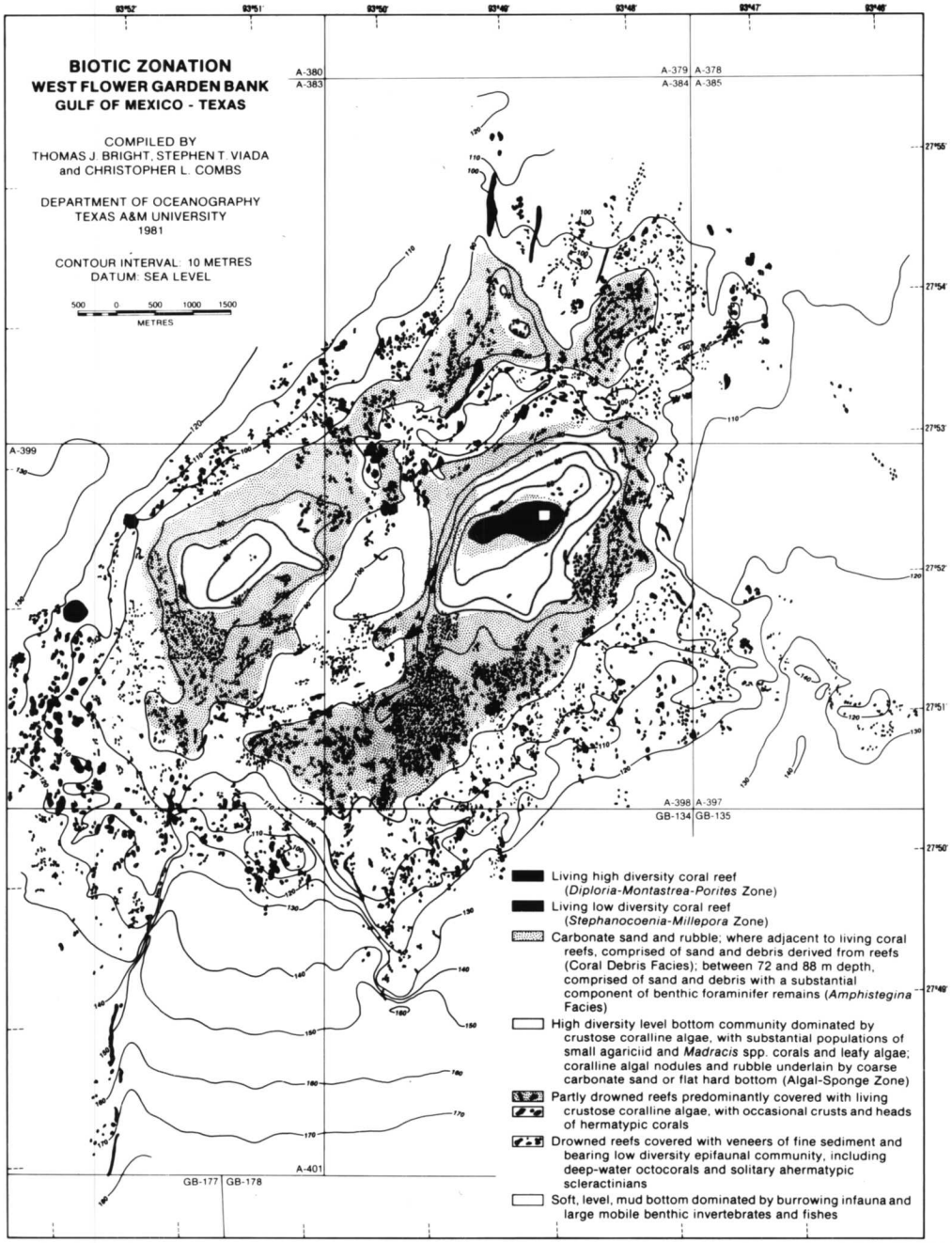


Figure 2-3. Biotic zonation of the West Flower Garden Bank. The darkest portion of the figure indicates the living high diversity reef. White box indicates approximate study site location and size. (from Rezak et al., 1985).

The Flower Garden Banks are unique in many respects, not the least of which is the fact that these isolated environments harbor coral reefs very near the northern physiological limits for tropical hermatypic corals. The annual temperature range at the Flower Gardens, roughly 19-31°C, imposes acceptable conditions for reef development. Less than 50 km northward, winter temperatures are too low for reef-building (Rezak et al., 1990). The Flower Garden Banks have comparatively low community diversity (Bright et al., 1984). Only 18 of the 65 Western Atlantic hermatypic coral species occur. It is not known whether the isolation of the Flower Gardens, the depth of the reef crest, or other environmental conditions limit species diversity, but abundance and growth rates of corals there compare favorably with those in more tropical locales at similar depths (Rezak et al., 1985).

As described by Rezak et al. (1985), within the Gulf of Mexico, the Flower Garden Banks appear to be elements of a discontinuous arc of reefal structures that occur on the continental shelf. Aside from some low diversity reef communities on neighboring banks, the coral reefs closest to the Flower Gardens are off Cabo Rojo, about 100 km south of Tampico, Mexico (Villalobos, 1971). Moore (1958) listed 43 species of Caribbean reef invertebrates from Cabo Rojo, many of which are common at the Flower Gardens. However, certain abundant corals typical of emergent reefs, such as *Acropora palmata* (elkhorn coral) and *A. cervicornis* (staghorn coral), do not occur at the Flower Garden reefs. Shallow-water octocorals (sea fans and sea whips), which surprisingly are absent from the Flower Gardens, are present at Cabo Rojo and other reefs several miles south near Isla de Lobos (Chamberlain, 1966; Rigby and McIntyre, 1966), and elsewhere in the southwestern Gulf of Mexico (Nelson et al., 1988). Octocorals are abundant on Alacran reef (Kornicker et al., 1959) and other reefs on the Yucatan continental shelf.

The Flower Garden Banks contain the northernmost thriving coral reefs on the continental shelf of North America (Bright et al., 1984). In the Atlantic Ocean, only the reefs of Bermuda, 900 km off South Carolina, are farther north. Though coral diversity at the Flower Gardens is lower than Caribbean and Florida reefs, it is similar to that of Bermuda reefs (Rezak et al., 1985). Bright et al. (1984) listed 21 species of scleractinians and one hydrocoral from the Flower Garden reefs. Of these, 18 were considered to be hermatypic (i.e., reef-building corals).

Biotic zonation (Figure 2-4) is distinct, stringently depth-related, and nearly identical on both the East and West Flower Garden banks. The characteristics and limits of biotic zones on the banks have been defined primarily on the basis of direct visual observations and selective sampling performed using the Texas A&M research submersible *Diaphus* and scientific scuba diving. Such techniques result in basically qualitative judgments. In pursuit of objective insight that may reveal subjectively overlooked subtleties in zonation, Rezak et al. (1985) compiled and analyzed algae and invertebrate occurrence and abundance observations taken from videotaped records of all submersible transects. Cluster analyses agree with and confirmed the authors' qualitative descriptions of benthic communities and zones at the Flower Gardens. A similar exercise has also been conducted for fish community determinations (Dennis, 1985; Dennis and Bright, 1988).

Submerged coral reefs constitute the shallowest reefal structures on the East and West Flower Garden Banks and occupy the crests of the banks down to a depth of 52 m (Bright et al., 1984). The majority of the reef top areas occur between 18 and 28 m, but 15 m depths can be found. The reefs are composed of closely spaced or crowded coral heads, some over four meters in diameter and height. Patches of sand or carbonate gravel occur among the frequently cavernous coral heads that show evidence of substantial, though not atypical, internal and surficial bioerosion.

Two biotic zones are recognizable on the coral reefs: a high-diversity assemblage (16 hermatypic coral species) limited to depths of less than 36 m (*Diploria-Montastrea-Porites* Zone), and a comparatively low-diversity assemblage (approximately 12 hermatypic coral species) between 36 and 52 m (*Stephanocoenia-Millepora* Zone).

Because it is accessible to divers, more is known of the *Diploria-Montastrea-Porites* community (where the permanent sites in this study were established) than any others on the Flower Garden Banks. Edwards (1971) considered the coral reef at the West Flower Garden Bank to be similar to submerged reefs described by Logan (1969) on the Yucatan Shelf, thus implying a comparable hierarchy of coral dominance (percent cover; *Diploria* dominated, followed by *Montastrea* and *Porites*). However, subsequent studies at the Flower Gardens by Bright et al. (1974, 1984), Tresslar (1974), Viada (1980), and Kraemer (1982) showed conclusively

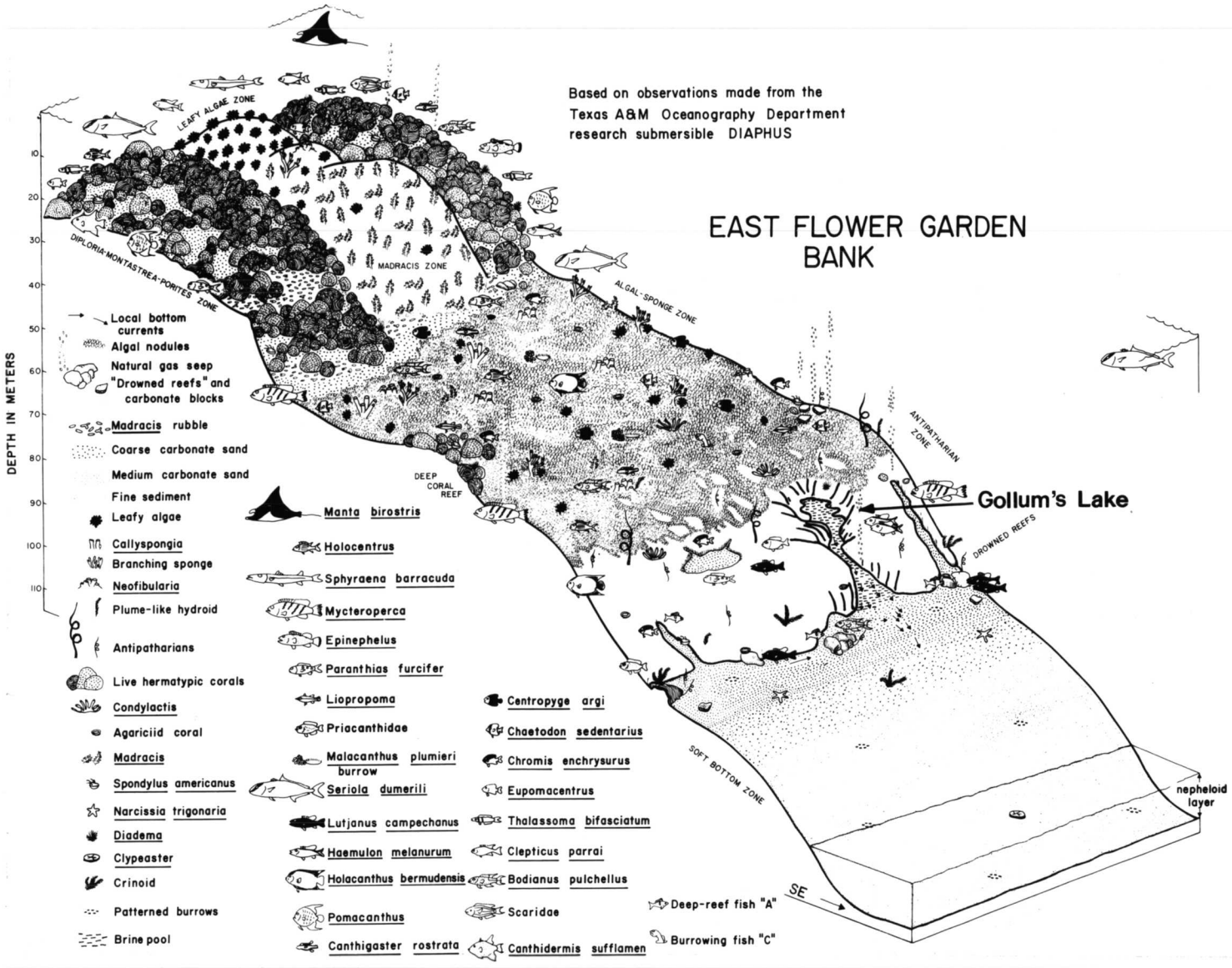


Figure 2-4. Cross-section through the East Flower Garden Bank showing the depth distribution of the various zones on the bank. Zonation is similar on the West Flower Garden Bank. (from Rezak et al., 1985).

that *Montastrea annularis* was the dominant coral, followed by *Diploria strigosa, Montastrea cavernosa, Colpophyllia* spp., and *Porites astreoides.* Convention should therefore dictate a change in zonal designation for high-diversity reefs at the Flower Garden Banks to *Montastrea-Diploria* Zone to reflect the true order of coral dominance above 36 m. For convenience, however, Rezak et al. (1985) retained the older designation.

Crustose coralline algae are abundant on the high-diversity reefs and add substantial amounts of calcium carbonate to the reef substratum. Standing crops of leafy algae on the high-diversity reefs are consistently low, possibly kept so by the grazing activities of fishes, including certain scarids (parrotfish), pomacanthids (angelfish), *Acanthurus* spp. (surgeonfish), and *Kyphosus* spp. (chub), as well as mobile invertebrates, such as gastropods and, until their mass mortality in 1983 or 1984, the long-spine urchin *Diadema antillarum.*

Sponges occupy a small portion of the high diversity reef and probably do not contribute substantially to reef development in this zone. On deeper portions of the banks, however, the sponge community is much better developed. Between 46 and 88 m, the Algal-Sponge Zone occupies plateau-like regions of the banks many times larger than the high diversity reefs. In this zone, sponges provide the majority of substrate relief, significant habitat for fish and invertebrates, and along with coralline algae, are the primary reef substrate producers.

The 253 species of reef invertebrates and 103 reef fishes reported by Bright and Pequegnat (1974) were almost all taken from the *Diploria-Montastrea-Porites* Zone at the West Flower Garden Bank. Subsequent studies showed nearly identical community structure and diversity for the *Diploria-Montastrea-Porites* Zone at the East Flower Garden Bank.

Among the typically caught sport and commercial fishes that frequent the high-diversity coral reefs are several species of grouper and hind, *Mycteroperca* spp. and *Epinephelus* spp.; amberjacks, *Seriola* spp.; great barracudas, *Sphyraena barracuda*; and porgies, *Calamus* spp.

Spiny lobsters, *Panulirus argus*, are known to occur on the high-diversity reefs at both banks and on several other banks in the northwestern Gulf of Mexico (Sonnier Bank, 18 Fathom Bank, and Bright Bank). Spotted lobsters, *Panulirus guttatus*, are much more common on the shallow coral reefs (26 m) at the East Flower Garden and also occur at the West Flower

Garden. The shovel-nosed lobster, *Scyllarides aequinoctialis*, has been observed on the high-diversity reefs at the both banks. These species of lobster are probably widely distributed on the outer continental shelf banks in the northwestern Gulf of Mexico, but nothing is known of the magnitude and dynamics of their regional populations or whether they could support a commercial lobster fishery.

Deeper biotic zones at the Flower Garden Banks include the *Madracis* Zone (28-46 m), *Stephanocoenia-Millepora* Zone (36-52 m), Algal-sponge Zone (46-88 m), Antipatharian-Transitional Zone (82-89 m) and biotic assemblages within a turbid bottom nepheloid layer (>86 m) (Rezak et al., 1985). Generally, reef building activity is negligible below the Algal-sponge zone (Bright et al., 1984).

2.4 Background

The Department of Oceanography at Texas A&M University has been involved in research on the reefs and banks offshore Texas and Louisiana since 1961. Until 1974, the research was funded by Texas A&M University and the Flower Garden Ocean Research Center at the University of Texas Marine Biomedical Institute. The Bureau of Land Management (a portion of which is now the Minerals Management Service [MMS]) began funding studies on the Flower Garden Banks and other banks off Texas and Louisiana in 1974. Earlier research had been aimed at developing a conceptual model of coral reef growth on a terrigenous shelf (Edwards, 1971) and documentation of the biota of the reefs and banks (Bright and Pequegnat, 1974). Beginning in 1974, there was a slight change in research goals in order to provide the MMS with baseline biological and geological data to assist in establishing policy with regard to the need for and nature of protective regulations to be imposed on drilling operations near the banks. MMS funding for this research continued until the middle of 1983. Thirty eight banks were mapped using precision navigation, precision depth recorder, and side-scan sonar. High resolution subbottom surveys were conducted on 20 of the banks. Submersible observations and sampling were conducted at 28 of the banks using the Texas A&M submersible DRV *Diaphus* operated from the R/V *Gyre* and other vessels. Extensive scuba diving investigations took place in the shallower parts of the East and West

Flower Garden Banks. The study of the Flower Garden Banks was much more extensive than of the other banks and as a result, the more complete sequence of biotic zones present there was used as a standard for comparison with other banks. MMS has remained responsible for (i.e., required through lease stipulations) or conducted all monitoring on the Flower Garden Banks since the mid-1970's.

Environmental factors that can be correlated with, and probably control regional patterns of community structure, distribution, abundance, and zonation of tropical epibenthos in the northwestern Gulf of Mexico include distance from shore, substrate type, bottom depth, bank relief, water temperature, salinity, river runoff, turbidity, sedimentation, currents, and seasonal variation of the last six (Rezak et al., 1985, 1990).

Conditions at the Flower Garden Banks are favorable to the development of tropical reef communities. First, currents come primarily from the southwest and are oceanic. These currents carry larvae, spores, and juveniles from the tropical waters of the southern Gulf of Mexico, and, possibly, the Caribbean. Second, coastal water masses, which are highly influenced by outflow from the Mississippi and other rivers in Louisiana and East Texas, are held onshore and directed west most of the year. As a result, turbidity at the Flower Gardens and other banks beyond the 80 m isobath is usually low (except in the bottom boundary layer), and salinity averages 36 ppt. Third, surface water seaward of the 80 m depth contour remains above 18°C year round. The minimum temperature for vigorous growth of coral reefs is 18°C (see Stoddart, 1969). Fourth, the high relief of the Flower Garden Banks above the surrounding soft bottom protects the reef top from the inimical effects of the bottom nepheloid layer. A substantial nepheloid layer at the Flower Gardens shallower than about 80 m has not been observed and the water is usually fairly clear.

3.0 Field Sampling and Logistics

3.1 Overview

The establishment of monitoring stations at the East Flower Garden Bank involved first delimiting a 100 m by 100 m area containing reef communities considered representative of the high diversity zone (*Diploria-Montastrea-Porites* Zone) of the bank. This was followed by establishing and mapping one hundred twenty (120) permanent stations for monitoring growth of *Montastrea annularis* and *Diploria strigosa* (60 stations for each species), forty (40) permanent posts to mark 8 m^2 repetitive sampling stations for monitoring individual coral colonies, and thirty (30) permanent accretionary growth spikes in coral colonies. This resulted in a study site comparable to that established by Continental Shelf Associates, Inc. (CSA, 1990) on the West Flower Garden Bank in the summer of 1988 during monitoring efforts conducted for Union Oil Co. (required by MMS under lease stipulation compliance). The coordinates of mooring buoys that mark the study sites (both within 25 m of the centers of the sites) are as follows: East Flower Garden Bank - 27°54'31.4"N, 93°35'50.8"W; West Flower Garden Bank - 27°52'30.6"N, 93°48'54.7"W.

Following study site establishment, photographic and video field work was conducted at both banks at roughly six month intervals. Cruises were conducted in late winter/early spring and late summer/early fall. These are periods immediately following yearly temperature extremes. The late winter/early spring sampling coincides with a period of rising temperature and rapid coral growth. Late summer/early fall sampling coincides with times often associated with "stress" and other significant events in coral reef ecosystems (e.g., bleaching events [Photo 3-1], slow growth, and coral spawning).

In order to enable relocation of this study site and the site on the West Bank, each corner was marked with subsurface floats attached to modified stainless steel eyebolts (1 cm diameter threaded rod) cemented into 8 cm diameter holes drilled approximately 20 cm into the reef substrate. Floats were made of closed-cell foam and attached to the eyebolts using stainless steel wire. They floated three to five meters above the bottom.

Photo 3-1. "Bleached" *Diploria strigosa* colony. White coloration is due to the loss of zooxanthellae, symbiotic algae which normally produce the green to brown shades in healthy coral tissue. Zooxanthellae loss results in slow growth, deficient nutrient recycling, and may lead to infection.

At the beginning of each sampling effort, divers located site corners, then tightly tied 100 m yellow or green polypropylene line along each side of the study site (lines were oriented north/south and east/west). The lines contained knots and loops every 25 m which, when coupled to line color, enabled divers to determine their exact location at any time. During periods with strong currents, divers used the lines to pull themselves to desired areas of the study site.

At the East Flower Garden Bank, most stations were established within 15 m of study site borders. Thus, only four lines adequately defined the site. At the West Flower Garden Bank, stations had been established by CSA throughout the 100 m x 100 m site. For this reason, two extra lines were installed during each trip to this bank. These lines crossed the center of the study site and had similar knots and loops for diver guidance. All lines were retrieved using hand reels after each sampling effort.

Sampling was conducted by scientific divers using equipment that included cameras, camera frames, magnifying framers, strobes, underwater maps, data sheets, and rulers. Water samples were taken near 1200 hours daily from one meter below the surface and one meter above the reef, and

initially processed on the ship. With exception of dives to document coral spawning, diving activities were conducted during daylight only.

Prior to May of 1990, field work was conducted with the research vessel either anchored in a large sand flat located outside the study site (West Bank), or tied to a large concrete block on the north edge of the study site (East Bank). In May of 1990, permanent moorings were installed on each bank (five on the West and seven on the East Bank). One mooring was installed in each study site. Each consisted of 1) a 2.5 cm diameter stainless steel U-bolt secured with Type II Portland cement in two, 56 cm deep by 10 cm diameter holes drilled in the reef surface, 2) 5 cm polypropylene line shackled to the U-bolt, and 3) a large surface float and tag line. Following this, Cruises 4 and 5 were conducted with the research vessel tied to moorings within each study site. Cruise 6 was conducted using a large vessel, which remained anchored in deep water at the edge of each bank. Divers were shuttled to and from the study sites in inflatable boats.

3.2 Cruise Summaries

Table 3-1 indicates cruise designations, cruise dates, dates on station, and diving activity on each cruise conducted during the study.

Due to extremely poor weather conditions during the first three months of 1989 and in May of 1989, six legs were required to complete station establishment and data collection on the first cruise. Each leg was suspended by deteriorating weather. A total of 462 dives (34% of all project dives) were required to complete the work on this cruise (predominantly station establishment). With the exception of the second cruise, no other cruise required multiple legs to complete data collection. The average number of person-dives required to complete semi-annual monitoring work was 178 per cruise. An average of 97 were required per cruise on the West Bank, and 81 were required on the East Bank. This was due to the group's familiarity with the East Bank and the study site maps (having established the stations and produced the maps), and the location of the majority of stations within 15 m of the site boundaries.

Table 3-1. Cruise activity, including dates, time on station, and diving activity. Total under Number of Divers (64) indicates number of different divers used on the project.

Cruise	Vessel	On-Site Dates	On-Site Days	Ship Days	Number of Divers	Person-Dives
1a	M/V *Fling*	12/13-12/16/88	3	4	10	75
1b	M/V *Fling*	2/25-2/26/89	2	2	11	57
1c	M/V *Fling*	4/7-4/9/89	3	4	12	97
1d	M/V *Fling*	4/17-4/21/89	4.5	5	10	155
1e	M/V *Fling*	6/3-6/3/89	1	1.5	8	28
1f	M/V *Fling*	6/19-6/20/89	1.5	2	8	50
2a	M/V *Fling*	8/11-8/12/89	2	2	15	96
2b	M/V *Fling*	8/23-8/24/89	2	2	12	92
3	M/V *Eunice B.*	4/22-4/25/90	4	4.5	15	169
4	M/V *Fling*	10/29-11/1/90	4	4	15	212
5	M/V *Fling*	3/24-3/27/91	4	4	8	121
6	R/V *J.W. Powell*	8/30-9/2/91	4	4.5	17	199
		Totals	35	39.5	64	1351

4.0 METHODS

4.1 Random Transects

4.1.1 1989-1991 Transects

During each sampling trip, twenty, 10-meter random transects were photographed at each study site (sand flats were avoided). To achieve randomization of the transect photography, divers were deployed at random throughout the site, where they descended directly to the bottom. Each diver carried a slate containing a list of random numbers between 20 and 100 and a list of random compass headings between 0° and 360°. After descending randomly into the study area, the divers proceeded to the beginning of the first transect by reading the first random number (X) and direction (Y) combination off the slate and swam X number of flipperkicks on a compass heading of Y. The divers photographed the transect along the same compass heading, then proceeded to the next random transect by kicking a second random number of kicks in a second random direction. Sand flats were avoided in order to maximize the amount of coral population data collected and maximize dive time efficiency.

Divers photographed the reef surface using non-overlapping photography along each transect. Seventeen photos produced 10-meter long transects. Each diver photographed two transects on each dive.

Photographic equipment included a Nikonos III or V underwater camera, 28 mm lens, 36 exposure, 100 ASA Kodacolor VRG or Fujicolor film, and two Ikelite 150 watt-second strobes mounted on a stainless steel camera frame that enclosed a 60 by 85 cm area of seafloor (Photo 4-1). Photos include approximately 44 by 63 cm of seafloor. The bottom of the camera frames were padded with foam pipe insulation to prevent damage to corals.

Areal coverage on random transects was considered the downward projection of a colony onto a two-dimensional substrate (Photo 4-2). Data on coral, leafy algae, and sponge cover was acquired using a Numonics Corp. model 1224 electronic digitizing planimeter and electronic graphics calculator. Colonies on photographs were outlined using the calibrated planimeter, and colony cover automatically calculated. Percent cover data

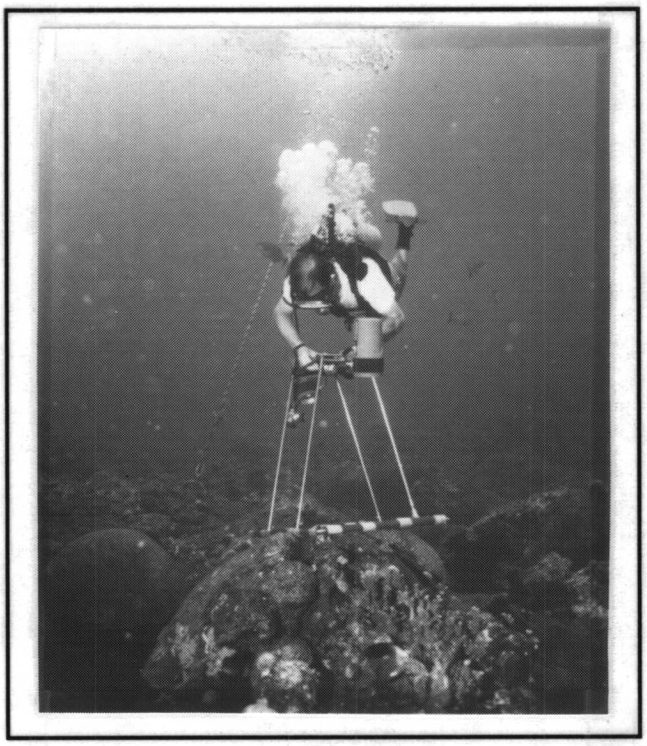


Photo 4-1. Diver using camera framer to photograph random transects 10 m in length. Seventeen side-by-side, non-overlapping photos compose each transect. Twenty transects were photographed on each bank during each sampling cruise. Foam pipe insulation on framer base protects corals from abrasions caused by bottom contact (photo by G.S. Boland).

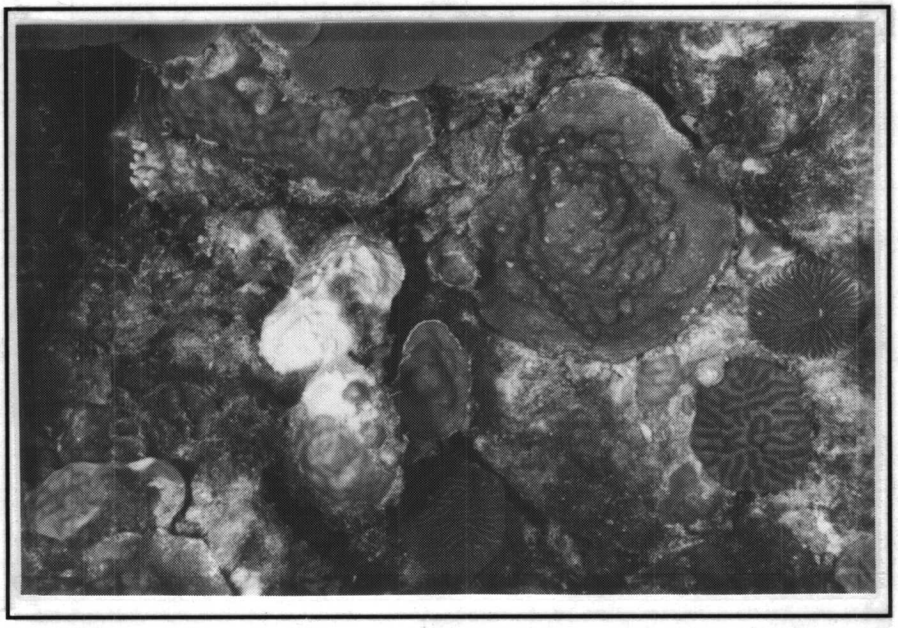


Photo 4-2. Example of photographs resulting from transect photography (color photos make species identification easier than black-and white photos such as this one). Colony borders were outlined using a digitizing planimeter and cover calculated electronically.

were acquired for all coral species, leafy algae, sponges, and reefrock on the photographs. Also calculated was the number of colonies of each species, relative dominance of each coral species (percent cover relative to total coral cover), species diversity (from the natural log form of the Shannon-Weaver Diversity Index), and evenness (species diversity divided by the maximum possible diversity; i.e., the natural log of the number of species present). For species diversity and evenness based on coral cover, p_i in the diversity formula $H'=-\Sigma\ p_i \ln p_i$ was relative dominance.

A distribution-free analysis of variance procedure for multiple samples, the Kruskal-Wallis test, was used to determine whether statistical differences existed between time periods or between sample sites. The parameters examined were those given above.

Where significant differences were found, a Tukey's multiple range test was applied in order to determine which time periods show differences. Tukey's test is recommended over the more commonly used Duncan's multiple range test, since it tends to reduce the experimentwise error rate (SAS Institute, Inc., 1985). That is, the tendency for so-called Type I errors, the probability of rejecting the null hypothesis when it is true, is reduced relative to less conservative multiple range procedures.

4.1.2 Historic Data

Population, recruitment, and growth data for corals at the Flower Gardens were presented by Abbott (1979), Viada (1980), Kraemer (1982), a number of Bureau of Land Management and Minerals Management Service reports prepared by Dr. Thomas Bright and his research group, Bright et al. (1984), Continental Shelf Associates (1985), Rezak et al. (1985), and Gittings and Bright (1986). Data from these studies, where appropriate, were compared to data collected during this study.

Plans for future research include reanalysis of photographs taken in the 1970's and early 1980's using methods developed in this study. This will be an effort to directly compare data. Previous studies used the line-intercept method to measure coral populations, whereby only portions of corals intersected by a transect tape were quantified. Using random transect photography and planimetry, recent photos have been analyzed by calculating areal cover of all corals in photographs.

4.2 Accretionary Growth

4.2.1 Growth Spikes

Thirty spikes were implanted in the tops of colonies of the star coral, *Montastrea annularis* to monitor accretionary growth of this species at each of the study sites at the Flower Garden Banks. The 20-cm stainless steel spikes were driven into corals using a modified air hammer attached to a diver's scuba tank. The air hammer had an attachment which drove the spike in 10 cm and left 10 cm exposed above the coral surface. Numbered plastic tags were attached to the spikes for station identification (Photo 4-3). Periodic measurements of the spike to the nearest millimeter provided estimates of accretionary growth.

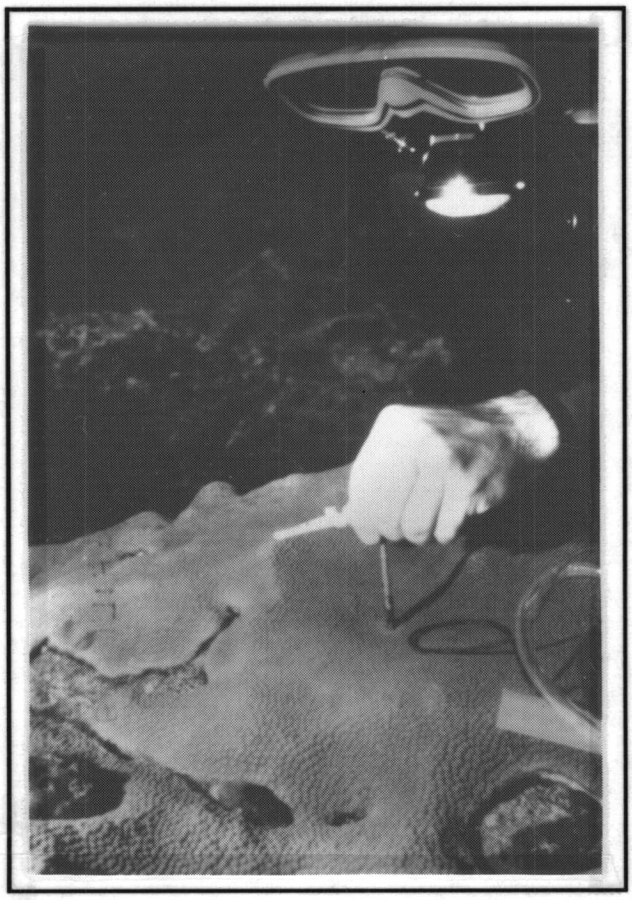


Photo 4-3. Accretionary growth spike in the top of a *Montastrea annularis* colony. Numbered, plastic tags were attached to the tops of each spike for identification. Measurements of spikes at six month intervals provide estimates of upward, or accretionary, growth of colonies (photo by G.S. Boland).

This method has been used by a number of investigators and can be problematic. This is because (1) nail height measurements can be difficult to make accurately due to the convoluted and rugged surface texture of coral heads (especially on the brain corals, *Diploria* spp.); (2) repeated contact with one area of coral tissue (i.e. during measurement) may lead to the death and necrosis of such tissue and the interruption of accretionary growth; (3) the implantation of growth spikes, which necessarily causes some tissue destruction, also sometimes leads to infection by filamentous algae; (4) occasional, but inevitable, loss of some growth spikes results in the loss of data; (5) loose spikes cannot provide meaningful data; and (6) the presence of the spike can alter growth patterns (e.g., occasionally, coral tissue rapidly grows upwards on the spike). Nevertheless, when the condition of spikes is carefully monitored, and data used judiciously, this method can be an effective way to acquire a large number of estimates from a large number of samples.

Data from growth stations were carefully examined to avoid including information from stations affected by any of the problems mentioned above. Some stations (11 of 60) were completely deleted from the analysis, generally because spikes were loose throughout the study. For those stations with spikes that were loose for only a portion of the program, data were deleted for those time periods only. Overall, 52% of measurements provided useful data.

In estimating growth rates from each bank, data from each station represented single estimates (samples) of accretionary growth. Each sample was based on two, three, four, or five intervals, depending on the integrity of the station.

Samples used to estimate accretionary growth rates between cruises were those stations for which data were collected on sequential cruises in the interval. Growth rate estimates for each interval were sample averages.

4.2.2 Sclerochronology

We also used sclerochronology (measurement of skeletal growth bands) to determine accretionary growth rates of corals (e.g. Hudson, 1981). Cores from coral heads were taken in May of 1990 from four *Montastrea annularis* coral heads, two at the East Flower Garden Bank, and two at the

West Bank (at approximately 23 m depth; J. Halas, pers. comm.). Growth rates were determined by measurement of annual corallum density changes (Hudson et al., 1976). It is widely recognized that these growth data are more accurate than underwater measurements, though acquisition is more difficult.

Coral cores were processed in St. Petersburg, FL, at the U.S. Geological Survey facility, under the direction of Dr. Robert Halley. Cores were "slabbed" using a diamond-impregnated saw, resulting in 3-4 mm thick samples, then X-rayed to reveal density bands. A pair of low and high density bands define one annual accretionary growth increment. (Knutson et al., 1972; Macintyre and Smith, 1974; Dodge et al., 1974; Dodge and Thompson, 1974; Hudson et al., 1976). The upper boundary of each high density band was considered as the line separating annual growth increments.

Previous studies of annual bands and coral growth generally have employed single or several linear measurements of individual growth bands along a "growth axis" (e.g. Hudson et al., 1976; Figure 4-1). Using planimetry, it is possible to integrate data throughout the entire growth band during any single year (or multiple fragments, if an entire band is not well defined). Acetate overlays were used to delineate annual growth increments, which were traced from the coral onto the overlay. Areas of each annual growth band were then measured on overlays using planimetry.

Accretionary growth was determined by first measuring annual growth areas contained between right and left parallel microstructural borders within each annual band (Figure 4-1). A given year band may contain several of these areas. The annual accretionary growth rate was then calculated by dividing the sum of calculated areas by the sum of the lengths of the bases of these areas.

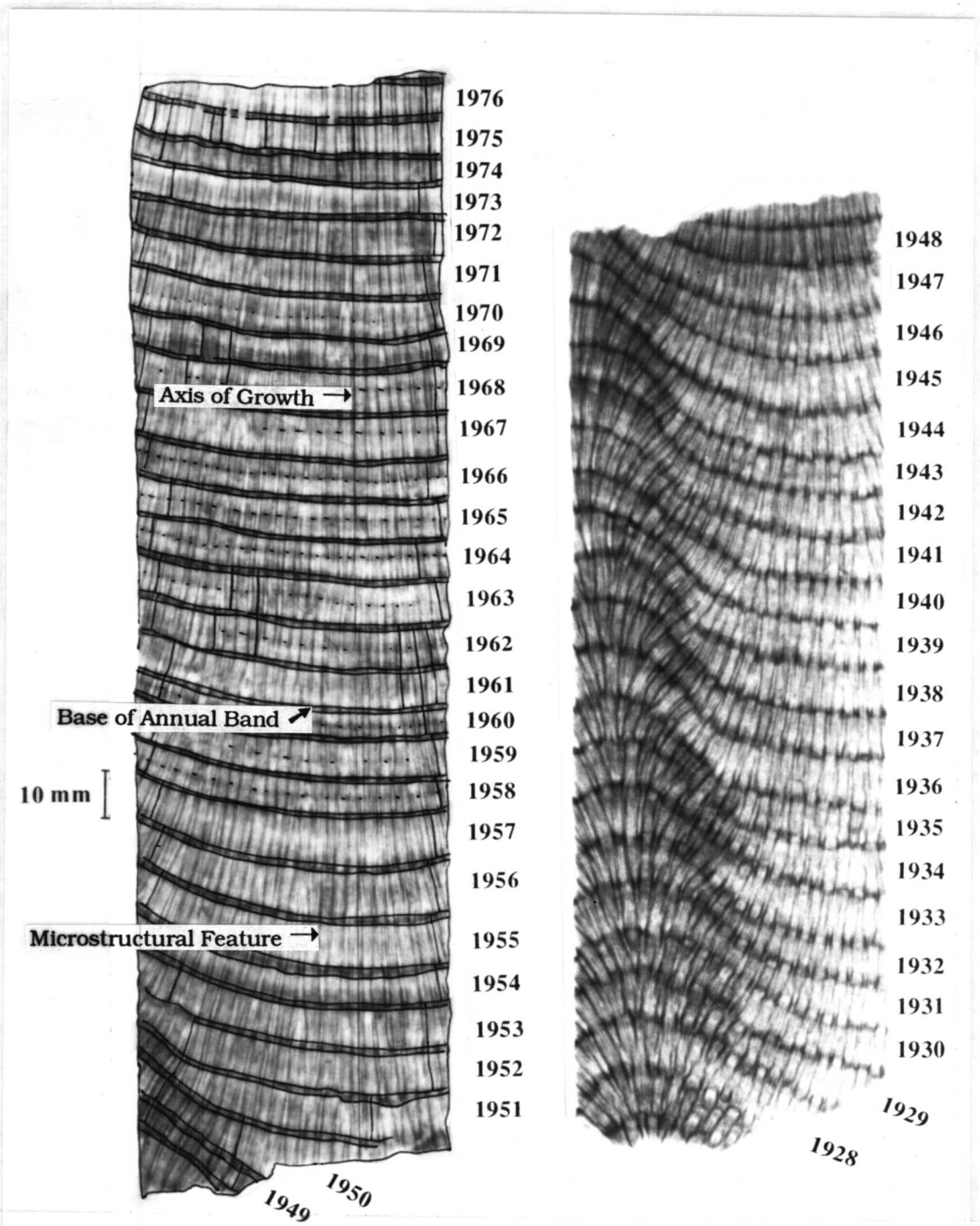


Figure 4-1. Elements of a portion of a processed coral core from the West Flower Garden Bank, showing axis of growth, annual bands (labeled by year), microstructural features within annual bands, and bases of annual bands. Left X-radiograph includes acetate overlay. Right X-radiograph does not.

4.3 Encrusting Growth

Each permanent station for monitoring encrusting (lateral) growth of *M. annularis* or *D. strigosa* was established using two 10 cm long nails made from 0.3 cm diameter stainless steel welding rod (Photo 4-4). They were installed 23 cm apart so that a Plus 5 diopter framer attached to an underwater lens and camera could be placed directly over the nails and encompass a repeatable 13.3 by 19.7 cm photographic area (Photo 4-5). The stations were established so that the colony border traversed the approximate center of the photographic frame (Photo 4-6). Nails were driven only into bare substrate and contained numbered plastic tags. This methodology was used successfully in studying coral growth on damaged and undamaged coral heads following a freighter grounding in the Florida Keys (Bright et al., 1987).

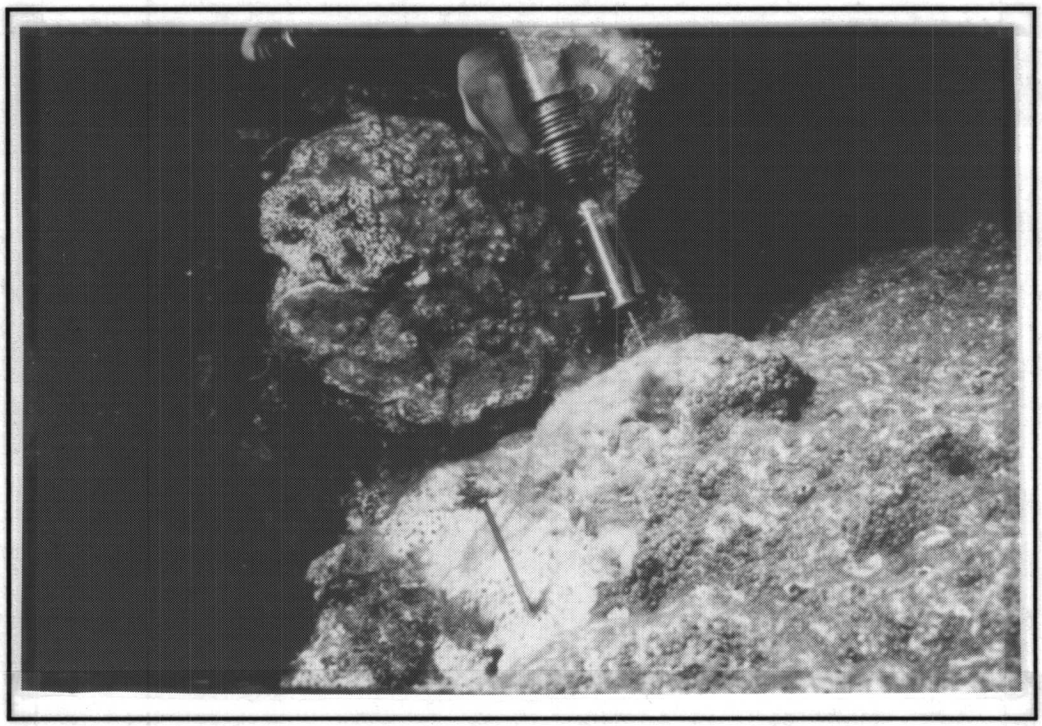


Photo 4-4. Establishment of encrusting growth station using a pneumatic hammer with modified hammer bit (air supplied from diver's tank). This apparatus was used to drive nails or accretionary growth spikes to specified depths into coral heads, leaving them exposed for easier location or measurement (photo by G.S. Boland).

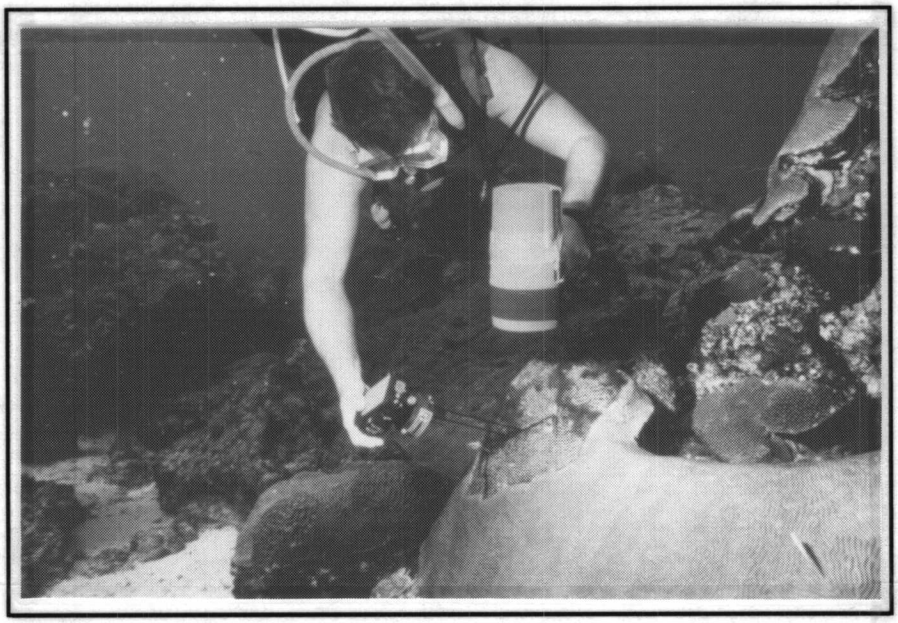


Photo 4-5. Diver photographing encrusting growth station with diopter framer attached to an underwater camera (photo by G.S. Boland).

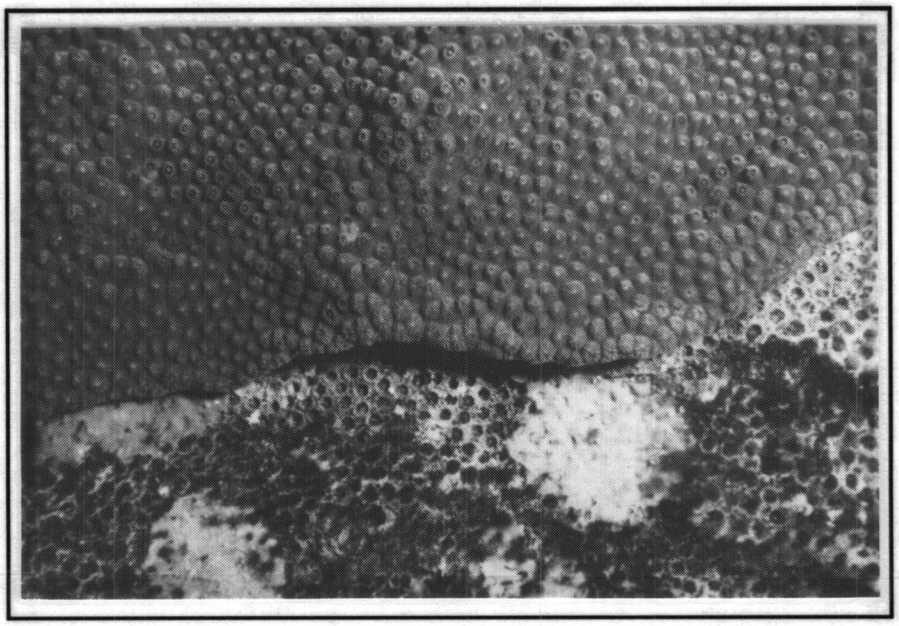


Photo 4-6. Close-up photograph of *Montastrea annularis* encrusting growth station. Polyp mouth positions are at the centers of each polyp, and many appear as white dots.

At each study site, 60 stations were established on coral heads of the species *Montastrea annularis* and 60 on heads of *Diploria strigosa*. Each station that remained intact between sampling visits was photographed using a Nikonos III or V underwater camera, 28 mm lens, plus 5 magnifying diopter framer, 100 ASA Kodacolor VRG or Fujicolor color print film and one Oceanic 2000 strobe, or Ikelite 150 watt-second strobe. Camera settings were 1/60 second (for the Nikonos III) or M90 (for the Nikonos V) shutter speed, minimum or maximum focus (depending on diopter lens used), and f/16 or f/22 (depending on strobe used). Stations were located using maps of the study sites printed on underwater paper. The maps were modified throughout the course of the study as stations were lost or altered.

Growth and retreat were measured by projecting sequential images of coral margins onto the same surface using an image enlarging/reducing map projector (matching polyp mouth positions for *M. annularis* and ridge features on *D. strigosa*). This was followed by planimetric measurement of areas of growth and retreat, and border lengths over which the changes occurred (Gittings et al., 1988). Growth and retreat rates for each station (in cm/6 months) were calculated by dividing planimetric measures of change (cm^2) by the total analyzed border length of the station (cm). Net growth was measured by pooling growth and retreat measurements. Stations provided single estimates (samples) of each measure (growth, retreat and net rates), regardless of the number of areas of growth or retreat present.

4.4 Repetitive Quadrats

Permanent posts marking repetitively photographed sites for monitoring changes in individual colonies were driven into 1.6 cm diameter holes drilled approximately 15 cm into the reef substrate (Photo 4-7 and 4-8) and tagged with numbered plastic tags. These holes did not contact living coral tissue.

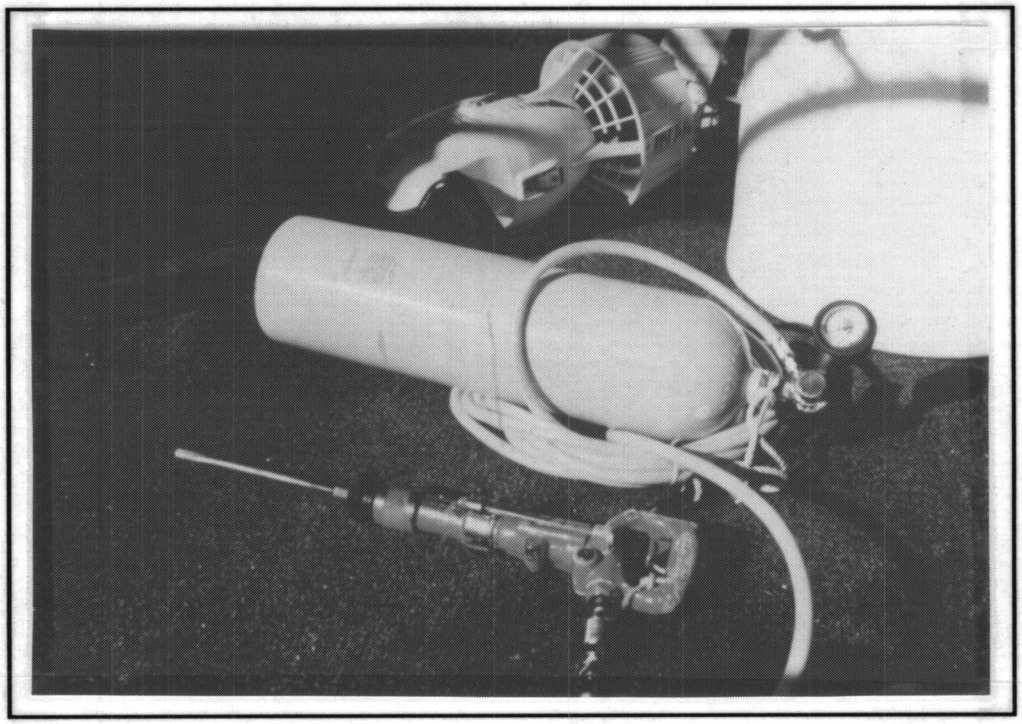


Photo 4-7. Pneumatic hammer and star drill bit used to drill holes in reef for the installation of permanent posts at repetitively photographed quadrats (photo by G.S. Boland).

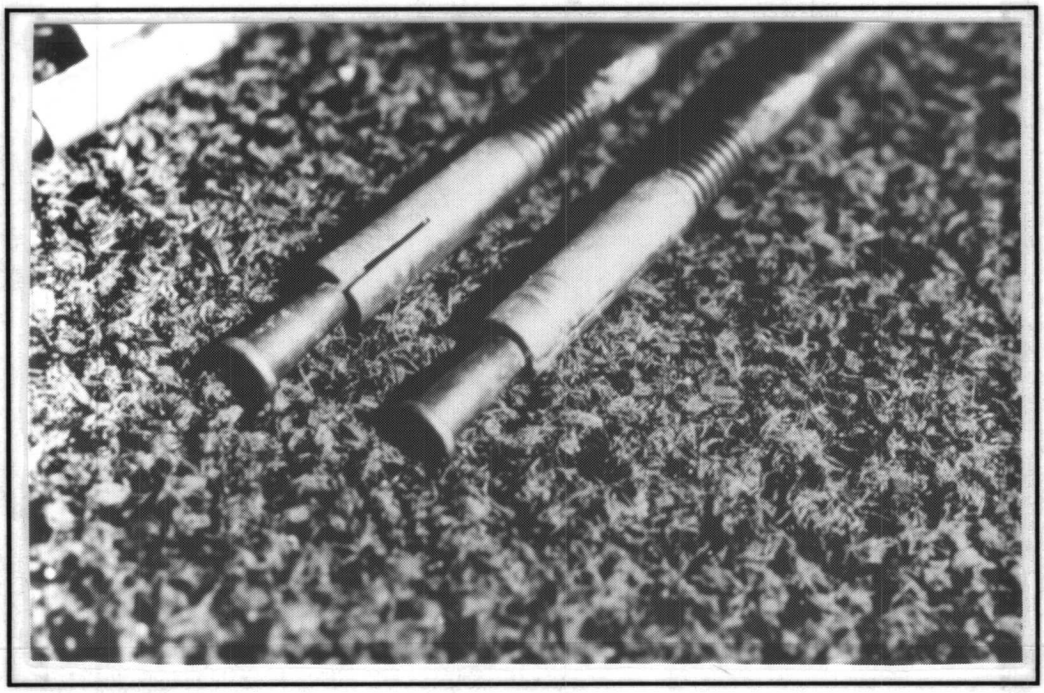


Photo 4-8. Stainless steel rod with attached stud anchors which flare when driven into holes in reef surface. Flared stud anchors secure the rods into the reef. Rods marked the centers of repetitively photographed quadrats (photo by G.S. Boland).

Initially, a camera frame was fabricated that was used to compose a photographic mosaic covering 10 m^2 surrounding each post. The camera frame (shaped like a Γ) was constructed to allow photography of an area out to 1.8 m beyond the center post marking the station. The camera was mounted on the camera frame 0.9 m from the post, and provided photographs of slightly over 2 m^2 each. A Nikonos V camera was used with a 15 mm wide angle lens, two 225 watt-second strobes, and 36 exposure, 100 ASA Kodacolor VRG or Fujicolor print film. Twelve photos were taken around each permanent post, one every 30° of a compass.

This method was used only on the first sampling cruise. It was determined that the method did not provide repetitive samples. Methodological problems led to analytical uncertainties so severe as to make the method inadequate for the detection of the coral community changes it was originally proposed to detect. These included:

- Many corals in each study site were duplicated in successive photographs due to the circular nature of the photography. This was especially so near the center of the study sites. Duplication of photographs wasted dive time and led to severe analytical problems described below.

- Distortion of duplicated coral heads caused by taking photos from different angles and different distances in successive photos resulted in individual colonies having apparent size differences of over 50% in overlapping photos. The problem was exacerbated by the considerable three-dimensionality of coral reefs. It was therefore impossible to overlay photos in the lab in a way which allowed the detailed analysis required for the detection of even moderate changes on the reefs. Only the largest disturbances could be detected in quantitative analyses.

- Tilt of the camera or camera frame affected distance above individual corals. Minor tilt caused significant camera movement due to the distance of the camera from the center post. It varied between photos on the same mosaic and between sampling periods, and depended on diver care and coordination.

- Inadvertent twist of the camera frame (angle variation averaged 2.5° or so) was a problem also accentuated by the distance of the camera from the center post. That is, a small compass error causes the camera position on the arc to change considerably. This resulted in photographs being taken at considerably different angles and distances from given coral heads over successive sample periods.

- Variations caused by the above problems resulted in large variations in the size of duplicated corals and in the relative position of duplicated and adjacent corals, making overlap impossible.

In September 1989, we proposed the elimination of multiple photograph, circular mosaics, and instituting a method that would provide single photos of each repetitively photographed stations.

We proposed the following method for the acquisition of field data for 8 m^2 repetitively photographed stations. The method was tested in the field and in the lab in order to examine its potential for fulfilling the objectives of the program. Single photographs were to be taken at each station during each sampling effort using a T-shaped camera frame equipped with a down-looking Nikonos V underwater camera, 15 mm lens, two 225 watt-second strobes, double sync cord, a compass, and a bubble level (Photos 4-9 and 4-10). The height of the camera above the bottom was maintained by a single aluminum angle post 2.0 m in length. The photos would be taken with a compass heading of 000° and the bubble level centered above the station post. Laboratory test results suggested that, over five sampling periods, we could expect to cover approximately 90% of each station in 100% of the photographs (Photos 4-11 to 4-15).

Important advantages offered by the alternate method were:

- Size distortion was minimized by the increased height off the reef, and lack of variation in distance to given corals resulting from camera angle error and tilt.

- Tilt caused only minimal distortion and was itself not a significant problem when care was taken for each photo. Also, the fact that the camera was a specified distance above the center point of the station meant that tilt did not affect the distance of the camera above given coral heads as it did with a Γ-shaped camera frame.

- Twist was not a serious problem because distance of the photograph mid-point from the centerpoint of each station was zero. Furthermore, twist did not result in significant analytical problems. The average twist of less than 2.5° (measured in tests) resulted in the loss of only 5% of the station data on sequential photographs.

- Even with tilt or twist, the slight change in the relative position of individual coral heads did not affect laboratory analysis. We detected no measurable difference in the apparent sizes of items of known size in successive test photographs in which twist and/or tilt occurred.

Photos 4-11 to 4-15. Sequence of repetitive quadrat photographs taken from Cruise 2 through Cruise 6. Note high repeatability of photography method. Even in photo areas that were not exactly repeated, apparent size of individual colonies did not vary measurably. Dark line in each photo is the T-frame post; it is in the south center of each photo. Note consistent loss of tissue in diseased coral slightly north of center and in colony in northwest corner. Large colony on eastern border appears to have "ridge-mortality" in Photo 4-12.

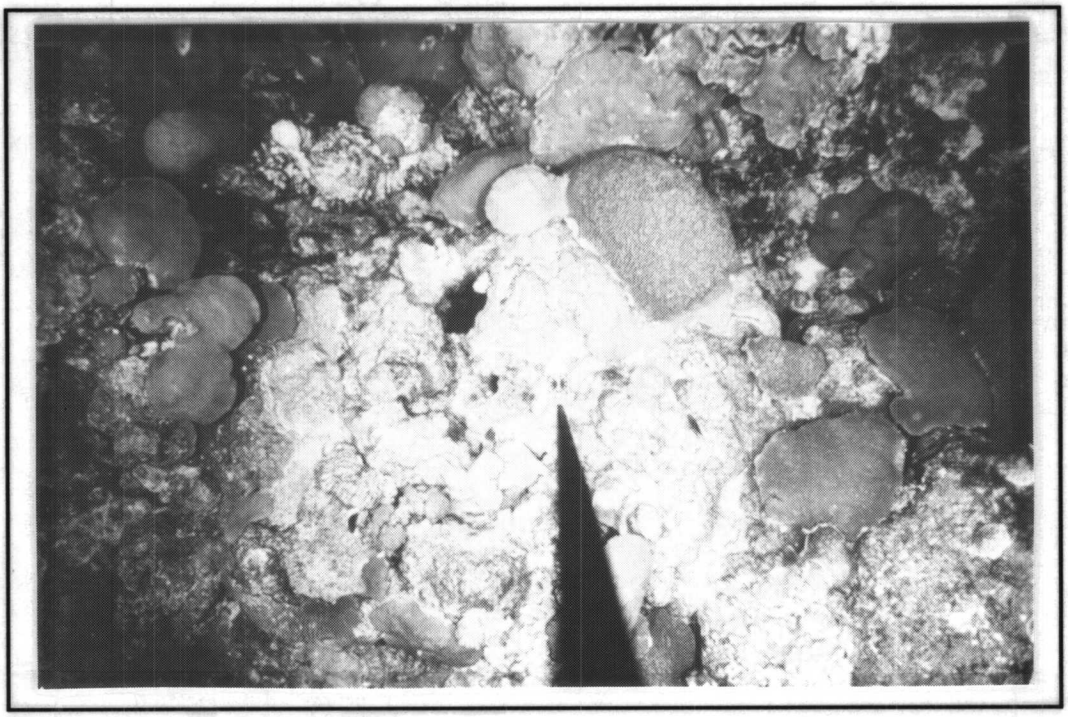


Photo 4-11

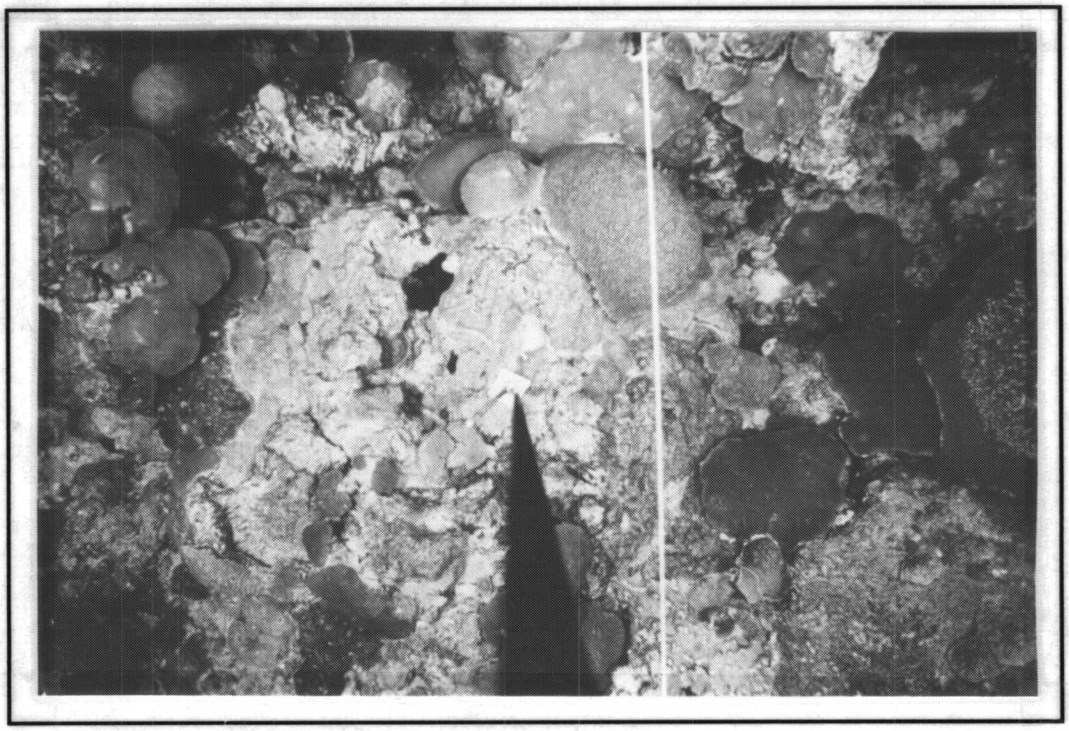


Photo 4-12

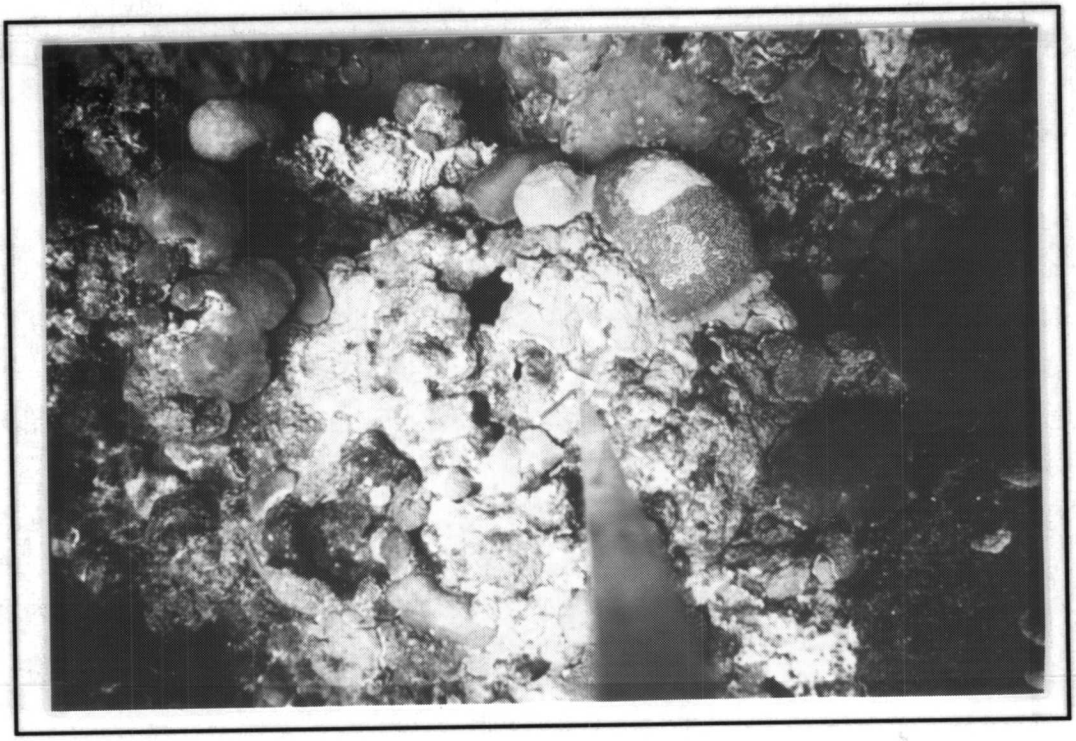


Photo 4-13

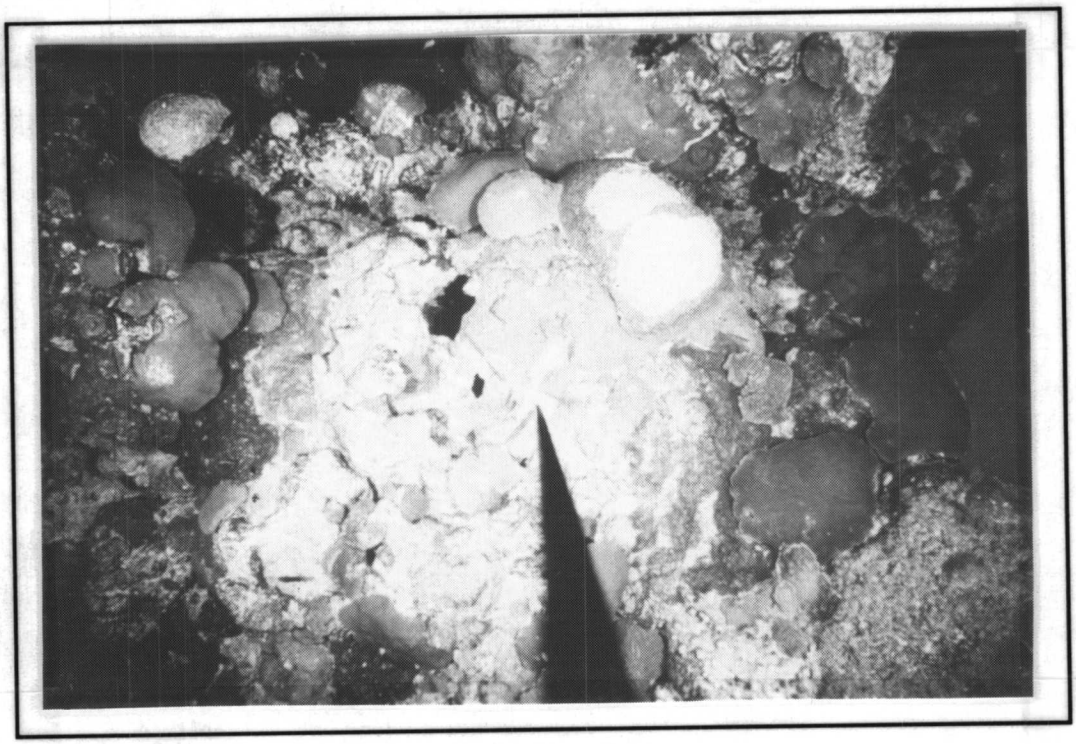


Photo 4-14

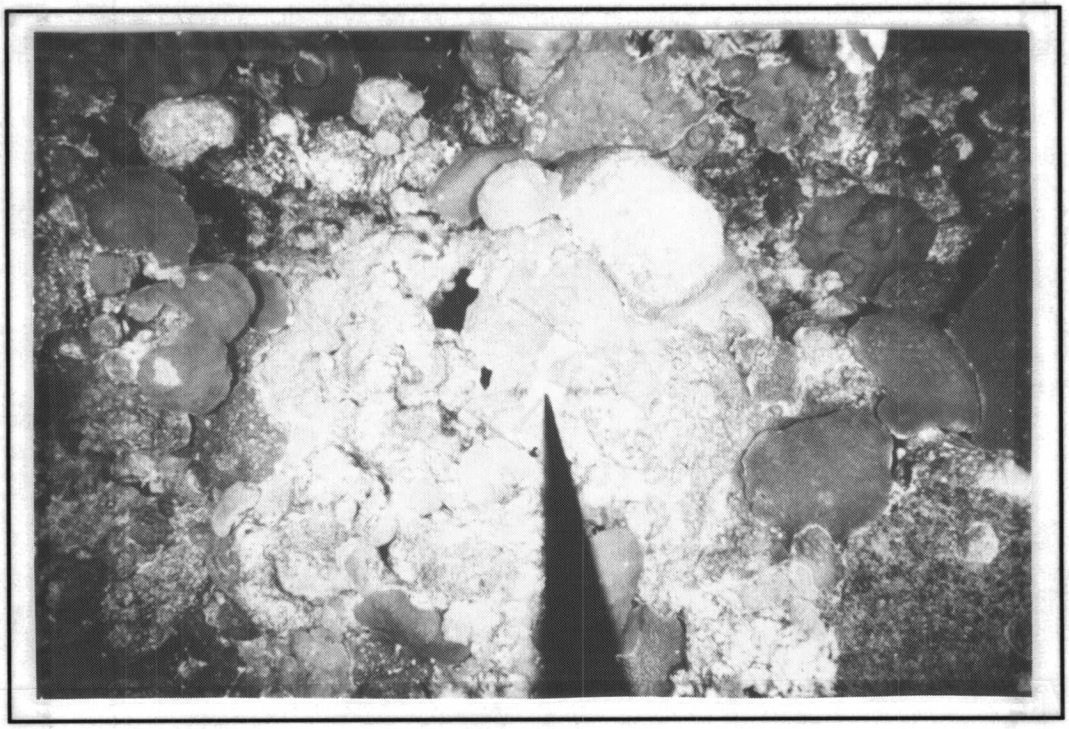


Photo 4-15

To determine the optimal size of samples, a series of species-area curves were generated from previous samples. Such curves can be used to indicate the photographic area necessary to provide representative samples of the coral reef community. We used data from 24 random transects (12 on each bank) taken in 1989 and determined that sample sizes of approximately 8 m^2 provided representative samples (based on the approximate top of the species-area curve). Increasing the effort beyond this point would only add an occasional rare species to the data. Thus, the majority of species were obtained in samples of 8 m^2.

Photographs from the first project cruise generated using the initial method were assembled into station mosaics. These mosaics were used for reference when questions arose on later slides of repetitive stations regarding, for example, species identification, causes of mortality, extents of bleaching, or the onset of infection.

Station slides produced on the second cruise were considered station masters, or baseline data against which subsequent slides would be compared. Slides were projected onto a table top to produce images 25.2

cm by 37.9 cm. Templates were produced for each station by tracing living and dead portions of all visible colonies. Colonies were counted, and percent coral cover calculated using overlays containing 100 randomly located crosses. Cover was the total number of crosses intersecting live coral. Three estimates were made of cover at each Cruise 2 station.

Comparisons of slides produced on Cruises 3 through 6 were made by overlaying baseline templates (Cruise 2 colony borders) on projected images, and comparing colonies one by one. Changes were determined by sketching differences between Cruise 2 templates and projected images from subsequent cruises with pencils color-coded by cruise. Changes were then characterized using the following categories: growth, disease, bleaching, algae-mediated or algae/sediment mat-mediated retreat, unexplained mortality, and mechanical damage. The result of changes was determined using the following categories: growth, mortality, recovery, or no effect.

4.5 Ancillary Measurements

4.5.1 Dissolved Oxygen

Water samples were taken daily while on site from PVC Niskin bottles tripped by divers at two depths: one meter below the surface and approximately one meter above the bottom. Samples were preserved in glass bottles rinsed with sample water before collection. Care was taken to ensure that bubbles were removed from tygon tubing before the flasks were filled. Flasks were overflowed one full volume and the stoppers inserted to avoid trapping air bubbles.

The technique used for analysis of oxygen was the modified Winkler technique of Carpenter (1965). As soon as possible after collection, samples were "pickled" by the addition of a divalent manganese solution (MgCl), followed by strong alkali (NaOH). The precipitated manganous hydroxide is dispersed evenly throughout the seawater sample which completely fills the stoppered oxygen flask. Any dissolved oxygen rapidly oxidizes an equivalent amount of divalent manganese to basic hydroxides of higher valency states. When the solution is acidified in the presence of iodide, the oxidized manganese again reverts to the divalent state, and iodine equivalent to the original dissolved oxygen content of the water, is liberated. The iodine is

titrated with standardized sodium thiosulfate (Strickland and Parsons, 1972). The accuracy and precision of the method are operator-dependent, but accuracy and precision are generally better than ±0.003 ml/L. Titrations were performed by Technical Operations in the Department of Oceanography of Texas A&M University.

4.5.2 Salinity

Surface and near-bottom salinity samples were taken from Niskin bottles and transferred to 500-ml citrate bottles that had been triple rinsed with sample water before collection. These bottles were air tight.

Samples taken for salinity were analyzed by Technical Operations using a Guildline Model 8400 Autosal Laboratory Salinometer by measuring conductivity directly.

4.5.3 Temperature

Temperature was measured by divers using a thermometer at approximately one meter depth and one meter above the bottom. Air temperature measurements were also frequently made. Temperatures were determined using a certified bucket thermometer. The bucket thermometer's calibration per NBS Monograph 150 is performed by the manufacturer (Brooklyn Thermometer Co.) at five points in the range of the thermometer. The accuracy of these points is ±0.03°C. All thermometers equilibrated at depth for at least five minutes before reading.

Sea surface temperature data between 1979 and 1990 were collected from records of AVHRR satellite transits. Temperature data were taken specifically from the vicinity of the Flower Garden Banks to determine the average weekly temperature regime over the course of a year and to compare 1990 data (an anomalous year) to long-term averages.

In 1990, Ryan TempMentor thermographs were installed on the banks to record bottom temperature every two hours. Accuracy is ±0.3°C. Thermographs were provided by the National Oceanic and Atmospheric Administration, Sanctuaries and Reserves Division. Depths of the thermographs were 19 m at the EFG and 24 m at the WFG. The thermograph on the East Bank was lost between its installation in August

1990 and October 1990. A replacement was purchased and installed in March 1991.

Data were collected from thermographs during each sampling cruise, and batteries replaced. Data were dumped to laptop computers, hard copies of data printed, and graphs produced.

4.5.4 Light

Light measurements were made on deck, at a depth of one meter, and one meter above the bottom using a Biospherical Instruments QSP 200L Submersible Quantum Scaler Irradiance Meter (Photo 4-16). Measurements were made for five minutes at each depth and converted to quanta/sec/cm^2.

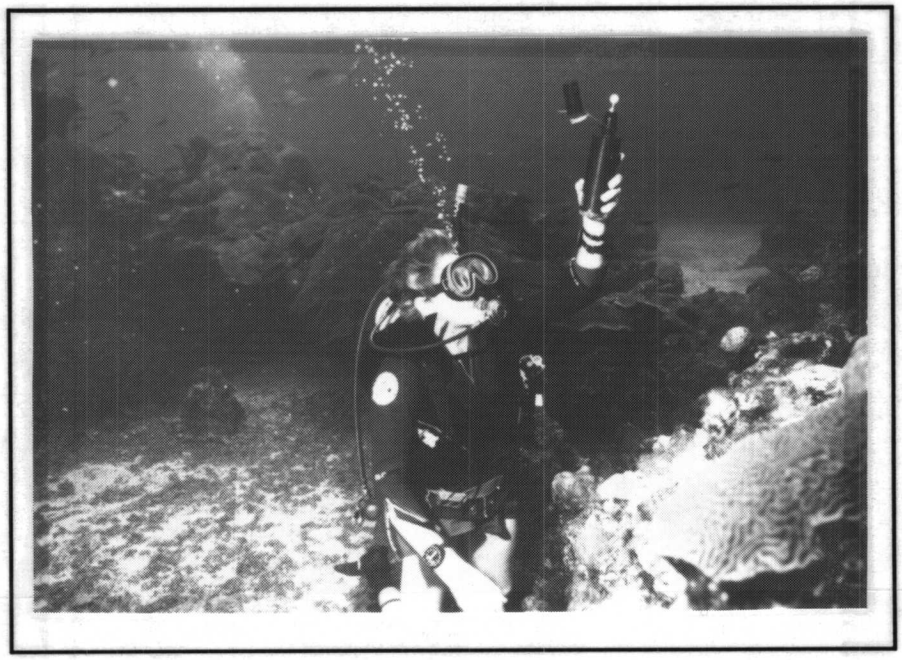


Photo 4-16. Diver taking five-minute light measurement approximately one meter above the bottom using a Biospherical Instruments QSP 200L Submersible Quantum Scaler Irradiance Meter (photo by G.S. Boland).

4.5.5 Barium

Skeletal samples of *Montastrea annularis* from the West Flower Garden Bank were analyzed for their trace metal content by Instrumental Neutron Activation Analysis (INAA), using a high resolution pure germanium detector. INAA was performed at the Center for Chemical Characterization and Analysis at Texas A&M University. Annual growth bands from 1910 to 1989 were taken from one *M. annularis* core sampled at the West Flower Garden Bank. Sclerochronology (see section 4.2.2) was used to delimit annual growth bands on core slabs. Individual annual bands were separated using a 0.28 mm thick Thin Flex Abrasive Tech diamond impregnated blade mounted on a variable speed Dremel tool. In order to clear samples of non-lattice-bound trace metals, cuttings were thoroughly cleaned before INAA following a modified methodology of Shen and Boyle (1988).

The dry weight of individual samples was recorded to 0.01 g before and after cleaning. Individual samples were cleaned in an Ultrasonic bath. The cleaning process involved six steps: 1) one wash with quartz distilled water; 2) two washes (4 min each) in 0.2N ULTREX HNO_3; 3) 20 min in 50%-50% oxidizing mixture of 30% H_2O_2 and 0.2N NaOH; 4) two washes (4 min each) in 0.2N ULTREX HNO_3; 5) two rinses with quartz distilled water; 6) samples were dried overnight at 65°C. Samples were then individually crushed using an agate mortar and pestle. One gram of each of the following annual growth increments was used for INAA: 1910, 1920, 1925, 1930, 1935, 1940, 1943, 1950, 1953, 1956, 1960, 1966, 1970, 1973, 1977, and 1980. Two replicates were done for 1985 and 1989.

Limitations to the determination of Ba/Ca molar ratios by INAA include interferences by the elements uranium (U) and strontium (Sr). For uranium, INAA induces the production of isotopes through neutron induced fission. Both interferences were taken into account for calculations of Ba/Ca molar ratios.

4.6 Video Transects

Diver-held-video recordings along repeated transects enables the observation of a relatively large area in some detail for the evaluation of long-term changes. Returning to the same location during two seasons each year

permitted a census of macro features of the coral reef habitat not possible in the larger scale of towed video systems or within the smaller scale of 10 m random transects. Gross changes in various community components along the video transect can be estimated, as can the temporal stability of megafauna and flora (i.e., presence/absence and variations in density) and significant changes in size or percent coverage (e.g., algal cover).

Two videotaped transects of 100 m length were acquired at each study site during each cruise to show the general conditions of the coral community at the sites. The video was taken from approximately two meters above the bottom at an angle of 45°. Video transects were taken along 100 m lines tautly strung along two sides of each survey area. These lines were laid for video transect sampling and to orient divers, and removed after each site survey was completed. They served to establish semi-repeatable survey transects that could be mapped to show distinctive features such as areas of sand, high coral density, and diseased or damaged corals. A weighted line two meters long was attached to the video housing during the swimming of video transects. The end of this line was kept near the bottom to maintain a nearly constant camera altitude.

Transects videotaped at the East Flower Garden Bank were along the north and east boundaries, beginning at the northwest corner. Transects videotaped at the West Flower Garden Bank were along the south and west boundaries, beginning at the southeast corner.

Equipment included a Sony CCD-V9 8mm, computer chip imaging camcorder, in an Amphibico housing. The Sony camera has a 12-72 mm f/1.6 macro lens with autofocus and automatic exposure.

Video transects were analyzed using a system of either one or two 8 mm videotape players, each with its own television monitor. Tapes were analyzed by viewing the recorded image(s) on the monitor(s) and recording pertinent information on pre-printed log sheets. Individual transects consisted of between four and seven minutes of videotape along one of two 100 m boundary marker lines at each bank. The resulting sample represented a transect width of 3.5 m (measured across the center of the monitor screen) by 100 m in length or a total of 350 m^2 per transect.

Initially, a number of results were anticipated from the videotape records including complete census of all fish and motile invertebrate species. This objective proved to be unattainable, primarily due to the

limitations imposed by the primary purpose of the video transecting (i.e., documentation of long-term changes in the coral community over a relatively large area). The method by which the transects were performed was designed as a compromise between sampling the largest area of coral possible (as determined by increasing camera altitude) and the limitations of resolution imposed by water clarity and 8 mm video image quality. As a result, it became evident early in the analysis that it would not be possible to consistently and reliably census the smaller reef fish, including the abundant brown and blue chromis (*Chromis multilineata* and *C. cyanea* respectively) and the cryptic species such as damsels and small wrasses. The necessary compromise was that fish counts were limited to larger-bodied species only, including creolefish (*Paranthias furcifer*), creole wrasse (*Clepticus parrai*), parrotfish, triggerfish, groupers, tangs, and large wrasses.

The video transecting method also imposed limitations on strict quantitative analyses of coral growth and changes in percent cover. The method was useful for discerning gross habitat changes. However, other still photographic techniques described in this report provided the precision and resolution required to document small-scale changes. Qualitative video analyses for changes in coral community health were performed by the simultaneous use of two video players and monitors. The same video transect from two separate cruises was loaded in each of the players and by use of pause/still frame capabilities on the players, the transects were viewed at the same time. There were some problems in obtaining consistency of position and orientation of the camera as it was "flown" along the transect lines. This is inherent in the technique of free-swimming photographic transects. However, it was generally possible to freeze images of between 10 and 20 large distinctive coral colonies along each 100 m transect and evaluate differences between cruises.

Coral bleaching was quantitatively evaluated by estimating area of complete bleaching. Notations were made of partial bleaching. Still photographic techniques, however, with consistent illumination provided by electronic strobes, were much better suited for evaluations of partial bleaching.

When a bleached coral head was observed, the video player was paused. Using the known field of view, the bleached surface area was estimated on the monitor screen using calipers and a metric ruler.

Planimetry was not utilized because field methodological variation caused by high relief and a lack of accurate camera-to-subject distance information far exceeded the increased accuracy provided by planimetry.

Reef fish density results were tabulated by taxa in numbers/100m^2. Statistical comparisons of densities utilized Student's *t* test, Multiple comparisons were tested using ANOVA.

5.0 RESULTS

5.1 Random Transects

Data analyses included coral counts, coral cover (total and that of individual species), the mean colony sizes of individual coral species, relative dominance of coral species, and species diversity and evenness (based both on coral counts and on coral cover). Comparisons were made between species, between study sites, and between cruises. Comparisons were also made between data acquired in this study and earlier studies at the Flower Gardens (Viada; 1980; Kraemer, 1982; Bright et al., 1984). Tables of results and graphs are presented within this section, where appropriate, and in Appendix A for comparisons not specifically discussed here.

Study sites were chosen because they appeared to represent typical coral reef areas of each bank. In the results presented below, it will be shown that several differences were detected between study sites among various coral community and species parameters. It should be noted that these differences may not reflect differences between the East and West Flower Garden Banks in general. The study sites established on each bank occupy comparatively small areas of the coral reefs atop the Flower Garden Banks (0.5 to 1% at the EFG, and 1.5 to 2% at the WFG). Differences may be due to depth and topographic differences, variations in coral distribution patterns between the sites, and study site locations relative to the currents and other topographic and physical factors which influence community composition. Determinations of differences between coral populations on the banks in general could be accomplished using random sampling techniques similar to those used in this study, but would require sampling over much larger areas of the banks. Nevertheless, monitoring of long-term changes requires knowledge of differences between study sites. In fact, the detection of subtle differences not previously observed at these sites reflects the sensitivity of methods chosen for use in this study.

5.1.1 1989-1991 Transects

5.1.1.1 Coral Cover and Relative Dominance

Total coral cover did not differ significantly ($p>0.05$) between study sites in general (Table 5-1; 46.0% on the EFG and 46.5% on the WFG), or between sites during any cruise (Table 5-2). No significant upward or downward trends in percent coral cover occurred at either study site during the study (Table 5-3).

Among species, significant differences in cover between study sites were observed for four of 14 taxa (data from all cruises were pooled). Cover of *Diploria strigosa* and *Siderastrea siderea* was higher at the West Bank; cover of *Porites astreoides* and *Agaricia* spp. was higher at the East Bank (Figure 5-1). With one exception, no significant differences were observed in cover of individual species between cruises at either site (Tables 5-4 and 5-5). *Porites astreoides* cover varied significantly on some cruises on the West Bank (Table 5-4), but the haphazard groupings suggest no significant temporal trends.

Table 5-1. Comparisons between study sites (cruises combined) of species diversity, species evenness, and percent coral cover. Kruskal-Wallis Tests compare Shannon-Weaver diversity based on coral cover, Shannon-Weaver diversity based on coral counts, evenness based on coral cover, evenness based on coral counts, and percent coral cover. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Cruises Combined	df	F	P-value	Results
H' Diversity (cover)	1,236	5.84	**0.0164**	**East >West**
H' Diversity (counts)	1,236	14.01	**0.0002**	**West >East**
Evenness (cover)	1,236	7.88	**0.0054**	**East >West**
Evenness (counts)	1,236	21.18	**0.0001**	**West >East**
Percent Coral Cover	1,236	0.22	0.6395	ns

Table 5-2. Comparisons between study sites by cruise of species diversity, species evenness, and percent coral cover. Kruskal-Wallis Tests compare Shannon-Weaver diversity based on coral cover, Shannon-Weaver diversity based on coral counts, evenness based on coral cover, evenness based on coral counts, and percent coral cover. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

	Cruise	df	F	P-value	Results
H' Diversity (cover)	1	1,37	0.06	0.8042	ns
	2	1,38	4.09	0.0501	ns
	3	1,38	2.75	0.1053	ns
	4	1,37	0.01	0.9123	ns
	5	1,38	13.44	**0.0008**	**East >West**
	6	1,38	1.50	0.2281	ns
H' Diversity (counts)	1	1,37	0.66	0.4225	ns
	2	1,38	7.36	**0.0100**	**West >East**
	3	1,38	1.18	0.2850	ns
	4	1,37	11.27	**0.0018**	**West >East**
	5	1,38	0.03	0.8735	ns
	6	1,38	20.65	**0.0001**	**West >East**
Evenness (cover)	1	1,37	0.61	0.4388	ns
	2	1,38	3.85	0.0572	ns
	3	1,38	2.20	0.1463	ns
	4	1,37	0.53	0.4724	ns
	5	1,38	18.46	**0.0001**	**East >West**
	6	1,38	1.00	0.3232	ns
Evenness (counts)	1	1,37	1.78	0.1903	ns
	2	1,38	13.13	**0.0008**	**West >East**
	3	1,38	0.02	0.8945	ns
	4	1,37	9.70	**0.0035**	**West >East**
	5	1,38	0.32	0.5767	ns
	6	1,38	24.20	**0.0001**	**West >East**
Percent Coral Cover	1	1,37	0.22	0.6392	ns
	2	1,38	2.29	0.1388	ns
	3	1,38	0.23	0.6325	ns
	4	1,37	0.04	0.8471	ns
	5	1,38	1.72	0.1980	ns
	6	1,38	1.30	0.2612	ns

Table 5-3. Comparisons between cruises (study sites separate) of species diversity, species evenness, and percent coral cover. Kruskal-Wallis Tests compare Shannon-Weaver diversity based on coral cover, Shannon-Weaver diversity based on coral counts, evenness based on coral cover, evenness based on coral counts, and percent coral cover. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$ ("no groups" indicates that the multiple range test was not able to distinguish groups).

	Bank	df	F	P-value	Tukey Groups
H' Diversity (cover)	EFG	5,113	1.48	0.2018	ns
	WFG	5,113	5.00	**0.0004**	**6 1 2 4 5 3**
H' Diversity (counts)	EFG	5,113	2.55	**0.0316**	**1 3 2 5 4 6**
	WFG	5,113	2.83	**0.0191**	**no groups**
Evenness (cover)	EFG	5,113	0.89	0.4903	ns
	WFG	5,113	4.69	**0.0006**	**6 1 2 4 3 5**
Evenness (counts)	EFG	5,113	1.47	0.2064	ns
	WFG	5,113	3.81	**0.0032**	**2 6 4 1 3 5**
Percent Coral Cover	EFG	5,113	2.01	0.0830	ns
	WFG	5,113	0.32	0.8994	ns

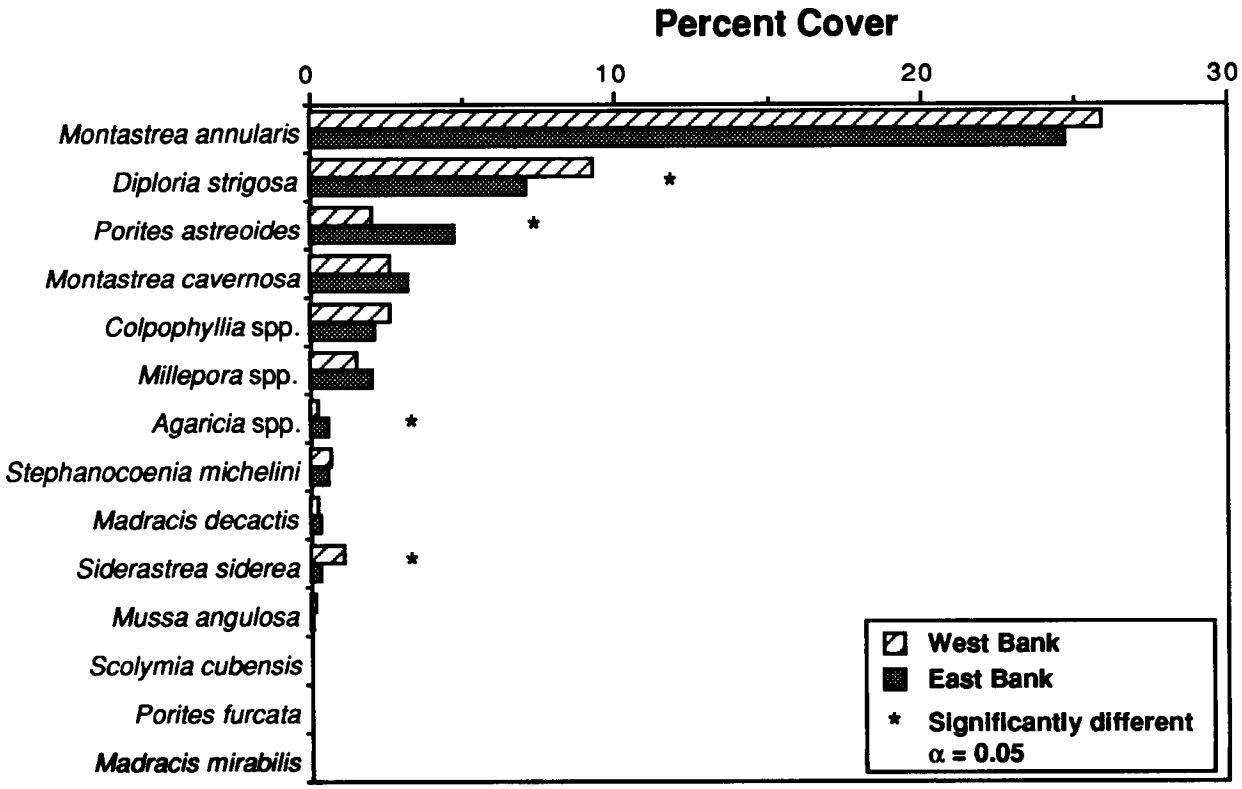


Figure 5-1. Comparison of percent cover of corals between study sites on the East and West Flower Garden Banks. (* indicates cover estimates which are significantly different between banks at $p<0.05$).

Table 5-4. Specific percent cover comparisons between cruises at the West Flower Garden Bank. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

Percent Cover West Flower Garden Bank				
Species	**df**	**F**	**P-value**	**Tukey Groups**
Agaricia sp.	5,111	1.72	0.1350	ns
Colpophyllia spp.	5,89	2.01	0.0845	ns
D. strigosa	5,112	1.52	0.1904	ns
M. decactis	5,49	2.16	0.0733	ns
M. mirabilis	-	-	-	-
Millepora sp.	5,106	1.25	0.2919	ns
M. annularis	5,113	1.47	0.2048	ns
M. cavernosa	5,95	0.27	0.9258	ns
M. angulosa	5,53	0.90	0.4856	ns
P. astreoides	5,113	4.55	**0.0008**	**1 6 4 2 5 3**
P. furcata	1,1	0.00	1.000	ns
S. cubensis	5,56	1.55	0.1883	ns
S. siderea	5,16	1.26	0.3287	ns
S. michelini	5,81	0.57	0.7233	ns

Table 5-5. Specific percent cover comparisons between cruises at the East Flower Garden Bank. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent Cover East Flower Garden Bank				
Species	**df**	**F**	**P-value**	**Tukey Groups (Cruises)**
Agaricia sp.	5,113	1.15	0.3396	ns
Colpophyllia spp.	5,81	1.06	0.3912	ns
D. strigosa	5,112	0.27	0.9268	ns
M. decactis	5,67	0.95	0.4539	ns
M. mirabilis	-	-	-	-
Millepora sp.	5,108	0.33	0.8924	ns
M. annularis	5,113	1.66	0.1506	ns
M. cavernosa	5,90	1.80	0.1216	ns
M. angulosa	5,28	1.73	0.1598	ns
P. astreoides	5,113	2.14	0.0660	ns
P. furcata	5,6	1.97	0.2169	ns
S. cubensis	5,46	1.37	0.2513	ns
S. siderea	5,15	0.36	0.8652	ns
S. michelini	5,86	0.29	0.9181	ns

Significant differences in relative dominance between study sites were observed for the same four species for which percent cover differences were observed. Relative dominance of *Diploria strigosa* and *Siderastrea siderea* was higher at the West Bank; relative dominance of *Porites astreoides* and *Agaricia* spp. was higher at the East Bank (Figure 5-2). With three exceptions, no significant differences were observed in relative dominance of individual species between cruises at either site (Tables 5-6 and 5-7). Relative dominance of *Porites astreoides* and *Montastrea annularis* varied significantly on some cruises on the West Bank, as did *Scolymia cubensis* on the East Bank. In each case, the haphazard groupings, broad overlap, and lack of significant differences between cruises conducted early and late in the study suggest no significant temporal trends.

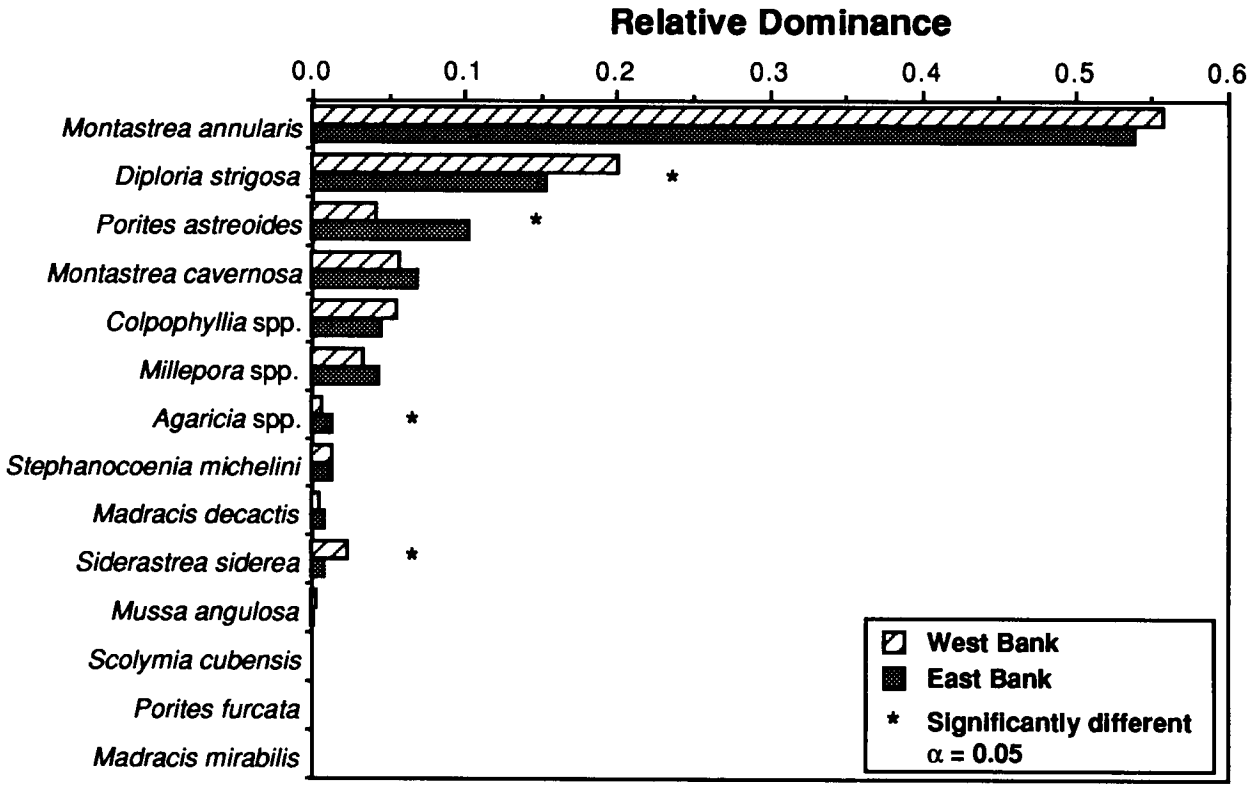


Figure 5-2. Comparison of relative dominance of corals between study sites on the East and West Flower Garden Banks. (* indicates relative dominance estimates which are significantly different between banks at $p<0.05$).

Table 5-6. Specific relative dominance comparisons between cruises at the West Flower Garden Bank. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

Relative Dominance West Flower Garden Bank				
Species	**df**	**F**	**P-value**	**Tukey Groups**
Agaricia spp.	5,111	1.50	0.1965	ns
Colpophyllia spp.	5,89	1.94	0.0954	ns
D. strigosa	5,112	1.36	0.2462	ns
M. decactis	5,49	1.89	0.1124	ns
M. mirabilis	-	-	-	-
Millepora sp.	5,106	1.28	0.2785	ns
M. annularis	5,113	3.32	**0.0077**	**5 3 4 2 1 6**
M. cavernosa	5,95	0.37	0.8668	ns
M. angulosa	5,53	0.98	0.4364	ns
P. astreoides	5,113	3.53	**0.0053**	**1 6 4 2 5 3**
P. furcata	1,1	3.00	0.3333	ns
S. cubensis	5,56	1.36	0.2547	ns
S. siderea	5,16	1.02	0.4410	ns
S. michelini	5,81	0.46	0.8039	ns

Table 5-7. Specific relative dominance comparisons between cruises at the East Flower Garden Bank. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

Relative Dominanace East Flower Garden Bank				
Species	**df**	**F**	**P-value**	**Tukey Groups**
Agaricia spp.	5,113	1.33	0.2574	ns
Colpophyllia spp.	5,81	0.64	0.6720	ns
D. strigosa	5,112	0.66	0.6552	ns
M. decactis	5,67	0.91	0.4822	ns
M. mirabilis	-	-	-	-
Millepora sp.	5,108	0.59	0.7057	ns
M. annularis	5,113	1.04	0.3978	ns
M. cavernosa	5,90	2.21	0.0602	ns
M. angulosa	5,28	2.21	0.0813	ns
P. astreoides	5,113	2.12	0.0683	ns
P. furcata	5,6	1.53	0.3065	ns
S. cubensis	5,46	3.29	**0.0128**	**2 1 3 5 6 4**
S. siderea	5,15	0.34	0.8834	ns
S. michelini	5,86	0.40	0.8473	ns

5.1.1.2 Species Diversity and Evenness

Species diversity and evenness based on coral counts (standard Shannon-Weaver species diversity; Figure 5-3) were significantly higher at the WFG study site (cruises pooled; Table 5-1), and on three of six project cruises (Table 5-2). Species diversity and evenness based on coral cover (Figure 5-4) showed the opposite pattern, being significantly higher at the EFG study site in general (Table 5-1), but on only one of six cruises (Table 5-2). The contrasting data are a result of the fact that coral population levels differed significantly between sites (114.8 per transect, or 24 m^{-2}, at the EFG [S.E.=2.93] vs. 84.6 per transect, or 18 m^{-2} at the WFG [S.E.=2.18]; $F=71.17$, $p<0.0001$), and the fact that mean colony area (size) of *Siderastrea siderea* (the largest of all species) and *Porites astreoides* (the most abundant of all species) varied significantly between sites (Figure 5-5). Nevertheless, results were consistent within indices, and future monitoring efforts require clearly stating whether diversity indices are based on colony counts or percent cover.

Differences between cruises for diversity and evenness based on coral counts and on coral cover were observed for both banks (Table 5-3). Like coral cover and relative dominance, however, broad overlap of Tukey groups and the lack of distinction between early and late project cruises suggest no temporal trends.

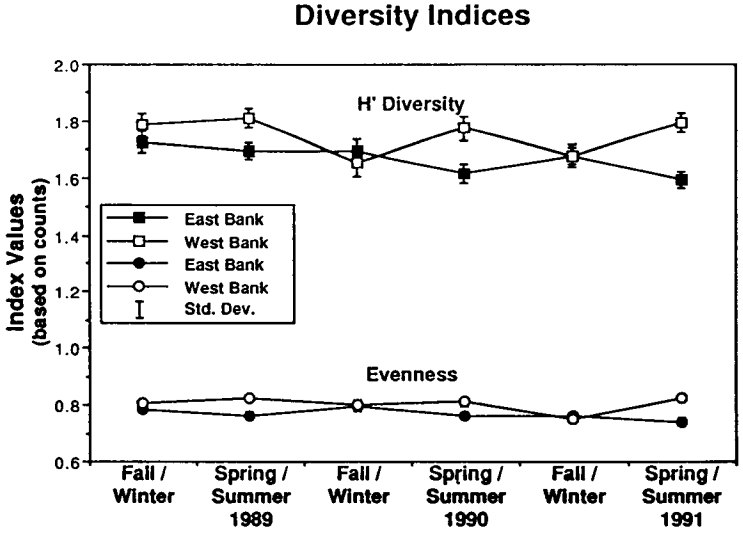


Figure 5-3. **Shannon-Weaver Diversity and Evenness between 1989 and 1991 at the East and West Flower Garden Banks. Diversity and evenness calculations were based on coral colony counts.**

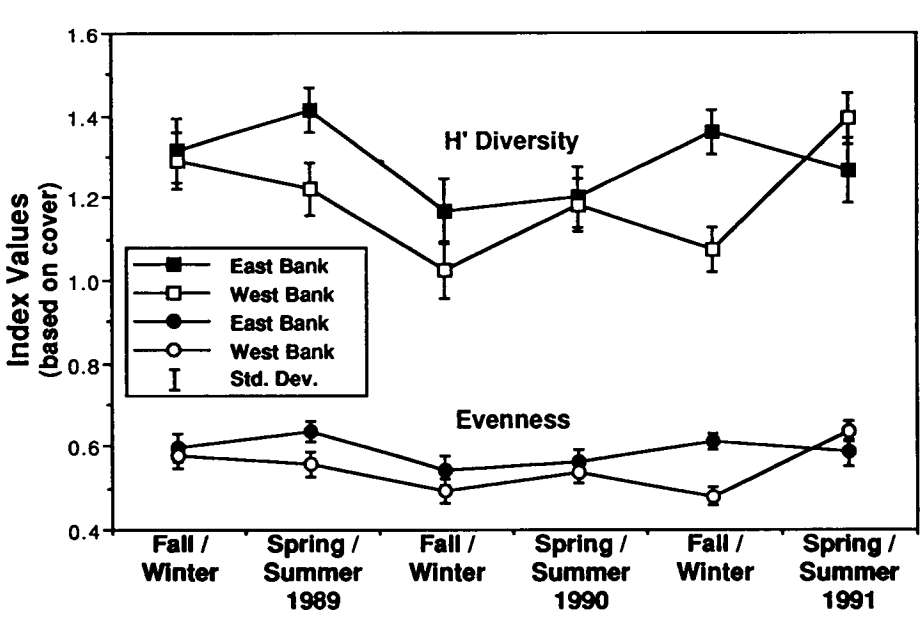


Figure 5-4. Shannon-Weaver Diversity and Evenness between 1989 and 1991 at the East and West Flower Garden Banks. Diversity and evenness calculations were based on coral **species cover**.

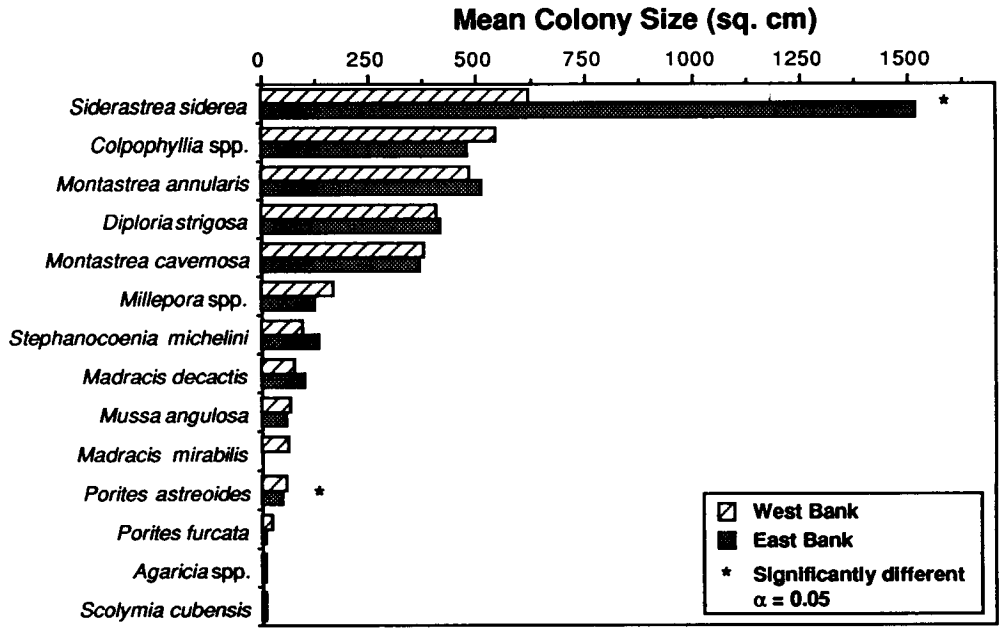


Figure 5-5. Comparison of mean colony size (colony area measured on down-looking photographs) for coral species on the East and West Flower Garden Banks. (* indicates size estimates which are significantly different between banks at $p<0.05$).

5.1.2 Historic Data

Data reported by Viada (1980) were used by Kraemer (1982) for a comparison of coral populations on reefs at the East and West Flower Garden Banks. Later, these data were summarized by Bright et al. (1984) and CSA (1985). Kraemer's data set was the most detailed of the four and therefore was used for comparison to data acquired in this study. Data collected from 1978-1982 reported cover of 50.4% ($45.1<\mu<55.7$) and 55.2% ($23.8<\mu<86.5$) for the EFG and WFG, respectively, but used a different method of analysis (line-intercept method rather than planimetry). Nevertheless, confidence intervals overlapped cover estimates acquired in this study (46.0% on the EFG and 46.5% on the WFG). Cover for individual species reported by Kraemer were close to those found in this study. Banks combined, cover for every species was within three percent. For each bank, data are presented in Figures 5-6 and 5-7. The higher variation within species is largely attributable to the smaller number of transects analyzed by Viada (1980) and Kraemer (1982); their data came from 18 WFG transects and 23 EFG transects, while in the present study, 238 transects were analyzed, 119 from each bank). Nevertheless, cover estimates from this study were within confidence limits reported from earlier studies for all species.

Relative dominance data are compared in Figures 5-8 and 5-9. Significant differences were observed only for *Porites astreoides* and *Colpophyllia* spp. between 1978-1982 data and the present study. *P. astreoides* had lower relative dominance in 1978-1982 samples. *Colpophyllia* spp. had higher relative dominance.

Kraemer (1982) based diversity and evenness estimates on coral cover (cover was estimated using the line-intercept method). Confidence intervals for diversity and evenness reported by Kraemer were quite wide compared to those in the present study (due to smaller sample size), and estimates from both banks overlapped those found here.

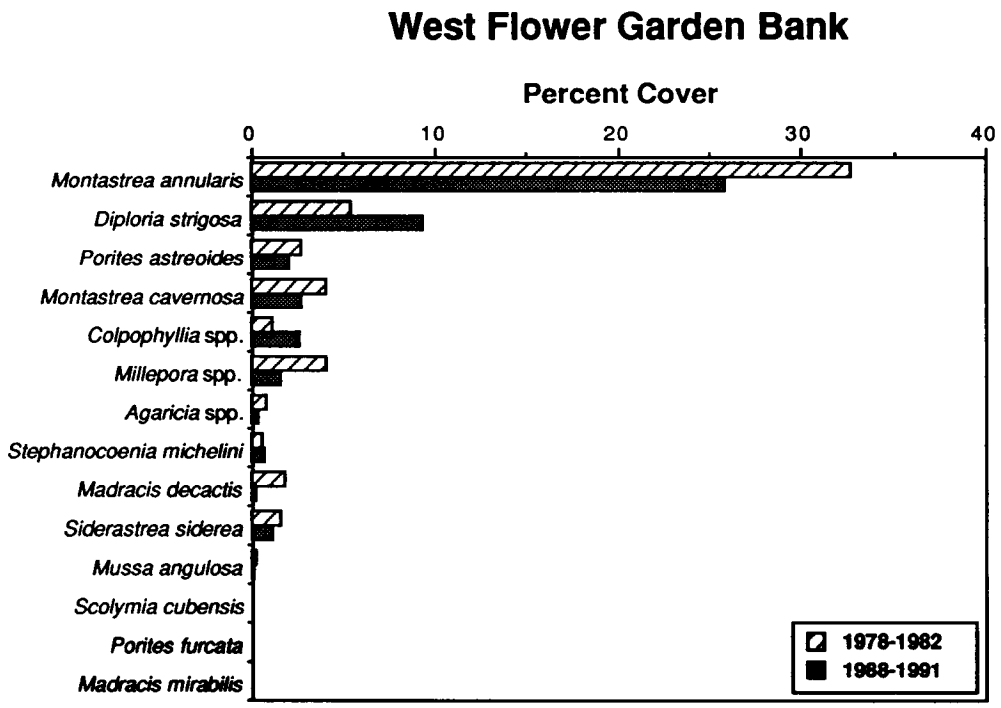


Figure 5-6. Comparison of percent cover of coral species at the West Flower Garden Bank between the 1978-1982 and 1988-1991 time periods. Earlier data were taken from Viada (1980) and Kraemer (1982).

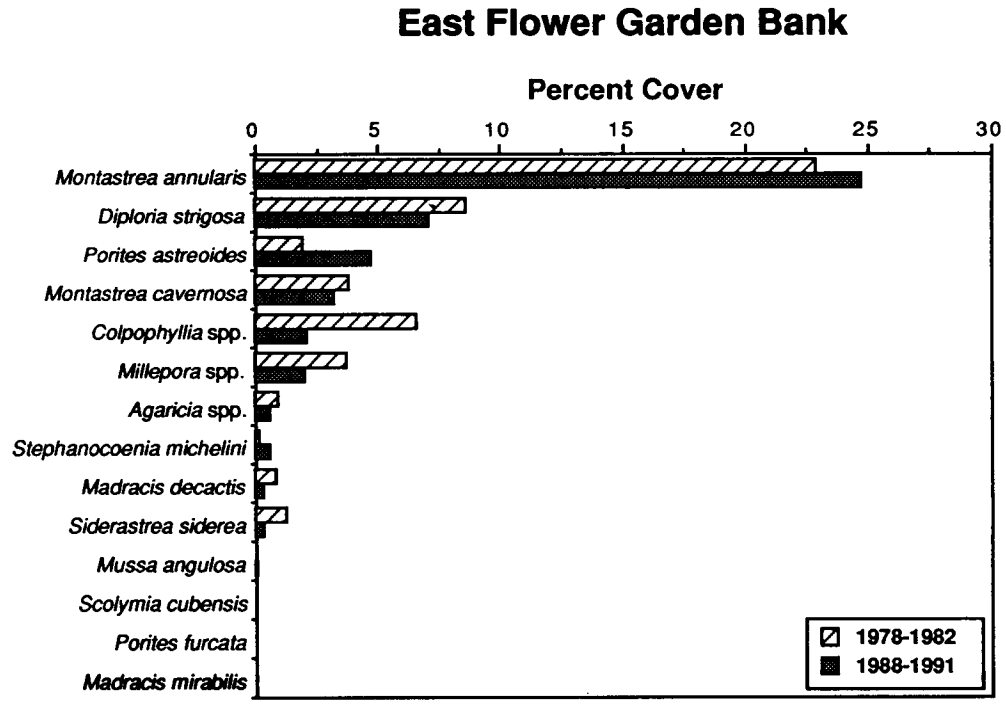


Figure 5-7. Comparison of percent cover of coral species at the East Flower Garden Bank between the 1978-1982 and 1988-1991 time periods. Earlier data were taken from Viada (1980) and Kraemer (1982).

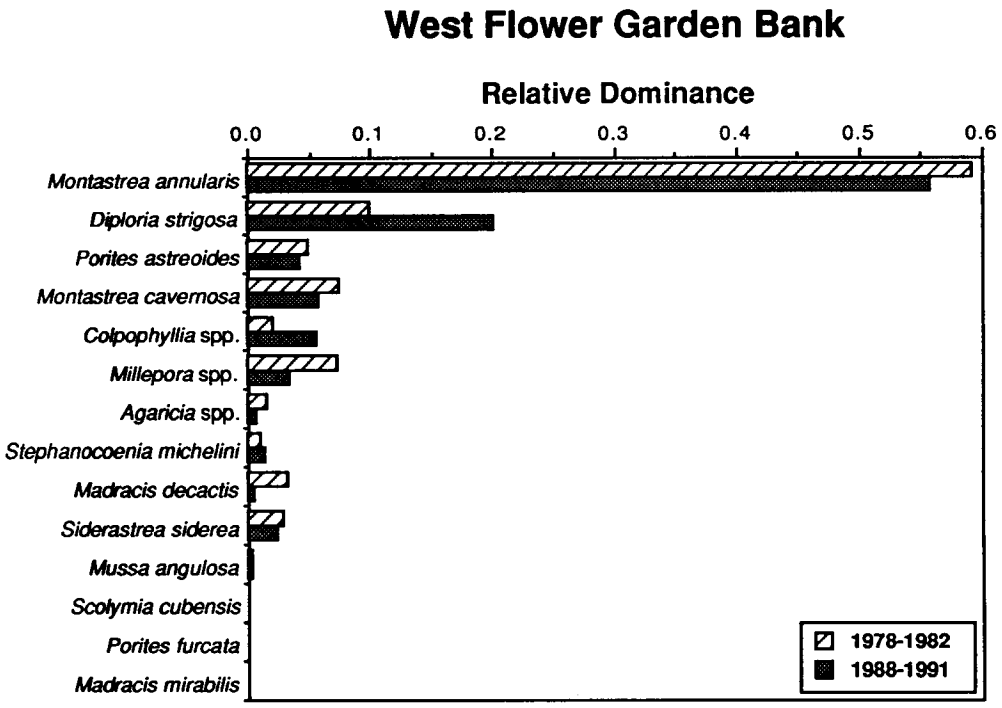


Figure 5-8. Comparison of relative dominance of coral species at the West Flower Garden Bank between the 1978-1982 and 1988-1991 time periods. Earlier data were taken from Viada (1980) and Kraemer (1982).

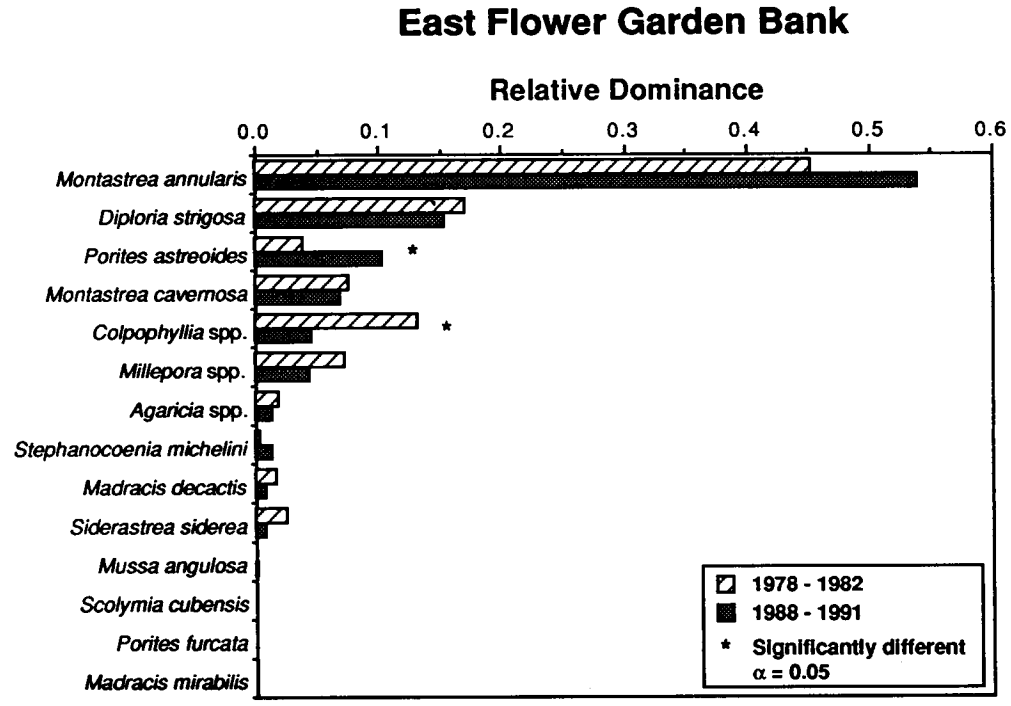


Figure 5-9. Comparison of relative dominance of coral species at the East Flower Garden Bank between the 1978-1982 and 1988-1991 time periods. Earlier data were taken from Viada (1980) and Kraemer (1982). (* indicates estimates which are significantly different between time periods at $p<0.05$).

5.2 Accretionary Growth

5.2.1 Growth Spikes

Data from 26 of 30 stations at the WFG and 23 of 30 stations at the EFG were used to calculate accretionary growth (Table 5-8). Data were not used from sample periods when stations had loose growth spikes (Appendix B).

Table 5-8. Accretionary growth measured from growth spikes installed on 30 *Montastrea annularis* colonies on each of the West (WFG) and East (EFG) Flower Garden Banks.

Bank	**Mean Growth** (mm/yr)	**Range** (mm/yr)	**N**	**Standard Dev.**	**Mean Sample Period**
WFG	6	3-11	26	2.3	663 days
EFG	7	4-13	23	2.4	616 days

Accretionary growth rates for individual time intervals are given in Figure 5-10. Rates averaged 3 mm for six month periods (7 mm/yr). No seasonal or site differences, or trends were detected.

5.2.2 Sclerochronology

The 1910 to 1989 accretionary growth record of four cores from the Flower Garden Banks is given in Appendix B.

The annual accretionary growth rate from 1910 to 1989 was 6.6 ± 0.1 mm/yr (Figure 5-11). Mean growth estimates of the four cores ranged from 5.0 to 8.0 mm/year; individual annual estimates ranged from 3.7 to 10.0 mm/year. The mean growth rate measured using sclerochronology was close to the 1989-1991 estimate obtained using accretionary growth spikes (6.8 mm/yr; Table 5-8).

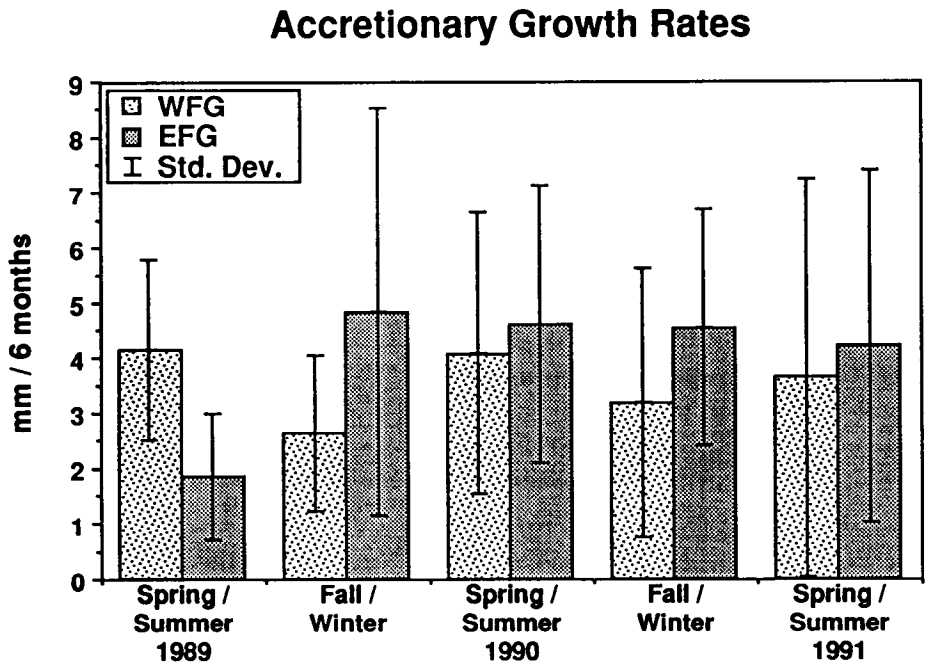


Figure 5-10. Accretionary growth (mm/6 months) of *Montastrea annularis* colonies from 1989 to 1991 at the East and West Flower Garden Banks. Growth was estimated by semi-annual measurement of stainless steel spikes implanted in the tops of thirty *Montastrea annularis* colonies in each study site.

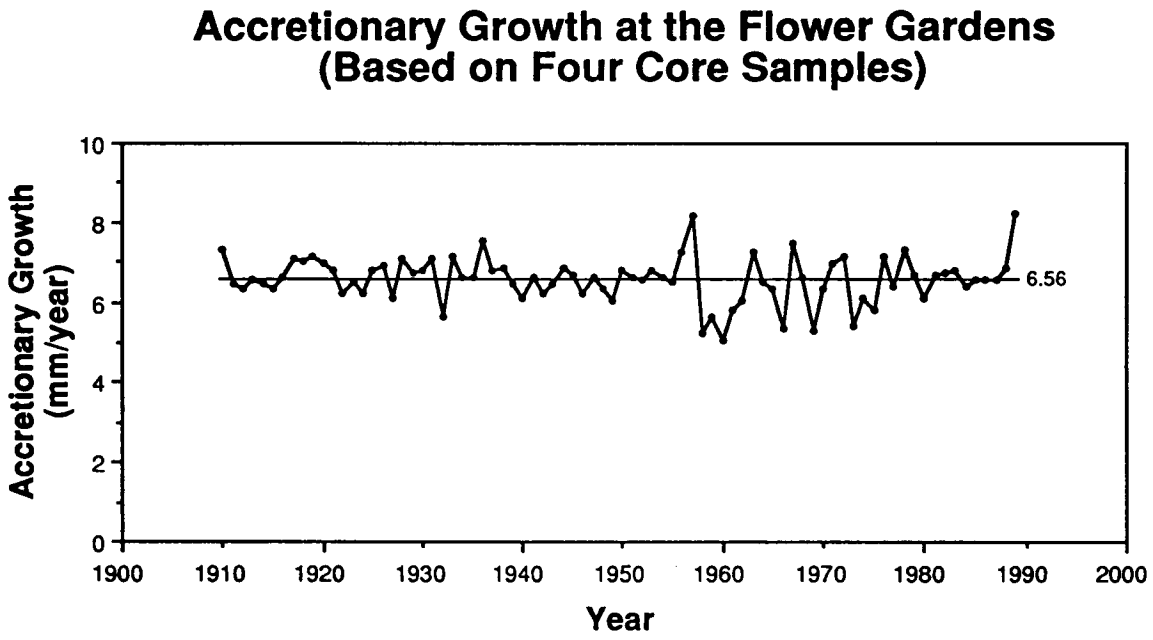


Figure 5-11. Accretionary growth (mm/year) of four *Montastrea annularis* colonies estimated from 1910 to 1989 at the Flower Garden Banks. Growth was estimated from annual band areas measured on X-radiographs of sections from 10 cm diameter cores. Mean of all estimates was 6.56 mm/yr.

An interesting feature shown in Figure 5-11 is the unexplained, yet distinctive decrease in growth rates and concurrent increase in variability of growth rates between years in the period between 1957 and 1980. Growth prior to 1957 was more tightly distributed around the mean. This trend was observed within each of the data sets (Appendix B) and was observed in 12 cores studied by Hudson and Robbin (1980). Following 1980, mean values for each year remained close to overall mean growth values.

5.3 Encrusting Growth

In the past year, it has been proposed that the species *Montastrea annularis*, one of the two species used to monitor encrusting growth in this study, is actually a complex of three species (Knowlton et al., 1992; Weil and Knowlton, in prep.). All three of the proposed species (*M. annularis, M. cascata, and M. inaequalis*) occur at the Flower Gardens, have distinctive morphologies, and have been classified as *M. annularis* exclusively. Of the three, encrusting growth stations are established on "*M. cascata*" and "*M. inaequalis*". If these are distinct species, it is likely that their encrusting growth rates will vary to some extent, particularly since competitive heirarchies have been demonstrated (Weil and Knowlton, in prep.).

If the above is true, growth rate data would be compromised by using information pooled for "*M. cascata*" and "*M. inaequalis*". The majority of stations established in the monitoring study were on "*M. cascata*", the generally smooth growth form of the *M. annularis* group. None were established on "*M. annularis*", the knobby form. Nevertheless, station data were reanalyzed after determination of their proposed new species. No significant differences were detected in net growth rates, advance rates, or retreat rates of *M. cascata* and *M. inaequalis* (Table 5-9). All *Montastrea* results, therefore, are from pooled information and refer to the species as *M. annularis*, as has been the case in previous studies. It should be understood, however, that the rates presented may largely represent a species that may soon be referred to as *M. cascata.*

Table 5-9. Kruskal-Wallis Test results comparing net growth rates, advance rates, and retreat rates (cm/6 months) of the two morphotypes *Montastrea cascata* and *M. inaequalis* at the East and West Flower Garden Banks. Study sites and cruises were combined for analysis. Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Montastrea cascata* vs. *M. inaequalis	**df**	**F**	**P-value**	**Results**
Net Growth Rate	1,324	0.05	0.8274	ns
Advance Rate	1,306	0.34	0.5587	ns
Retreat Rate	1,214	0.45	0.5011	ns

5.3.1 Net Growth Rates

Net growth rates (average rate of change of areas observed to advance or retreat) of *Montastrea annularis* and *Diploria strigosa* at the Flower Gardens were positive for nearly all semi-annual periods from 1989 through 1991 (Figure 5-12; Appendix C). For *D. strigosa*, net growth averaged 0.10 cm/6 months. For *M. annularis*, the rate was 0.15 cm/6 months. During the period between Cruises 4 and 5 (fall of 1990 and through the following winter), both species exhibited virtually zero net growth, though high variability at this time resulted in no significant differences between time periods. Following this, net growth of *D. strigosa* was relatively high, and that of *M. annularis* was the highest of all periods (significantly higher than all but spring/summer 1990).

Comparisons of net growth of each species by bank (Figure 5-13; Appendix C) indicated that *D. strigosa* rates were higher on the EFG than on the WFG. Comparison between cruises indicated that *M. annularis* on the WFG had higher growth rates in the last period than all periods except spring/summer 1990.

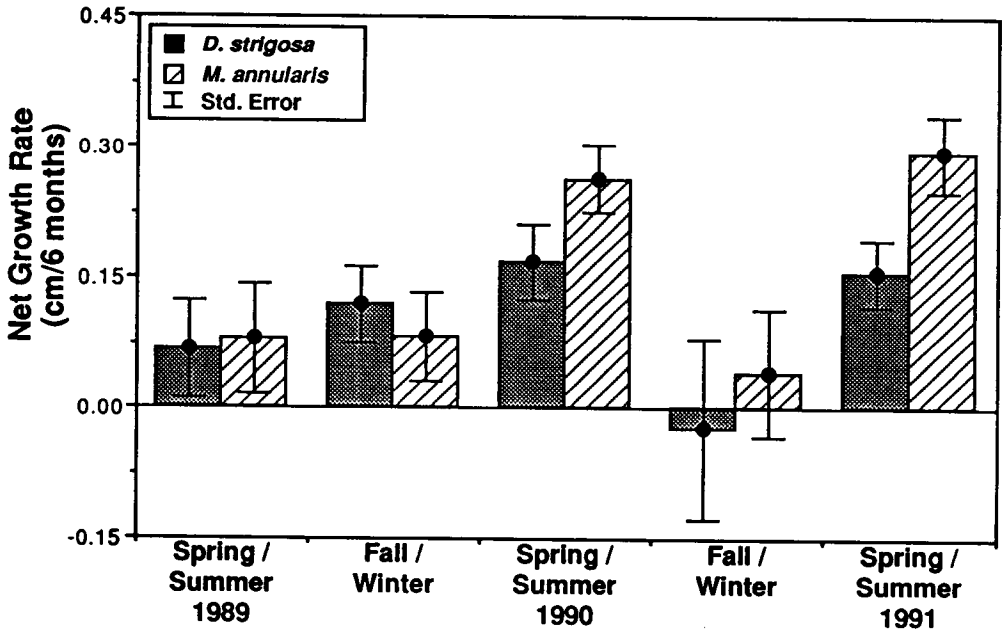


Figure 5-12. Net lateral growth rates of *Diploria strigosa* and *Montastrea annularis* from 1989 to 1991 at the Flower Garden Banks. Data from both banks were combined for each period.

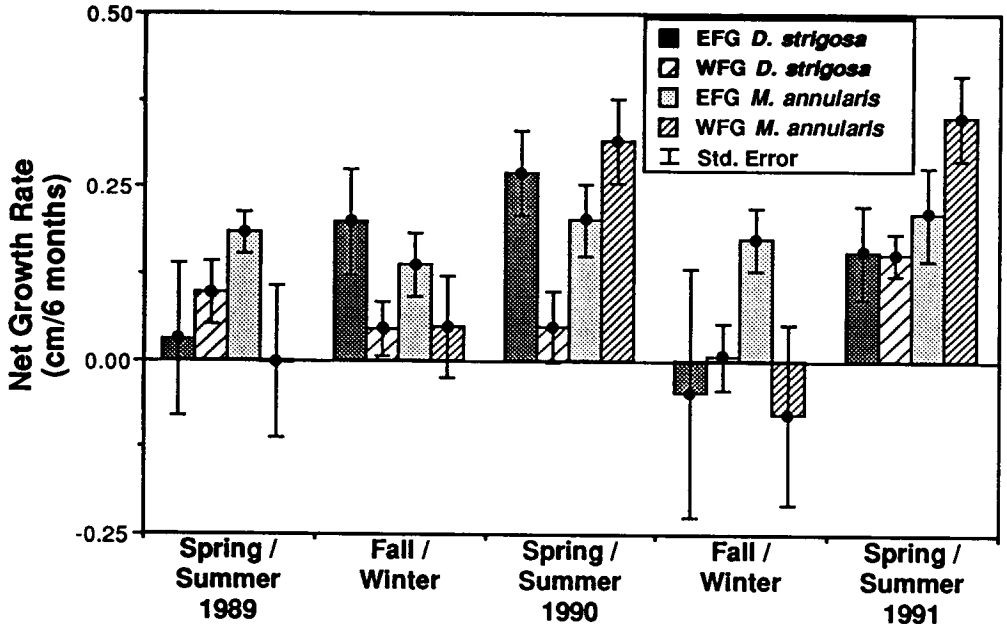


Figure 5-13. Net lateral growth rates of *Diploria strigosa* and *Montastrea annularis* from 1989 to 1991 at the East and West Flower Garden Banks.

5.3.2 Advance and Retreat Rates

Encrusting growth data are generally more revealing when advance and retreat rates are analyzed separately. Figures 5-14 and 5-15 show advance and retreat rates for *M. annularis* and *D. strigosa*, respectively, on both banks. Note first that standard errors are much higher for retreat of either species than for advance. This is simply because corals can die (retreat) much faster than they grow (advance), since disease and other factors causing mortality are capable of destroying tissue at a rapid rate. Growth, on the other hand, occurs at a comparatively constant rate, hence reduced variability.

Despite differences in the magnitudes of standard error for advance and retreat, the average rates of advance and retreat for either species were not significantly different (0.38 cm/6 months vs. -0.43 for *M. annularis*; 0.42 vs. -0.40 for *D. strigosa*). However, the advance rate of *D. strigosa* was higher at the EFG than the WFG, and the retreat rate of *M. annularis* was higher at the WFG than the EFG (Table 5-10). The WFG advance rates of *M. annularis* were similar during most cruises (Table 5-11). The advance rate of *D. strigosa* was significantly different between cruises on both banks though groups were not discernable (i.e., though analysis of variance indicated significant differences between cruises, multiple range test did not discern cruise groupings). Rates on both banks were highest in the fall/winter season between 1990 and 1991 (Figure 5-15). Interestingly, this was the season with the lowest net growth rate (and the only one with average rates below zero; Figure 5-12). Due to high variability, differences in retreat rates between cruises were not discernable.

Table 5-10. Advance and retreat rates of *D. strigosa* and *M. annularis* between study sites, cruises combined. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Cruises Combined	Species	df	F	P-value	Results
Advance	*D. strigosa*	1,365	13.13	**0.0003**	**East > West**
	M. annularis	1,306	2.12	0.1468	ns
Retreat	*D. strigosa*	1,271	0.10	0.7512	ns
	M. annularis	1,214	4.37	**0.0377**	**West > East**

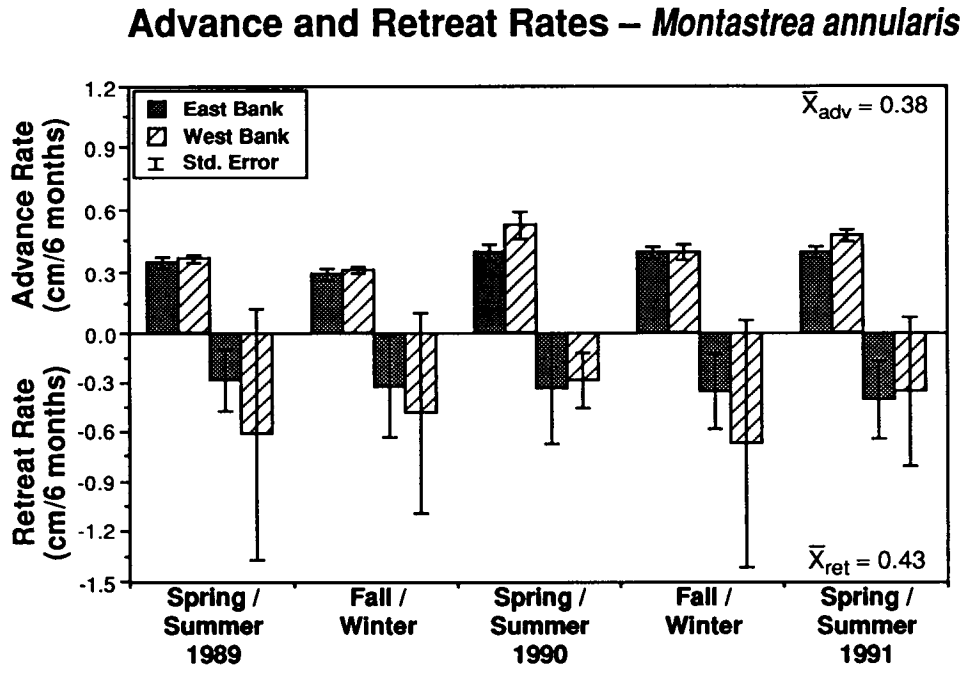


Figure 5-14. Advance and retreat rates of *Montastrea annularis* from 1989 to 1991 at the East and West Flower Garden Banks. Note high standard errors for retreat rates relative to those of advance rates.

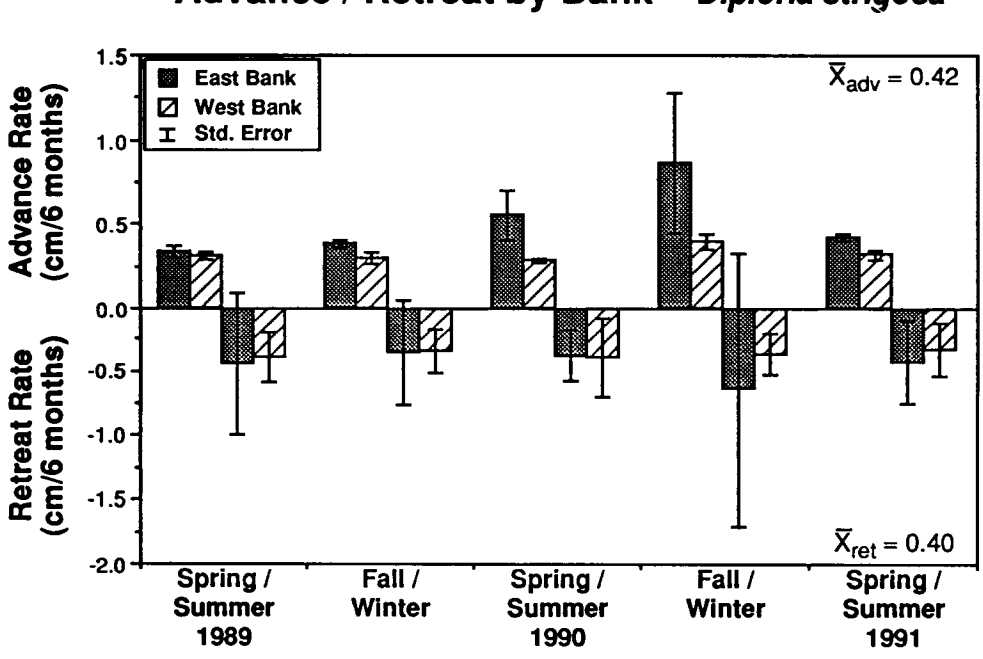


Figure 5-15. Advance and retreat rates of *Diploria strigosa* from 1989 to 1991 at the East and West Flower Garden Banks. Note high standard errors for retreat rates relative to those of advance rates.

Table 5-11. Advance of *D. strigosa* and *M. annularis* at the East and West Flower Garden Banks. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest and those underlined together are not significantly different at $\alpha = 0.05$.

Advance	Species	df	F	P-value	Tukey Groups
EFG	*D. strigosa*	4,183	2.71	**0.0315**	no groups
WFG	*D. strigosa*	4,174	2.48	**0.0460**	no groups
EFG	*M. annularis*	4,131	2.37	0.0558	ns
WFG	*M. annularis*	4,167	5.96	**0.0002**	**6 4 5 2 3**

Kraemer (1982) measured lateral growth and retreat rates of corals at the Flower Gardens using methods similar to those used here. Though significantly fewer samples were analyzed, he analyzed both *M. annularis* (n=13) and *D. strigosa* (n=3). Growth rates of *M. annularis* averaged 0.20 cm/6 months ($0.02<\mu<0.37$), not significantly different from the 0.38 cm/6 months measured here (95% confidence intervals overlapped). Retreat rates for *M. annularis* averaged 0.12 cm/6 months ($0<\mu<0.26$), somewhat lower, but not significantly different than the rate determined in this study (0.43 cm/6 months).

For *D. strigosa*, Kraemer (1982) found advance rates averaging 0.28 cm/6 months ($0.19<\mu<0.37$), and retreat rates averaging 0.34 cm/6 months ($0<\mu<0.69$ cm/6 months), neither of which was significantly different than rates determined in this study (0.42 and -0.40).

5.3.3 Retreat to Advance Ratios

Though rates of advance and retreat are informative, of principal importance to the long-term maintenance of a species is the avoidance of net tissue loss. Net tissue gain, on the other hand, not only suggests favorable conditions of growth for a species, but may imply competitive dominance. The amount of tissue added vs. the amount lost between cruises was therefore calculated for both *M. annularis* and *D. strigosa*. Figure 5-16 shows the ratios of tissue lost to tissue gained (Retreat to Advance Ratio) between cruises for each species. Values above 1.0 indicate net tissue loss; those below one indicate net tissue gain. With the exception of the fall/winter season between 1990 and 1991, all values were below one. Thus, significantly more tissue was gained than lost on growth stations for both

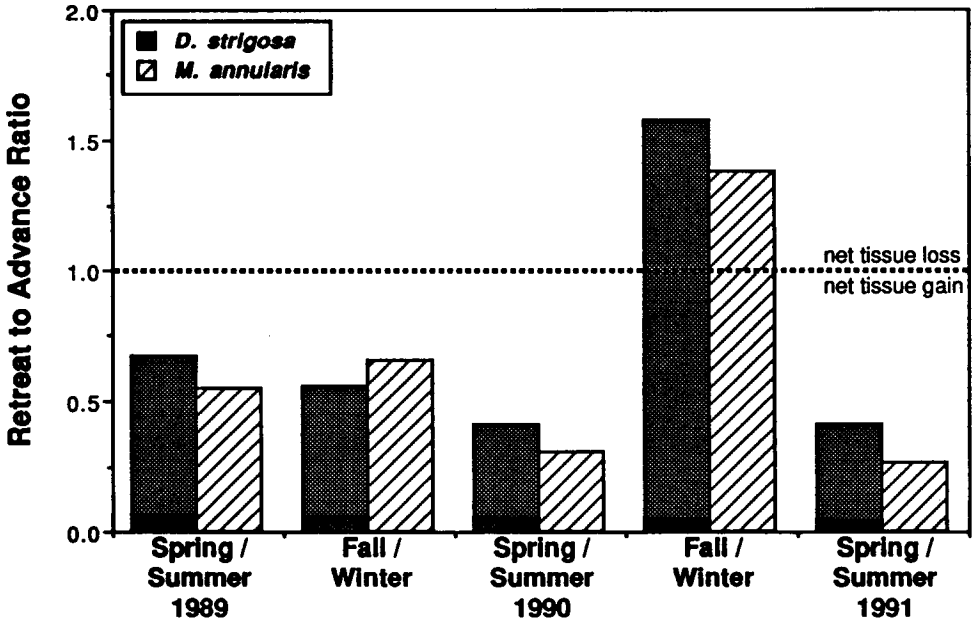


Figure 5-16. Retreat to advance ratios (total tissue lost divided by total tissue gained) of *Diploria strigosa* and *Montastrea annularis* from 1989 to 1991 at the Flower Garden Banks. Data from both banks were combined for each period. Dotted line indicates ratio of one, where net tissue change between sample periods is zero.

species. The most substantial tissue loss in the fall/winter period between 1990 and 1991 occurred for *D. strigosa* at the EFG and for *M. annularis* at the WFG (Figure 5-17), the same groups with net growth rates below zero during the period (Figure 5-13).

Overall, the ratio of retreat to advance for *D. strigosa* was 0.65. Thus, for every square centimeter of tissue that died, approximately 1.5 cm^2 grew. For *M. annularis*, the ratio was 0.55; for every square centimeter lost, approximately 1.8 cm^2 grew.

5.3.4 Marginal Stability

Ternary plots can be produced which depict the "condition" of coral margins at growth stations. These compare the relative amounts of advancing, retreating, and stable margins without regard to the rates of change along the margins. With the exception of *D. strigosa* on Cruise 5, combined data for each species indicated consistently high proportions of marginal growth (Figure 5-18). That is, considerably greater than 50% of all

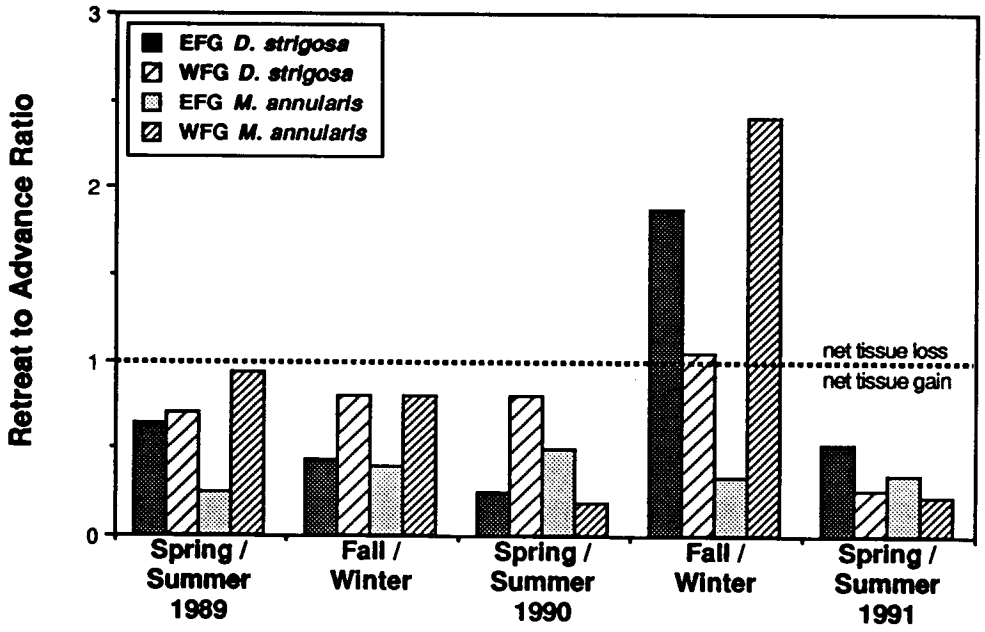


Figure 5-17. Retreat to advance ratios of *Diploria strigosa* and *Montastrea annularis* from 1989 to 1991 at the East and West Flower Garden Banks.

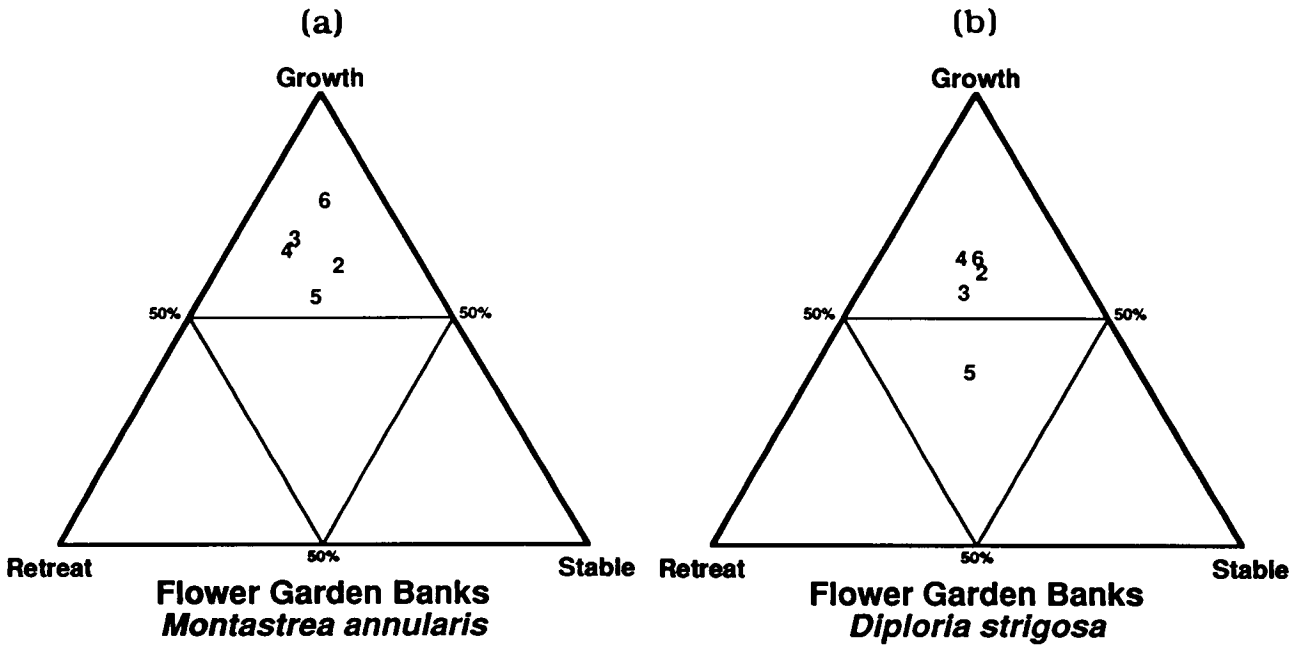


Figure 5-18. Ternary diagrams showing the proportions of growing, retreating, and stable coral margins of *Montastrea annularis* (a) and *Diploria strigosa* (b) at the Flower Garden Banks. Numbers indicate cruise numbers (Table 3.1) and denote seasonal time frames as follows: 2 = spring/summer 1989; 3 = following fall/winter; 4 = spring summer 1990; 5 = following fall/winter; 6 = spring/summer 1991.

the marginal length analyzed was advancing. Much shorter lengths were retreating or remaining stable between cruises.

The proportion of advancing margin length of *M. annularis* (Figure 5-19) was 48-83% on both banks for all periods. In the fall/winter 1990-1991 period, when there was a net tissue loss for *M. annularis* on the WFG (Cruise 5; Figure 5-17), the advancing margin length was 48% of the total length. Tissue loss during this period can be attributed to high retreat rates at the WFG (Table 5-10), and possibly to an increased proportion of retreating margin length (32%), but not to reduced advance rates (Figure 5-14).

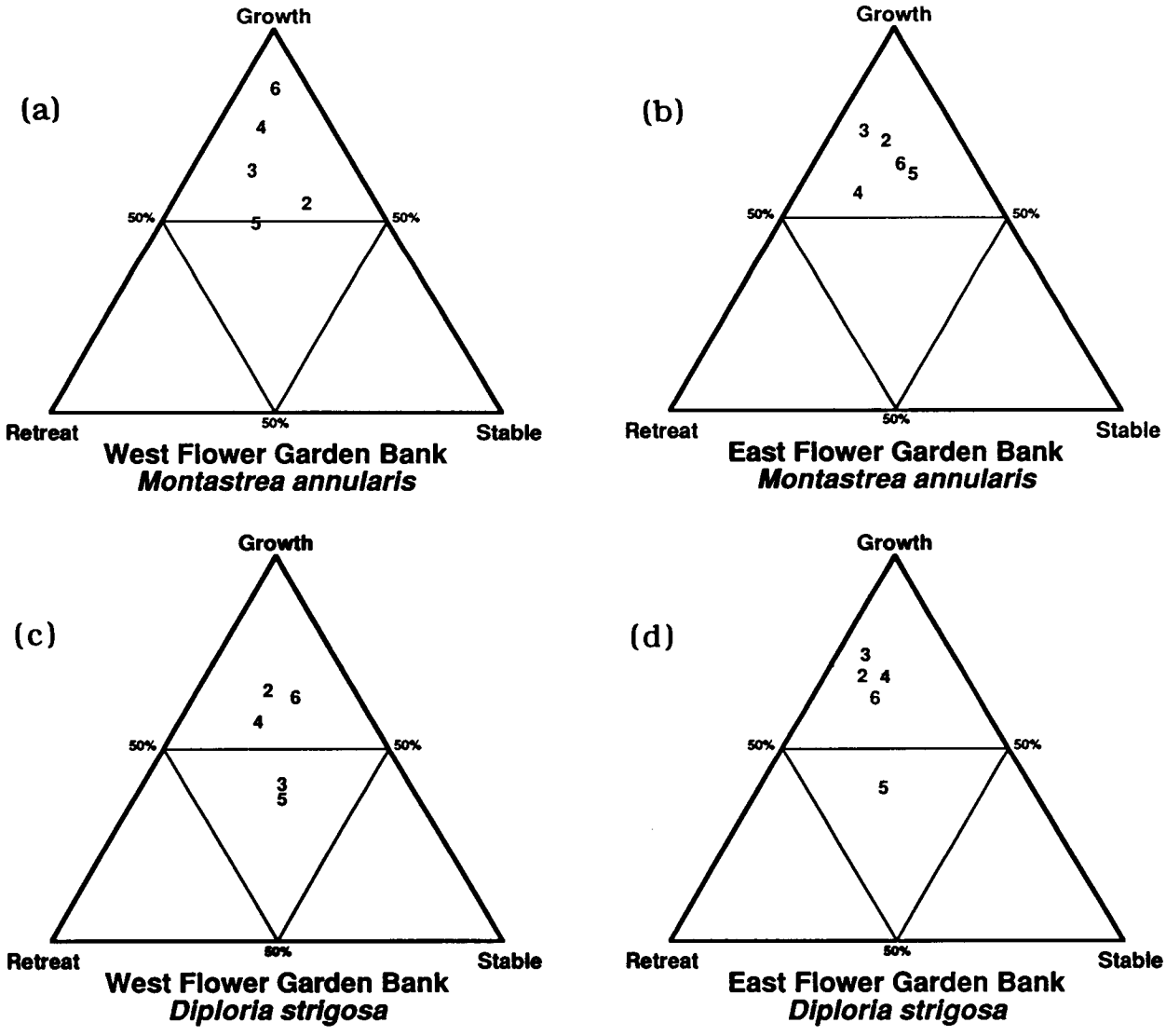


Figure 5-19. Ternary diagrams showing the proportion of growing, retreating, and stable coral margins of *Montastrea annularis* at the West (a) and East (b) Flower Garden Banks and *Diploria strigosa* at the West (c) and East (d) Banks. Numbers indicate cruise numbers, as described in Figure 5-18.

The proportion of advancing margin length of *D. strigosa* was low on both banks during fall/winter 1990-1991 (Cruise 5; Figure 5-19), averaging 37%. On both banks, there was a net tissue loss during the period, even though advance rates were the highest of all periods for *D. strigosa* (Figure 5-15). Thus, tissue loss in this case can be attributed to low relative proportions of advancing margin length, and possibly increased retreat rates, particularly at the EFG (Figure 5-15), but not reduced advance rates.

5.4 Repetitive Quadrats

A total of 4,160 colonies were individually analyzed at 80 stations on the East and West Flower Garden Banks. Coral cover averaged 48.5% overall; 46.5% at stations on the WFG (range of 23-76%) and 50.5% on the EFG (range of 14-85%). Apparent coral populations averaged 6.5 colonies m^{-2}. This, however, underestimates actual populations, since it is the number of corals large enough to detect on large-scale photographs. The number probably represents about 30% of all colonies present, based on random transect data presented in Section 5.1.1.2, which suggest about 21 corals m^{-2}. It is evident that the undetected colonies, which represent a majority of colonies present on the reefs, account for very little coral cover.

Coral growth was clearly identifiable at repetitive stations, but was difficult to quantify because areas of growth were small relative to the large scale of the photographs (4,566 occurrences at all stations; Table 5-12).

Table 5-12. Observations of growth, retreat, coral bleaching, and disease at repetitively photographed 8 m^2 quadrats. Data are from both banks, and all cruises were combined. Data are in number of observations without regard to the sizes of areas affected. "New disease" occurrence is the number of colonies infected since the previous sampling period. "Pre-existing disease" occurrence is the number of colonies infected at least six months prior to a given sampling period. Mortality from each type of disease is the number of colonies exhibiting mortality within six months of the observation. Eventual mortality is tissue loss occurring after the first six months, but prior to the end of the study period.

Change	Cause	Occurrence	Mortality	Notes
Growth	-	4566	-	
Retreat, Bleaching, and Disease	unknown cause	2526	2526	generally minor
	algae mediated	20	20	
	algae/sediment	18	18	
	new disease	67	17	eventual mortality - 46
	pre-existing disease	83	62	
	bleaching	194	14	temp>30°C
	TOTAL	2908	2657	

Coral mortality was also clearly identifiable, particularly when acute (severe). Mortality from all causes, while frequent (2,657 occurrences, 2,578 excluding disease; Table 5-12), usually occurred on a very limited scale (commonly several cm^2 on a colony between cruises). Although the cause for most minor tissue loss could not be determined, there were several cases of evidence suggesting aggression between different species (e.g., Lang, 1973), resulting in limited but consistent loss. Algae, and algae/sediment mat mediated retreat (Abbott, 1979; Gittings, 1988) were also factors suspected of causing marginal retreat, but were seldom indentifiable as conclusive causes.

Nearly all extensive mortality appeared to result from "ridge-mortality" (Abbott, 1979) or unidentified diseases (no black band or white band disease has been identified at the Flower Gardens). Figure 5-20 illustrates the effects of disease on corals during the period of the study. Of a total of 67 "newly" diseased colonies (i.e., disease was not detectable in previous station photograph) observed and monitored during the study, 69% eventually exhibited mortality, most with comparatively large-scale tissue loss. Yet, infection did not always cause tissue loss and 31% of colonies apparently recovered. Futhermore, in only 26% of cases (17 of 67 colonies) was mortality evident within six months of the apparent onset of disease. On the other hand, 75% of colonies with pre-existing disease (i.e., onset at least six months prior to sample; 62 of 83 cases) exhibited mortality over the following six months. Though infections were most frequently observed on both banks following fall and winter seasons (Figure 5-21), it is unlikely that this represents significant seasonal variation in infection, particularly since "new" infections (i.e., first observations; Figure 5-20) did not show this pattern. Seasonal patterns of mortality were not evident on either bank (Figure 5-21). Diseased corals at the EFG suffered a higher mortality rate (85%) than those at the WFG (58%), though the number of observations is undoubtedly too few to generalize (see Tables 5-13 and 5-14).

Coral recruitment was not observed at repetitive stations during the period of this study. It is likely that juvenile corals require several years (5 to 10, depending on the species; e.g., Szmant-Froelich, 1985) of growth before being identifiable at the scale used in repetitive quadrat photos.

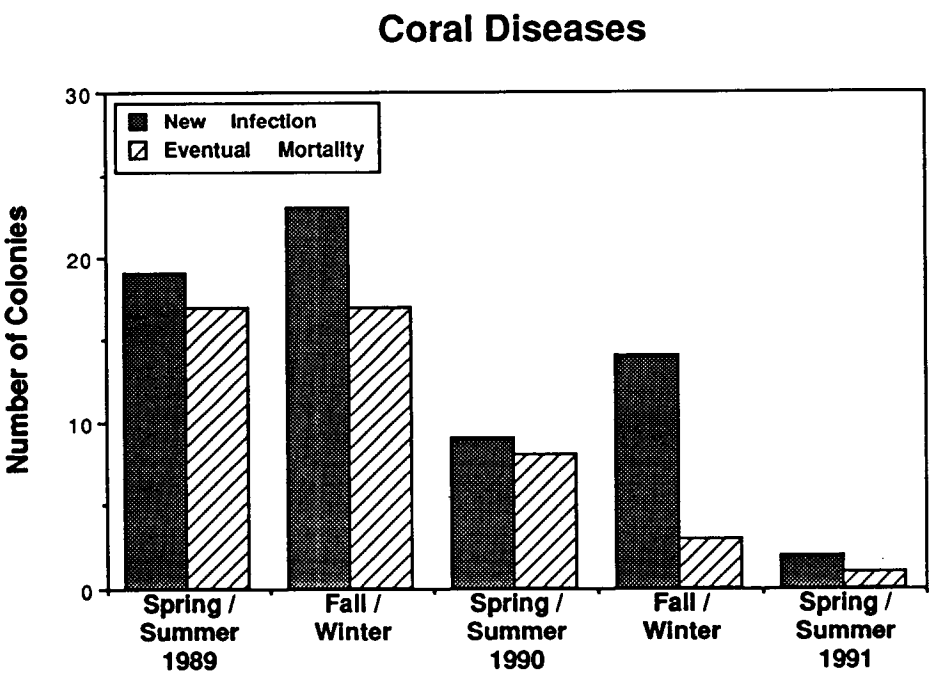


Figure 5-20. **Numbers of colonies in 8 m^2 repetitive quadrats with "new" infection (i.e., first observation) during each sample period (as determined in photographs taken at the end of that period), and the number of these colonies exhibiting eventual tissue mortality. Data from both banks were combined.**

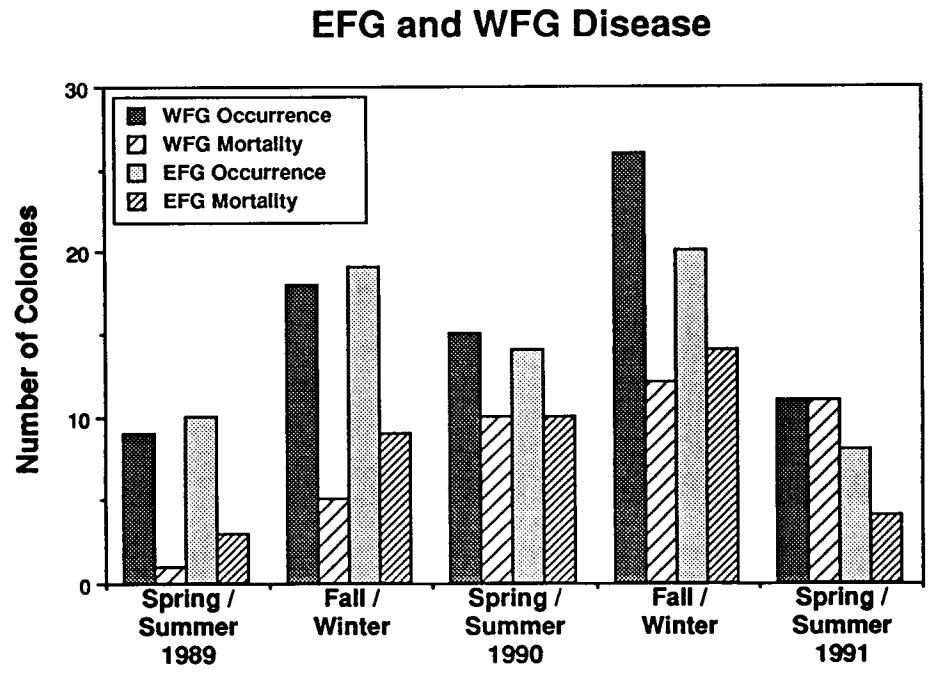


Figure 5-21. **Numbers of colonies in 8 m^2 repetitive quadrats at the East and West Flower Garden Banks with disease (not necessarily "new" infection) during each sample period, and the number of colonies exhibiting tissue mortality since the previous sampling.**

Table 5-13. Observations of growth, retreat, coral bleaching, and disease at repetitively photographed 8 m^2 quadrats at the West Flower Garden Bank. Data were combined for all cruises, and are in number of observations without regard to the sizes of areas affected. Disease terminology defined in Table 5-12.

Change	Cause	Occurrence	Mortality	Notes
Growth	-	2691	-	
Retreat, Bleaching, and Disease	unknown cause	1640	1640	generally minor
	algae mediated	5	5	
	algae/sediment	0	0	
	new disease	40	11	eventual mortality - 23
	pre-existing disease	39	28	
	bleaching	51	4	temp>30°C
	TOTAL	1775	1688	

Table 5-14. Observations of growth, retreat, coral bleaching, and disease at repetitively photographed 8 m^2 quadrats at the East Flower Garden Bank. Data were combined for all cruises, and are in number of observations without regard to the sizes of areas affected. Disease terminology defined in Table 5-12.

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1875	-	
Retreat, Bleaching, and Disease	unknown cause	886	886	generally minor
	algae mediated	15	15	
	algae/sediment	18	18	
	new disease	27	6	eventual mortality - 23
	pre-existing disease	44	34	
	bleaching	143	10	temp>30°C
	TOTAL	1133	969	

Repetitive photography was useful in examining the extent of coral bleaching and the fate of bleached colonies. Bleaching occurred during all summer periods following temperature maxima. Species most affected by the phenomenon were *Millepora alcicornis* and *Montastrea cavernosa*, and bleached *Diploria strigosa*, *M. annularis*, *Porites astreoides* and *Agaricia* spp. were observed to a much lesser extent. Other species did not appear to bleach. Though clearly evident to the eye due to the vivid white coloration and the number of colonies exhibiting the white color, the coral cover affected by bleaching was generally minor (ranging from 0.2% to 2.4% cover; Figure 5-22). Though bleached coral cover was similar between banks in 1989 (0.3% WFG vs 0.4% EFG), there were substantial differences between banks in 1990 and 1991. Bleached cover at the EFG (2.4%) was nearly twice that of the WFG (1.4%) in 1990 (the most significant bleaching event), and was over six times higher than the WFG (1.3% vs 0.2%) in 1991. Furthermore, in all summer samples, and overall, the EFG contained more bleached colonies (Tables 5-13 and 5-14; Appendix D), and higher bleached cover.

Only 7% (14 of 194; Table 5-12) of coral colonies observed to bleach showed any evidence of mortality (7.8% of colonies on the WFG and 7.0% on the EFG). Those that were affected usually exhibited minor tissue loss. Only one small colony out of 194 bleached colonies died entirely. Interestingly, "paling" (pale color that may be due to partial loss of zooxanthellae; not counted in bleaching data in this study) or bleaching often recurred in the same colonies and in the same pattern within colonies every summer. Mortality was no higher in colonies that underwent recurrent paling or bleaching than in other colonies.

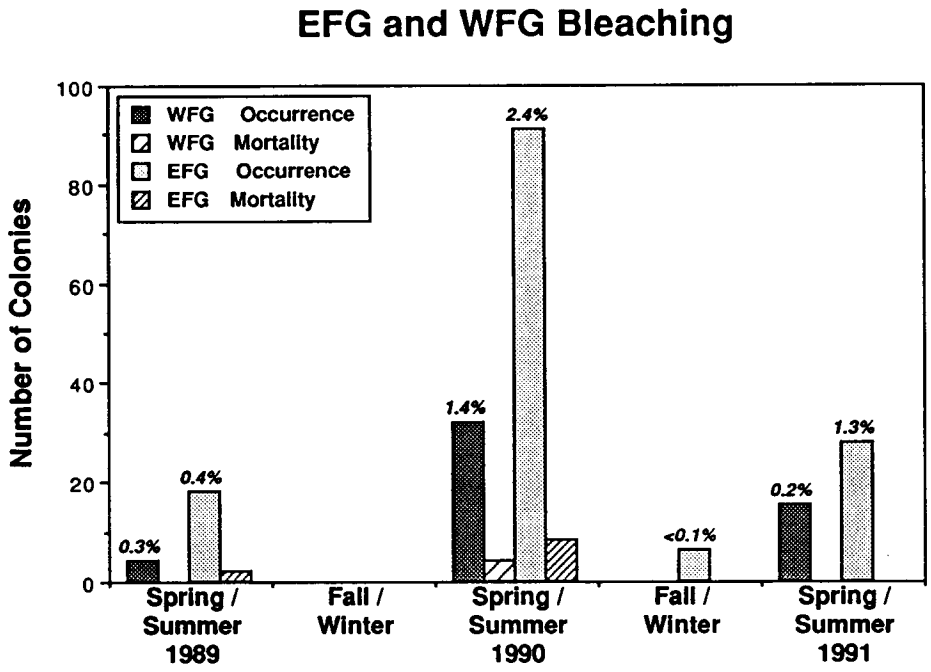


Figure 5-22. Numbers of colonies in 8 m^2 repetitive quadrats at the East and West Flower Garden Banks exhibiting tissue bleaching, and the number exhibiting tissue mortality in areas of bleaching. Values at top of each bar indicate percent coral cover bleached.

5.5 Ancillary Measurements

5.5.1 Dissolved Oxygen, Salinity, Temperature and Light

Ancillary data are presented in Appendix E. Oxygen concentrations ranged from 4.940 ml/l (1 m depth, WFG in April 1989) to 7.775 ml/l (21 m, EFG in December 1988). Salinity ranged from 33.459 at the surface of a strongly stratified water column at the WFG in June 1989 to 36.593 at 25 m at the WFG in August 1991. Most salinity measurements were near or above 36. The lowest bottom water salinity (actually one meter above the reef) was 35.909 (20 m, EFG in October 1990).

Light intensity on the bottom at the EFG averaged 19.1% of surface (in-air) intensity (S.D.=5.39). Average depth at which light measurements were taken was 20.0 m. At the WFG, intensity on the bottom averaged 13.1% of surface intensity (S.D.=3.84). Depth of measurements at the WFG averaged 22.2 m. Values ranged from a low of 7.4% of surface illumination at the WFG in April 1990 at the WFG to 26.7% at 20 m at the EFG in August 1991.

Discrete temperature measurements (i.e., taken during cruise dates only, and not thermograph data) are also presented in Appendix E. The coldest surface water observed during the cruises was 21.1°C (1 m, EFG in February 1989). The coldest bottom water (one meter above the reef) was 20.9°C (24 m, EFG in March 1991). The warmest surface water was 29.8°C (1 m, EFG in September 1991). The warmest bottom water was 29.5°C (19 m, EFG in August 1990).

During 1990, the first significant coral bleaching event reported at the Flower Garden Banks occurred. The event was reported by sport divers and appeared to coincide with unusually high water temperature. Because concurrent bottom temperature data were not being collected at that time, an analysis of sea surface temperatures for the period was conducted. Data were collected from interpretations of AVHRR satellite information to obtain surface temperature on a weekly basis between 1979 and 1990. Analysis indicated unusually high temperatures in 1990. Plotted against an 11-year mean and range (1979-1989; Figure 5-23), temperatures in 1990 were higher than the 11-year mean for 42 of 52 weeks. Furthermore, they were at or above maximum values observed between 1979 and 1989 for 29 of 52 weeks, or over half the year. Most of these excursions occurred during the second half of the year. No years between 1979 and 1989 exhibited such prolonged excursions (Appendix E; Figure E-1).

Ryan TempMentor thermographs were installed on the banks in August of 1990, after isolated occurrences of coral bleaching were reported. Thereafter, bottom temperature (at the reef surface) was recorded every two hours (Figures 5-24 and 5-25; the thermograph at the EFG was lost between August and October 1990, and was replaced in March 1991). The lowest bottom temperature observed since installation was 19.40°C, at 24 m at the WFG in March 1991. The highest temperature, 30.5°C, occurred at the EFG at 20 m in mid-August 1991, during a coral bleaching event.

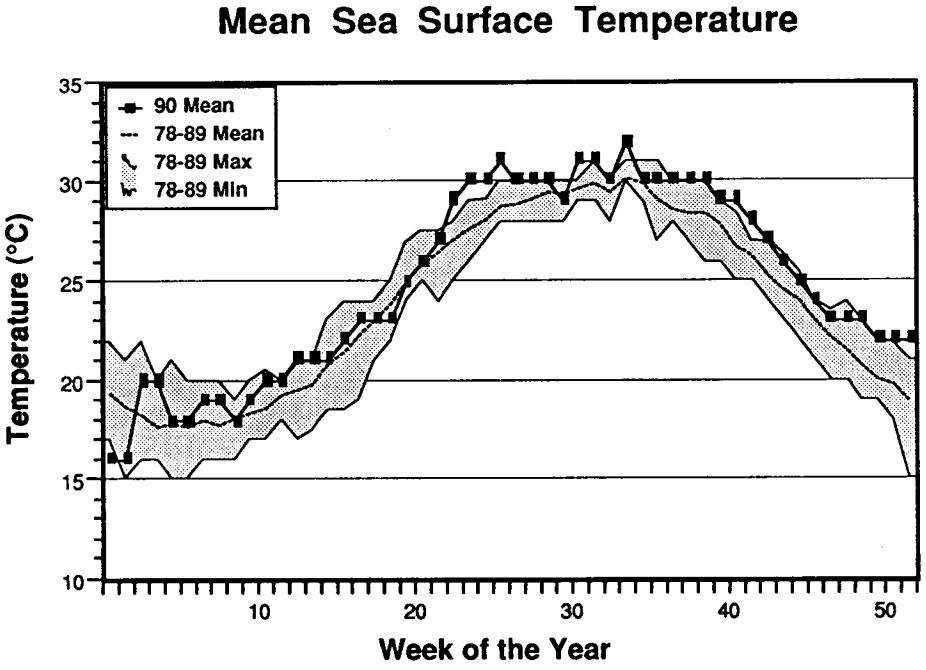


Figure 5-23. Satellite-derived sea surface temperature during 1990 (rectangles) compared to an 11-year mean (dashed line) based on 1979-1989 data. Also given is the range of values between 1979 and 1989 (solid lines indicate maxima and minima).

5.5.2 Barium

INAA data were acquired from 16 annual growth bands from one WFG *Montastrea annularis* core (replicate samples were analyzed from two annual bands). Radiation counts after INAA were been done for barium (Ba) and calcium (Ca). Measures of Ba/Ca molar ratios in corals at the West Flower Gardens and in the Florida Straits (data from Shen and Boyle 1988) are presented in Figure 5-26.

Ba/Ca molar ratios at the Flower Gardens were generally higher than those from the Florida Straits. No significant temporal trends were found based on these preliminary data. However, 1985 and 1989 replicates showed consistently higher ratios than those prior to 1970, as did all post-1970 samples. This coincides with a significant increase in drilling activity on the outer continental shelf in the vicinity of the Flower Garden Banks (Figure 5-27). More recent findings using more sophisicated analysis techniques (directly coupled plasma atomic emission spectrometry) and more samples, however, suggest that no correlation exists between the two data sets (Deslarzes, in prep.).

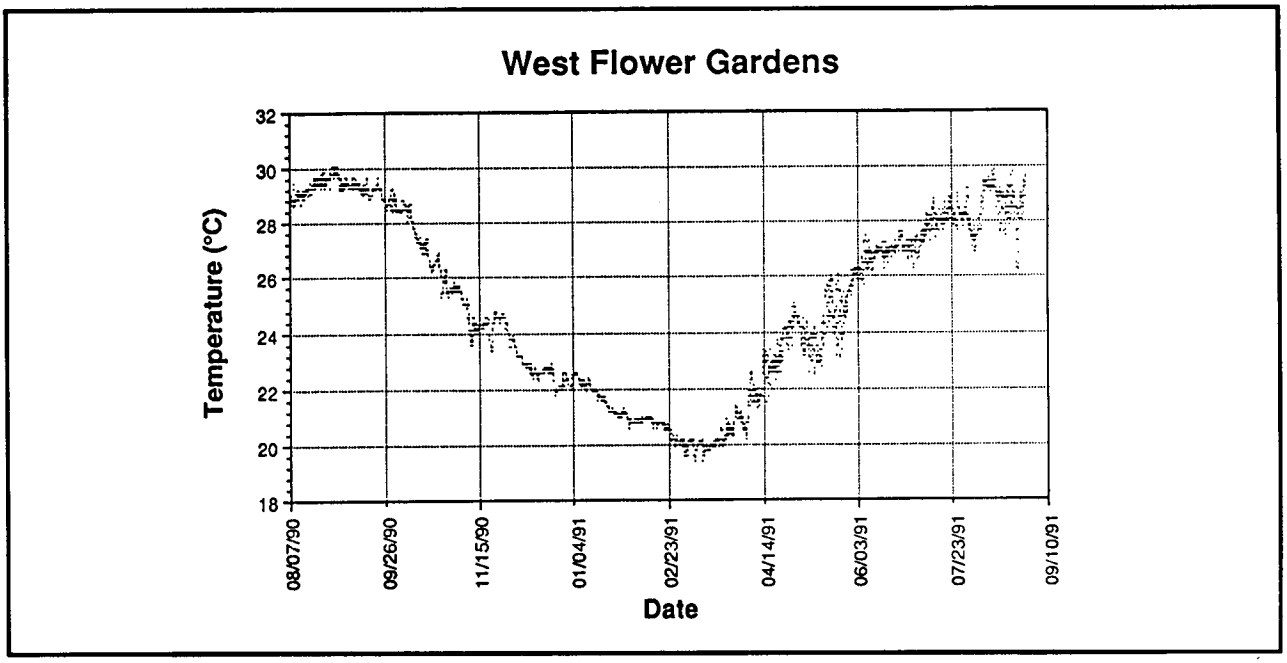


Figure 5-24. Thermograph data showing water temperature every two hours at 24 m depth on the West Flower Garden Bank between 7 August 1990 and 28 August 1991.

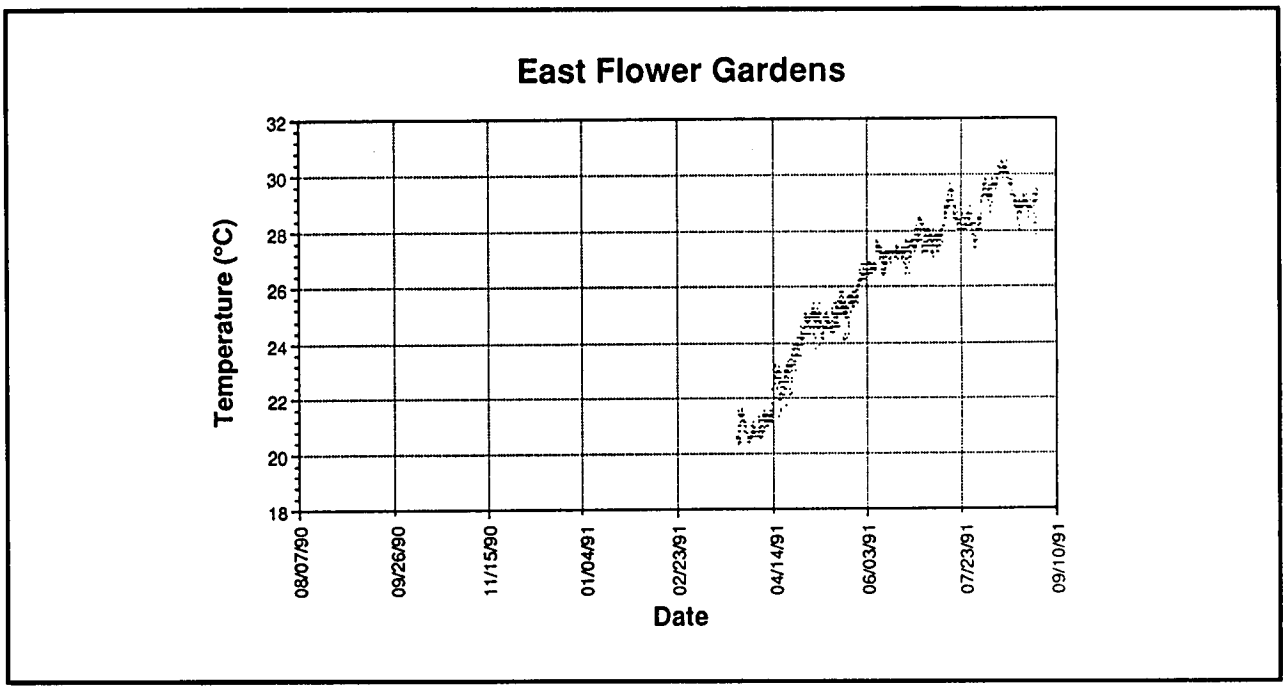


Figure 5-25. Thermograph data showing water temperature every two hours at 20 m depth on the East Flower Garden Bank between 24 March and 30 August 1991.

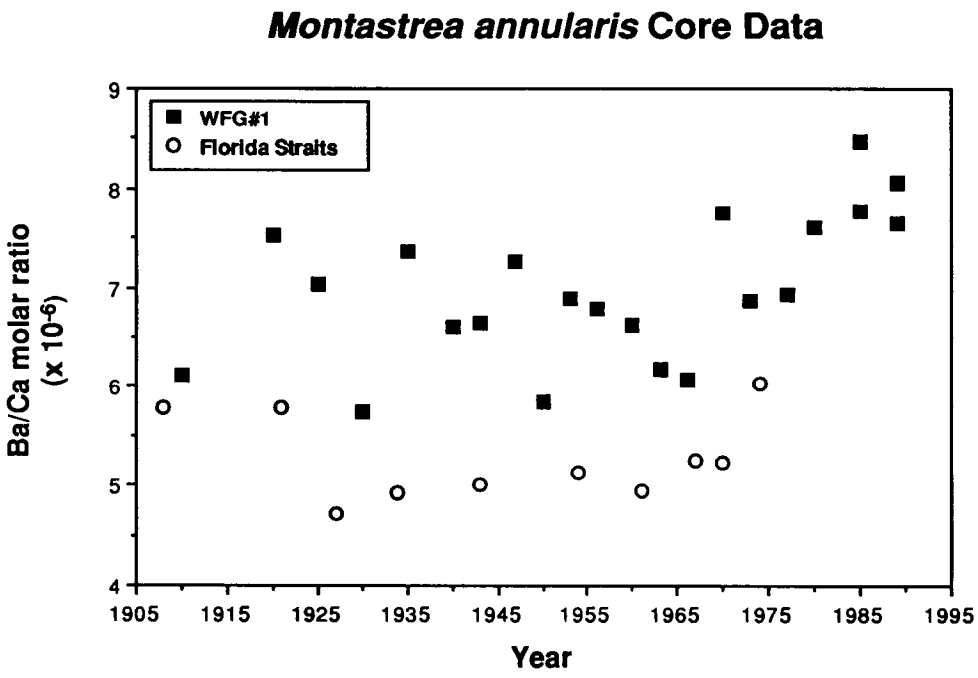


Figure 5-26. Barium to calcium molar ratios in samples taken from *Montastrea annularis* at the West Flower Garden Bank and the Florida Straits.

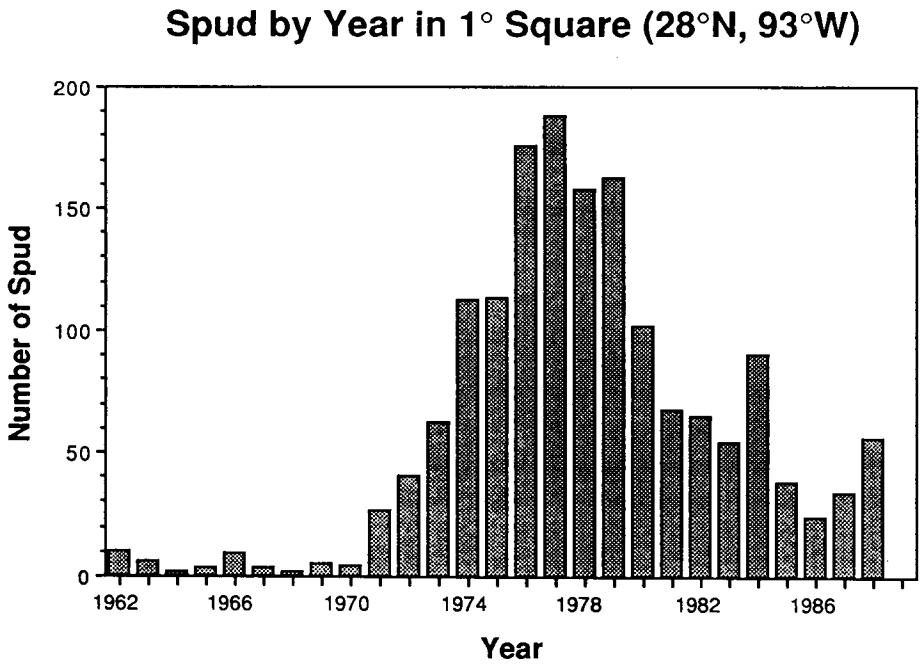


Figure 5-27. Drilling activity (spuds by year) in the region bounded by 28°N and 29°N, and 93°W and 94°W (Minerals Management Service, 1989).

5.6 Video Transects

All transects were obtained on each of six cruises (Table 5-15), resulting in 24 transects, 130 min, 9 sec of recording time, and a total area of 8,400 m^2.

Table 5-15. Dates and duration of video transects.

	EFG North	EFG East	WFG South	WFG West
Cruise 1	17 April 1989	17 April 1989	20 April 1989	20 April 1989
min:sec	5:12	6:17	5:22	4:43
Cruise 2	11 October 1989	11 October 1989	23 October 1989	24 October 1989
min:sec	4:29	4:58	5:31	4:55
Cruise 3	25 April 1990	25 April 1990	24 April 1990	24 April 1990
min:sec	5:58	5:15	6:31	5:56
Cruise 4	31 October 1990	31 October 1990	30 October 1990	30 October 1990
min:sec	5:49	5:16	5:51	4:41
Cruise 5	26 March 1991	26 March 1991	24 March 1991	24 March 1991
min:sec	5:07	5:14	6:12	4:55
Cruise 6	1 September 1991	1 September 1991	31 August 1991	31 August 1991
min:sec	5:12	5:16	6:57	5:32

5.6.1 Transect Habitat Descriptions

All four transects were located in apparently healthy portions of the upper coral reef habitat on the banks and ranged in depth from approximately 20 m to 27 m. There was very little sand and few sand flats in any transects. The two East Flower Garden Bank transects (north and east lines) did not have any sand within the 350 m^2 transect areas. The south transect on the West Flower Garden Bank included the largest sand area, 14.6 m^2, or 4.2% of the total transect area. The west transect line on the West Bank had only 2 m^2 of sand, or 0.6% of the transect. The size and shape of sand patches remained virtually identical throughout the study. There were, however, variations in the appearance of the sand patches between cruises. The patterns of rubble laying on the sand, as well as algae growth, changed over time and there were indications that the depth of portions of the sand patches changed slightly between cruises.

Reliable measurements of percent live coral cover were not possible for entire transects due to the lack of sufficient video resolution. A reasonable estimate of average live coral cover would be around 50%, or similar to that obtained using still photographic techniques (McGrail et al.,

1982; Bright et al., 1985; data in this study). However, some portions of transects, particularly on the southern half of the east line at the EFG, contained 80-100% live cover.

5.6.2 Changes in Coral Community Condition

5.6.2.1 Mortality

In general, there was a lack of significant visible change in coral community condition and composition through the study period. In all but a few cases there were no observed differences in cover of live tissue on repetitively videotaped colonies. Only three observations were recorded where small patches of coral suffered mortality. In no cases were tissue loss areas larger than 0.05 m^2.

Shortly before Cruise 4, a relatively large patch of algae on a coral head on the WFG west transect was consumed by parrotfish, leaving behind a bright white patch of dead coral skeleton approximately 1 m^2 in size. This patch was on an area of dead coral substrate, but similar parrotfish activities were observed on live corals on other occasions outside the video transects.

5.6.2.2 Bleaching

Three cruises, 2, 4 and 6 occurred during or shortly after summer temperature maxima. During these periods, coral bleaching was observed by divers and recorded in still photographic data. Definitive observations of coral bleaching on video transects were made only during Cruise 4 (on all transects) and only a single observation was made during Cruise 6. No obvious bleaching was observed on Cruise 2, the remaining summer cruise.

As described in Section 4.6, only complete bleaching could be distinguished on video transects. The single Cruise 6 observation was of a bleached fire coral (*Millepora* sp.) measuring 5.8 m^2 on the WFG west transect. This area represented 1.7% of the transect. During Cruise 4 (29 October - 1 November 1990) all four transects exhibited areas of complete bleaching. Table 5-16 summarizes bleached coral areas observed during Cruise 4.

Table 5-16. Total bleached area (m^2) observed on video transects during Cruise 4 (29 October to 1 November 1990) and percent of transect affected.

	WFG South	WFG West	EFG North	EFG East
Total Bleached Area	0.74	0.96	4.12	1.37
Percent of Transect	0.2	0.3	1.2	0.4

The total Cruise 4 bleached area was 2.1 m^2, or 0.53% of the transected area. This likely underestimates bleaching during Cruise 4 since observations were generally limited to areas greater than 0.01 m^2. It does, however, indicate a measure of bleaching relative to other cruises. All areas of bleaching apparently fully recovered prior to subsequent cruises.

5.6.3 Transect Counts

There were no marine mammals, sea turtles or large motile invertebrates observed during any of the 24 video transects. Invertebrates would have included sea urchins, starfish, crabs, lobsters, and large gastropod molluscs. This result was generally expected because the only abundant, relatively large motile invertebrates on the Flower Garden Banks are the spotted lobster (*Panulirus guttatus*), shovel-nose lobsters (*Scyllarides aequinoctialis*) and the long-spine sea urchin (*Diadema antillarum*), all of which are low in density They are also nocturnal and generally stay well hidden during the day. *Diadema* sea urchins were especially scarce as a result of the Caribbean-wide die-off in 1983 and 1984 (Lessios et al., 1984) and the lack of recovery of the sea urchin population at the Flower Gardens.

Counts of large-bodied reef fish totalled 2,043 individuals (Table 5-17 and Appendix F). A total of 20 different taxa were recorded. Only one taxon, the grouper genus *Mycteroperca*, was not identified to species, since diagnostic characters were not visible using video census techniques.

Fish counts within transects were relatively low, ranging from one to 207 individuals. This represents individual taxon density extremes of 0.3 to 59.1 individuals per 100 m^2. Total densities for all taxa along a single transect ranged from 0.6 per 100 m^2 on the East Flower Garden east transect during Cruise 4 to 62.9 individuals/100 m^2 during Cruise 5, also on the east line at the East Flower Garden Bank (Appendix F).

The two transects made at each bank during each cruise were considered replicate samples. Duplicate transects were taken on three occasions; during Cruise 2 on both the EFG and WFG, and during Cruise 6 on the WFG. Comparison of total fish counts in duplicate samples, using each minute of video as separate samples, indicated no significant differences between two of the three sets (the duplicates made on Cruise 2 on the WFG were significantly different; p=0.028).

As a method to test for temporal differences (season) and locations (banks), the robust Student's *t*-test was used. The null hypothesis was: H_o: $\mu_1=\mu_0$, or the density observed for a particular fish species was the same during each season or at each bank. These comparisons resulted in some significant differences. Seasonal differences between winter and summer cruises were not significant on the West Flower Garden Bank but winter densities were significantly higher than summer densities on the East Bank ($p<0.001$) (Table 5-17; Figure 5-28). When East and West Bank densities were combined for a seasonal comparison, there was a significant difference between winter and summer, with winter higher than summer at $\alpha = 0.05$ (Figure 5-29). There were no significant differences in fish density between the East and West Banks for either winter or summer cruises ($\alpha = 0.05$).

Using one-way ANOVA, there were no significant differences in fish density between cruises (all transects during each cruise combined; p=0.06) or between summer or winter cruises considered as separate groups (which would represent changes over years; p=0.15 and p=0.32 respectively).

Table 5-17. Summary of total observed fish density by cruise, bank and transect; bold type indicates "winter" cruises (number/100 m^2).

	EFG North	EFG East	WFG South	WFG West
Cruise 1	**20.02**	**49.29**	**6.29**	**8.29**
Cruise 2	8.58	3.15	55.44	38.60
Cruise 3	**33.43**	**55.71**	**61.72**	**12.02**
Cruise 4	6.60	0.58	3.44	5.44
Cruise 5	**29.43**	**62.86**	**50.87**	**17.16**
Cruise 6	13.44	18.30	18.20	18.87
Cruises 1,3,5	**27.68**	**54.95**	**39.63**	**12.49**
Cruises 2,4,6	9.54	4.01	25.69	20.97

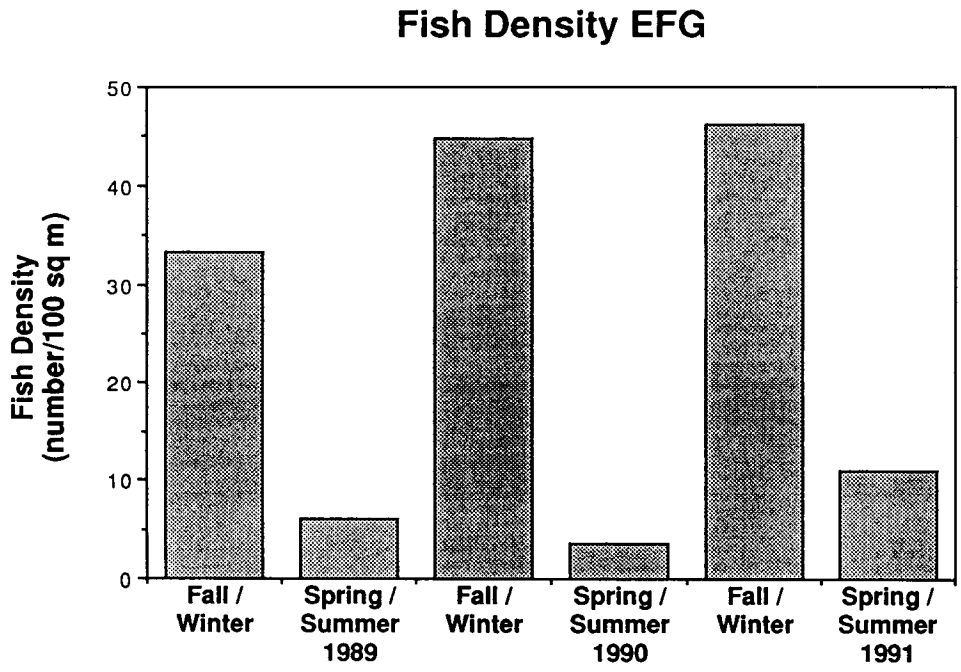


Figure 5-28 Large-body fish density by cruise on the East Flower Garden Bank (number/100 m^2).

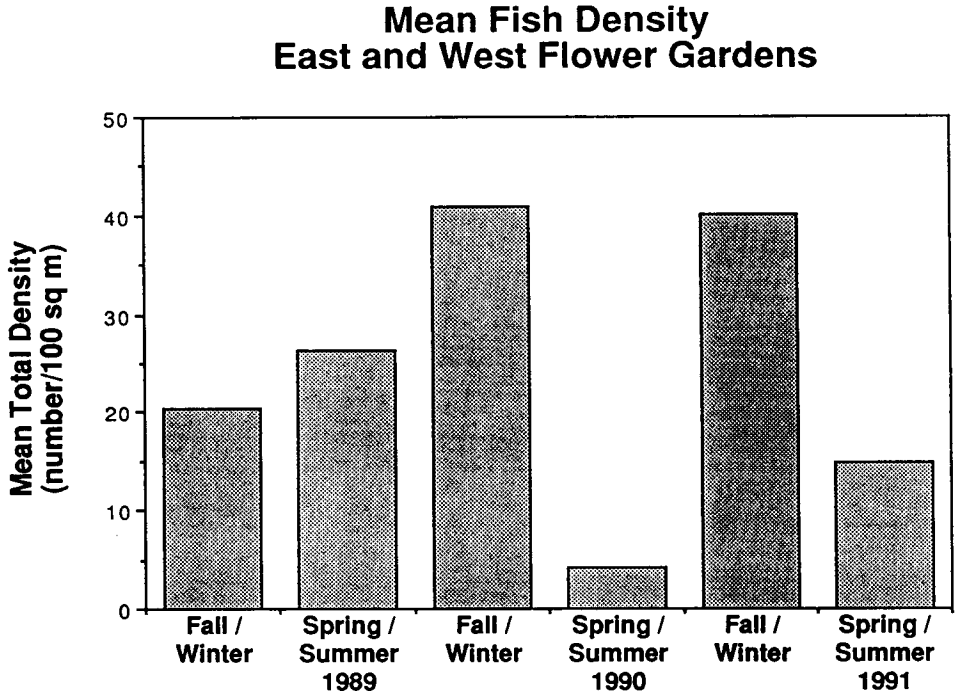


Figure 5-29. Mean large-body fish density by cruise on the Flower Garden Banks (banks combined; number/100 m^2).

Densities of three reef fish species were compared between cruises, banks and seasons. The three numerically dominant species (large-bodied taxa) were the creolefish (*Paranthias furcifer*), creole wrasse (*Clepticus parrai*) and the queen parrotfish (*Scarus vetula*). They represented slightly more than 93% of all observations (Appendix F). All other taxa represented less than half the density of the queen parrotfish, and were not compared statistically.

Figure 5-30 depicts creolefish density by cruise for both EFG (a) and WFG (b). The creolefish was by far the most abundant taxon of the large-bodied fish censused during this study. Like total densities, there were no significant differences between cruises ($F=1.05$; $p=0.42$) or between seasons (*t* test) with banks combined. Considering banks separately, the EFG seasonal difference was significant, with winter higher than summer ($\alpha = 0.001$). This comparison indicated no significant difference between seasons on the WFG.

Figure 5-31 shows creole wrasse density by cruise for both banks. There were no significant differences between cruises with all transects combined ($F=1.30$; $p=1.31$), between banks, or between seasons with the East and West Banks combined or considered separately (*t* test, $\alpha = 0.05$).

Figure 5-32 shows queen parrotfish density by cruise for both EFG and WFG. Densities were much lower than for creolefish or creole wrasse. There were no significant differences between cruises with all transects combined ($F=1.29$; $p=0.31$). However the difference between banks was significant (*t* test; $\alpha<.001$), the WFG being higher than EFG. No seasonal differences were detected.

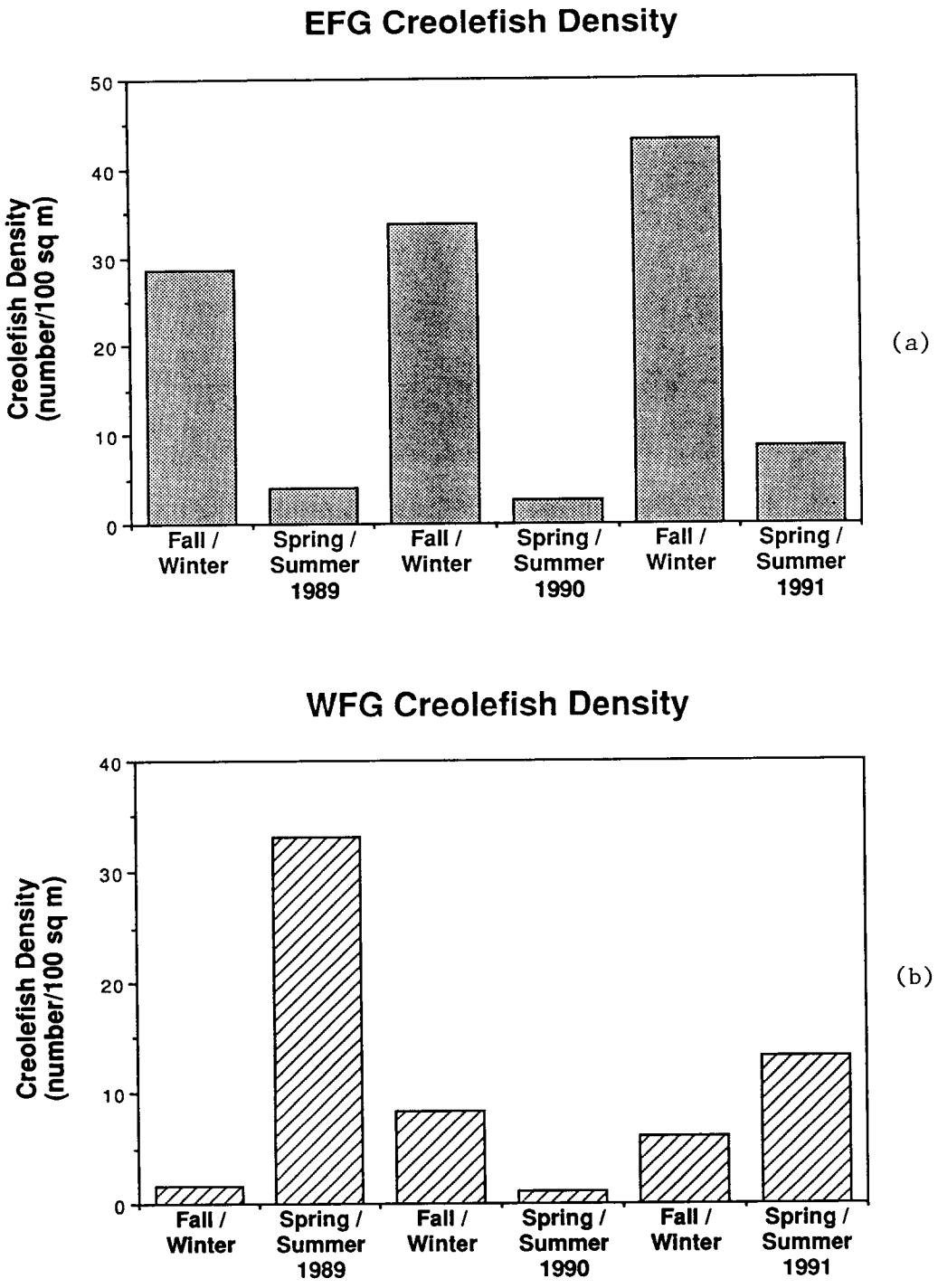


Figure 5-30. Creolefish density by cruise on the East (a) and West (b) Flower Garden Banks (number/100 m^2).

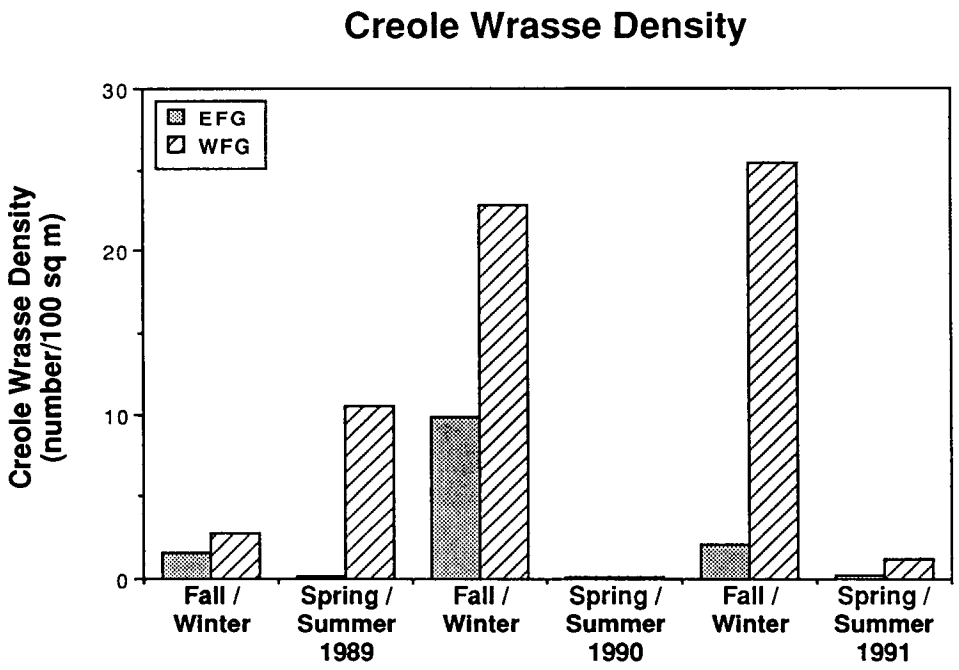


Figure 5-31. Creole wrasse density by cruise on the East and West Flower Garden Banks (number/100 m^2).

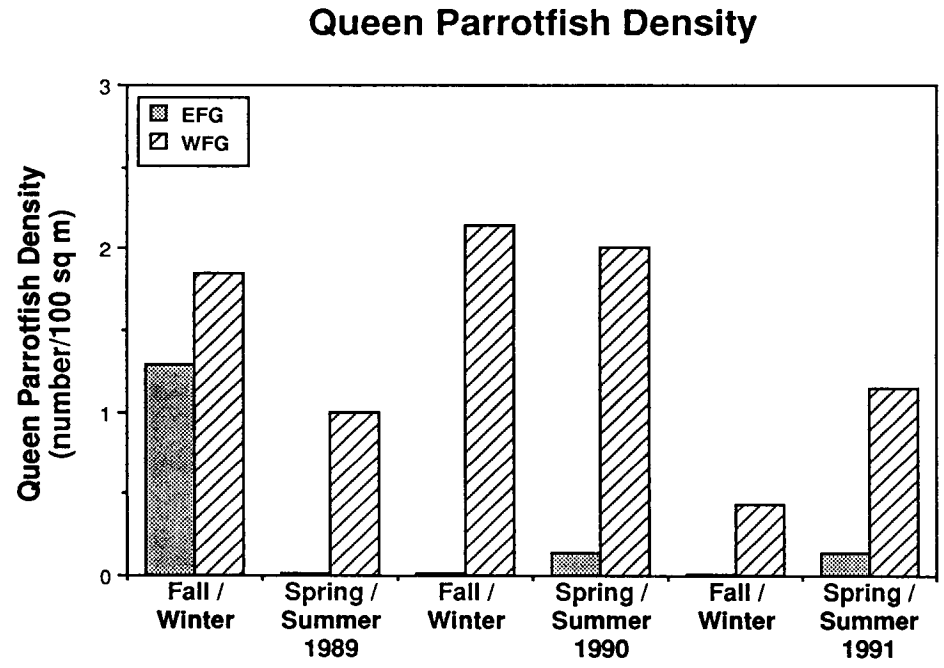


Figure 5-32. Queen parrotfish density by cruise on the East and West Flower Garden Banks (number/100 m^2).

6.0 DISCUSSION

6.1 Coral Community - Status and Trends

Approximately 15% of the surface area within the high diversity reef zones at the Flower Garden Banks contains sand or sand flats (Bright et al., 1984). Coral cover at the Flower Garden Banks is nearly 50%. Comparatively small percentages of the bottom are occupied by sponges. Soft algae can be abundant, but generally are recurrent and ephemeral (e.g., algae cover by *Dictyota* spp. and *Stypopodium zonale* was over 14% in September 1985 following the *Diadema antillarum* mass mortality which occurred between November 1984 and August 1985; Gittings and Bright, 1987). Much of the remaining surface is occupied by coralline algae, bryozoans, and other encrusting organisms. Coral cover and colony development exceed that on many Atlantic reefs. For these reasons, and because corals are generally thought to be sensitive to environmental perturbations (e.g., Thompson et al., 1980), community monitoring has focused on coral cover, relative dominance of coral species, and reef diversity indices.

With the exception of the sizes of high diversity reef areas on the banks, no substantial differences have been reported previously between the East and West Flower Garden Banks (Kraemer, 1982; Bright et al., 1984). The present study identified several differences with respect to the average sizes and population levels of several species, cover and relative dominance of certain species, species diversity, and evenness. This study, however, was not designed to characterize bank-level assemblages. The study was designed to monitor changes within specified study sites. Study areas were limited to 10,000 m^2 on each bank, or roughly one percent of the total reef area on the banks. Within these areas, the differences alluded to above occurred and were regularly identified. It is not known whether these differences are indicative of differences between reef assemblages on the banks in general. Though methods used in this study would be applicable to a study to determine bank differences, such a study would have to be conducted over a much wider area of each bank.

From a monitoring standpoint, virtually no identifiable temporal trends occurred over the period of the present study. The few differences

between periods that were identified did not persist, and thus did not constitute trends. Furthermore, with few exceptions, very little change was observed in the time since the 1970's, when the first quantitative reef surveys at the Flower Gardens were conducted. Part of the reason for this may be the fact that substantially fewer samples were obtained in early surveys, and sample analysis techniques, though appropriate for the time and probably accurate, were somewhat different from those used in this study. Thus, confidence limits of early estimates were quite broad, making long-term trends difficult to distinguish or demonstrate statistically. Notwithstanding these problems, most estimates of cover, relative abundance, and diversity produced in this study compared closely with those of earlier surveys, suggesting few, if any substantial changes in the last decade on either bank.

Repetitive large-scale photography has been used only to a limited extent previously for Flower Gardens research (Abbott, 1979). Nevertheless, it has proven effective in augmenting random transect data, and for monitoring gradual and acute changes in individual coral colonies. It is particularly useful for detecting the probable causes of tissue mortality, and for monitoring the nature and effects of coral bleaching and disease. The rates of occurrence of these phenomena are probably linked to the condition of an ecosystem. Both are thought to be indicators of the effects of natural and anthropogenic change (Williams et al., 1987; Antonius, 1981a).

Interestingly, a clear dichotomy between the effects of disease and coral bleaching was observed in this study. Where it occurred, disease resulted in comparatively large scale tissue mortality (69% of affected colonies exhibited some level of tissue necrosis). Coral bleaching, though comparatively widespread at times, resulted in negligible tissue loss (7% of affected colonies sustained tissue mortality, most tissue loss areas being very small). Though reports of coral bleaching are frequent, and frequency may be on the rise worldwide (Williams et al., 1987), until bleaching becomes a more serious threat to coral survival at the Flower Gardens, disease should be considered the more important cause of coral mortality, and possibly a more important vector of long-term change on the reefs.

6.2 Coral Growth - Status and Trends

Virtually all encrusting growth data suggested favorable conditions for coral growth at the Flower Garden Banks. Positive net encrusting growth rates were found in this study for both *Montastraea annularis* and *Diploria strigosa*. Gittings (1988) found net growth rates of essentially zero on apparently healthy, adult *M. annularis* corals on Molasses Reef, in the Florida Keys. Furthermore, though retreat rates often exceed advance rates (corals usually die faster than they grow [Abbott, 1979; Gittings, 1988]), the Flower Garden corals exhibited nearly equal rates over much of the study period.

Retreat to advance ratios showed that, on average, corals gained over 1.5 times as much marginal tissue as they lost during the study, a much higher value than found in the Florida Keys (Gittings and Bright, 1990).

Analyses of the proportions of margins advancing, retreating, and remaining stable between cruises (see ternary diagrams; Figures 5-18 and 5-19) showed that over half of the marginal tissue on *M. annularis* and *D. strigosa* was undergoing advance between cruises (averaging 63% for *M. annularis* and 56% for *D. strigosa*). By contrast, the proportions of retreating margins averaged only 22% for *M. annularis* and 26% for *D. strigosa*. Studies in Florida suggested roughly equal proportions of advance, retreat, and stable margins on Molasses Reef (Gittings and Bright, 1990).

All these data suggest a condition at the Flower Gardens whereby retreat is dictated by natural factors, such as competition for space, rather than man-induced stress (e.g. Marszalek, 1987; Gittings et al., 1988), or a situation wherein vectors such as disease, which can cause considerable tissue loss, are acting on limited scales. Environmental deterioration caused by human activities would be expected to exhibit evidence of at least some of the following: accelerated retreat relative to advance rates; reduced advance rates and net growth; diminished extent of advancing and stable margin length; and/or increased retreating margin length. None of these effects have been observed at the Flower Garden Banks.

A new method making use of planimetry (Section 4.2.2) was developed in this study to estimate annual accretionary growth. Instead of determining linear growth measurements along given "growth axes" (Hudson et al., 1976), as has been done in the past, a more comprehensive and probably more conservative accretionary growth estimate was obtained by integrating

annual growth increments. Previous studies estimated annual growth rates of one or a number of single polyps within annual bands. These polyps grew along what are called growth axes. On cores obtained in this study, growth axes generally intersected the fastest growing polyps in the band. Measurements along these axes may not reflect the average behavior of polyps on the colony, and probably would result in consistent overestimation of annual colonial growth. Estimates may represent maximal growth within annual bands. By integrating growth along entire annual bands, planimetry allows one to determine annual growth rates which reflect more of the *colonial* response to internal and environmental conditions. In addition, within-year variability between samples, typically high in these data sets due to the limited number of estimates within each yearly band, was minimized using planimetry.

Two other investigations of accretionary growth rates of *M. annularis* at the Flower Gardens have been conducted. Hudson and Robbin (1980) found a mean growth rate of 8.3 mm/year from 1910 to 1979 (12 cores). Kraemer (1982) reported a mean growth rate of 7.6 mm/year (four cores; 1964 to 1980). We report here a growth rate of 6.6 ± 0.1 mm/year (4 cores; 1910 to 1989). The lower growth rate found here may reflect the conservative nature of our measuring method. Planned research efforts include planimetric reexamination of X-radiographs made from cores taken by other investigators.

The reduced variability between samples provided by planimetry should allow the detection of significant events and temporal trends using fewer samples than would be necessary using linear measurements. The significant change in growth rates for a period of time after 1957 reported by Hudson and Robbin (1980) by the analysis of 12 cores was clearly evident in the analysis of only four cores in this study. Furthermore, an increased variability between years was evident in this study in the post-1957 period (not reported by Hudson and Robbin).

The decreased growth rate after 1957 may have been transitory. For some post-1957 years, growth measurements exceeded the overall mean. Also, growth after 1980 was similar to the overall mean, and 1989 growth averaged the highest of any year since 1910.

6.3 Historical Water Quality

It should be reiterated that a relationship between Ba/Ca molar ratios and drilling activity has not been shown to be statistically significant. Also, increases in Ba/Ca molar ratios at the level observed here have not been demonstrated to have any effect on coral growth or other essential functions. Current research efforts include analysis of annual samples not yet analyzed, increasing the number of replicate samples, and examination of correlations between barium signals and coral growth rates. Moreover, the level of sensitivity of barium detection could be increased by isolating it from the coral lattice (i.e., separating the incorporated barium from the coral) by post-irradiation chemistry, and by the use of a different analytical method such as Inductively Coupled Plasma Mass Spectroscopy (ICP; e.g., Lea, 1990).

In the future, tissue studies of the Atlantic thorny oyster (*Spondylus americanus*), a reef-dwelling bivalve which filters seawater, and for which data were obtained in the 1970's from the Flower Gardens, may be useful in elucidating possible water quality changes on the outer continental shelf.

Other than potentially recording increased oil and gas exploration in the northwestern Gulf of Mexico, barium may be useful as a proxy of upwelling, as has been suggested by sampling the coral *Porites lobata* in Southeast Asia (Moore et al., 1991). Annual, bright yellow-green fluorescing bands were observed on slabs of the cores used in this study. Similar fluorescence has been shown to be indicative of fulvic acid incorporation (Boto and Isdale, 1985). The intensity of the observed signal at the Flower Gardens is comparable to that reported by Boto and Isdale in near-shore corals. Potential sources of the abundant organic matter necessary for such signals could be terrestrial or oceanic (e.g., upwelling-induced productivity), or the combination of the two. Dodge and Lang (1983) discussed the possibility of river runoff (Atchafalaya and Mississippi Rivers) as a cause of water quality changes at the Flower Gardens. One approach to elucidate the source(s) of transitory and recurrent organic enrichment at the Flower Gardens would be to analyze stable carbon isotope signals within annual bands in the coral lattice (McConnaughey, 1989).

Future INAA radiation counts could also provide time series data for other trace metals such as iron and scandium, which indicate terrigenous

input; cobalt and zinc, which are potentially altered by anthropogenic sources; and strontium, a potential temperature variation indicator.

6.4 Reproductive Viability

Information regarding the reproductive viability of most coral species at the Flower Gardens is limited. Reproductive viability is of consequence to the potential for repopulation after mass mortality caused, for example, by extreme environmental perturbations, pathogens, or man-induced catastrophes. Moreover, reproductive viability controls the success of colonization and development of coral communities on other topographic highs, artificial reefs, and hydrocarbon production platforms in the region. The potential for repopulation of the Flower Garden Banks is of particular concern because of their isolation. Such geographically isolated reefs may rely on larval retention (self-seeding) for reef coral community maintenance and recovery. Depending on the reproductive potential of local corals and the extent of mortality, the reefs could be forced to depend on long-distance dispersal from other locations, resulting in prolonged recovery. During the final monitoring cruise conducted on this project, divers observed mass spawning of three coral species on the East Flower Garden Bank. This observation, as well as coral recruitment data collected over the last decade, and observations of corals on nearby platforms, shed light on the viability of these unique coral reefs.

6.4.1 Observations of Mass Spawning

Mass spawning is the synchronous release of gametes by multiple species of corals (Harrison and Wallace, 1990). The phenomenon has been reported primarily in the Pacific Ocean for broadcasting coral species, which release eggs and sperm into the water column for external fertilization and larval development. Attention has been paid to this reproductive strategy because mass spawning is a visually impressive event predictably related to annual and lunar cycles, and because it has important evolutionary implications. The correlation between moon phase and spawning of some species has been reported on numerous occasions, but it

is not known whether the regulatory mechanism is moonlight, tidal cycle, or related factors (e.g., Harrison and Wallace, 1990).

The first observation of mass coral spawning at the Flower Garden Banks was made on 13 August 1990. Recreational divers observed synchronous sperm release from several male *Montastraea cavernosa* colonies 1.5 hours before sunset, seven days after the full moon (Bright, 1991). At approximately 2100 hours, other colonies (species not noted) "as far as you could see" released "eggs" which floated to the surface to form "a brownish-orange, pollen-like blanket on the calm sea surface" (observation of Mr. Matt Scherzinger; Bright, 1991).

In 1991, late summer full moons over the Flower Garden Banks occurred on 26 July (98% illumination just prior to sunrise and after sunset) and 25 August (100% illumination at 0400, CDT; Zihua, 1991). Maximum water temperature, near 30°C, generally occurs in early to mid-August. Based on observations made by Szmant (1986) at La Parguera, Puerto Rico, and the 1990 observations at the Flower Gardens reported by Bright (1991), mass spawning was predicted to occur at the Flower Gardens on or about 2-3 August, or 1-2 September, 1991.

A recreational diver (Ms. Jennifer Lang) reported spawning of one *Montastraea cavernosa* colony at dusk on 2 August. Descriptions of the incident are consistent with observations of sperm release. The final monitoring cruise was scheduled to coincide with the later potential mass spawning date.

On 31 August, at the West Flower Garden Bank, no eggs or sperm were observed floating on the surface during the evening. At approximately 1800 hours on 1 September, limited sperm release by a colony of *Montastraea cavernosa* was observed at the East Flower Garden Bank. Small clouds of sperm were forcefully ejected synchronously by approximately 25% of the polyps on the colony.

During a night dive on the East Bank, no spawning colonies were observed at 2114 hours, but a small number of buoyant gamete bundles were seen in the water column (we have not confirmed that both eggs and sperm were contained in each bundle, but most hermaphroditic species contain such bundles; Harrison and Wallace, 1990). Also, a number of *Diploria strigosa* colonies were seen with retracted tentacles, white gamete bundles below their oral discs, and distended oral discs (the "setting" stage which

occurs just prior to spawning; Babcock et al., 1986). At 2116, the first spawning was observed. A *Diploria strigosa* colony began to expel a large number of white gamete bundles. From that time through the end of the dive at 2142, mass spawning of many colonies of *D. strigosa*, *Montastraea annularis*, and *M. cavernosa* occurred, though the majority of observations during the dive were of *D. strigosa*. Estimates made from macro photographs and video suggested production by one *D. strigosa* colony of approximately 34,000 bundles/m^2 of coral surface (3.4 gamete bundles/cm^2).

A surface slick of gametes streamed past the research vessel, which was anchored in approximately 100 m of water slightly over a kilometer ESE of the reef crest, until 2300, after which the water column was clear. At peak levels, gamete bundles, each containing dozens to over one hundred eggs, were present in densities estimated at up to three per cubic centimeter.

6.4.2 Coral Recruitment

The characteristics of coral recruitment at the Flower Garden Banks reveal the reproductive viability of several coral species which occur there. Two coral recruitment studies at the East Flower Garden Bank utilized molded cement plates and unglazed terracotta tiles as settling substrates (Bright et al., 1982; Baggett and Bright, 1985). In both studies, recruitment was limited almost exclusively to spat of the scleractinian families Agariciidae and Poritidae. Species in these families on the Flower Garden Banks include *Agaricia agaricites*, *Helioseris cucullata*, *Porites astreoides*, and *P. furcata*, (Rezak et al., 1985). Of these, *A. agaricites* and *P. astreoides* are by far the most abundant. Both are characterized as brooders (van Moorsel, 1983; Szmant, 1986), corals which retain larvae until they are completely developed and ready to settle.

Recruitment generally peaked in mid-summer, but commonly occurred between June and November (Bright et al., 1982; Baggett, 1985). Recruitment in December through May was rare. No broadcasting species were identified on settling plates.

Compared to data from recruitment studies in the Florida Keys, which used similar test substrates (Gittings et al., 1988), the Flower Gardens had high recruitment rates of brooding corals.

6.4.3 Platform Corals

Bright et al. (1991) reported a number of hermatypic corals occurring on platforms along the outer continental shelf of the northwestern Gulf of Mexico. Species included *Diploria strigosa*, *Diploria* sp., *Porites astreoides*, *Madracis decactis*, *Madracis asperula* and *Millepora alcicornis*. Based on Gulf of Mexico current patterns, proximity of the Flower Garden Banks, and species composition, the authors concluded that it is likely that these colonies originated from larvae produced at the Flower Gardens or nearby banks containing coral communities.

Both broadcasting and brooding species occurred among the platform corals. *Diploria strigosa* is a broadcaster with low reported recruitment rates (Szmant, 1986). *Porites astreoides*, a brooding species, has a high settlement rate, probably limited dispersal abilities, and high spat mortality (Baggett and Bright, 1985). Species of the genus *Millepora* are thought to be infrequent breeders, dioecious, with short-lived, gamete-bearing, free-swimming medusae which are shed into the water by the benthic colony (Lewis, 1989). However, Gittings and Bright (1990) found that *M. alcicornis* was an effective colonizer of a variety of surfaces, and had a high rate of recruitment comparable to some brooding scleractinians.

6.4.4 Coral Reproduction at the Flower Gardens

Nearly all reports of mass spawning have come from Pacific reef localities (see Harrison and Wallace [1990] for summary). Among Atlantic corals, Szmant (1986) observed spawning of a *Diploria strigosa* colony seven nights after the July/August, 1985 full moon. She also reported laboratory spawning of *Montastraea annularis* eight days after the September, 1984 full moon. In Bermuda, which contains high-latitude reefs comparable in many respects to the Flower Gardens (Rezak et al., 1985), Wyers (1985) showed that *Diploria strigosa* oocytes were present in colonies by February, but were still immature in late June. They were uniformly mature within and

between colonies by early August. Nearly all had been released by September, although spawning was not observed.

Differences and similarities occurred between the timing of Flower Gardens spawning and that of many Pacific species and localities. On the Great Barrier Reef, mass, multi-species (>100) spawning episodes occur between dusk and midnight, generally four to eight days following late spring full moons during neap tides, particularly in October and November (Harrison et al., 1984; Willis et al., 1985; Babcock et al., 1986; Bull, 1986; Willis and Oliver, 1988). This is a period of rapidly rising seawater temperature, and prior to the summer maximum. In contrast, mass spawning in Western Australia has been observed in autumn (March or April), following the seawater temperature maximum (Simpson, 1985; Harrison and Wallace, 1990). Nevertheless, the Western Australia spawning is also nocturnal, multi-specific, and takes place during neap tides 8-9 days after full moon. Its timing is much more like that observed at the Flower Gardens and elsewhere in the Atlantic for broadcasting species than that observed on the Great Barrier Reef. Elsewhere in the Pacific, mass spawning occurs in a variety of temporal patterns, most of which exhibit predictable lunar periodicity (Harrison and Wallace, 1990).

At the Flower Gardens, growth rates and population levels demonstrated to be at least comparable to those elsewhere in the Atlantic, relatively high rates of reproduction and recruitment by brooding corals, and prolific sexual reproduction by broadcasters during mass spawning events suggest favorable environmental conditions for corals. Indications are that these ecosystems could persist for some time without gene flow originating from outside sources. In addition, it would appear that there is high potential for repopulation following substantial disturbance. Monitoring and research should be conducted to elucidate the persistence of mass spawning on a year-by-year basis.

6.5 Coral Bleaching

During 1990, bleaching was observed on both the East and West Flower Garden Banks following a period of time when summer bottom temperature peaked above 30°C (Figure 5-24). At the time of installation of thermographs, which occurred prior to the summer temperature maximum,

bleaching was considered to be somewhat higher than previous summer conditions, but not severe. By late September, bleaching reached its maximum on the banks. It had become readily detectable by recreational divers by mid-September (Capt. Gary Rinn, pers. comm.). Unfortunately, the thermograph on the East Bank was lost during this time, and correlations between bleaching and temperature that year depended solely on data from the West Bank.

In 1991, coral bleaching was again observed after the summer temperature maximum, but was much more prevalent on the East Flower Garden Bank. Thermograph data indicated that water temperature exceeded 30°C for over a week on that bank, but never exceeded 30°C on the West Bank (Figures 5-24 and 5-25). Unusually high temperature has frequently been correlated with coral bleaching elsewhere (e.g., Williams et al., 1987; Glynn, 1988). Data from this study suggest a threshold temperature of around 30°C for the most sensitive coral species at the Flower Gardens.

As discussed in Section 6.1, coral bleaching lead to very little coral mortality. Only 7% of affected colonies lost any tissue at all. Those that did sustained loss over a very small percentage of the colony. Coral bleaching has been shown to affect calcification rates (Leder et al., 1991), and may cause substantial mortality when severe (Glynn, 1984). Data collected so far at the Flower Gardens suggest either considerable resilience of corals there, or lack of high temperature excursions of sufficient intensity or duration to induce mortality.

Further research on this phenomenon is clearly required. The Flower Gardens offer a unique environment to conduct such research because environmental factors that could complicate interpretations of bleaching data are limited. These include the occurrence of cold snaps, excessive freshwater inflow, tidal emergence, unusual ultraviolet light levels, water stagnation, and pollutants, all of which have been shown to either cause bleaching themselves or to be synergistically associated with other causitive factors (e.g., Coles and Jokiel, 1978).

6.6 Diseases

At present, diseases may be the most serious natural threat to corals at the Flower Garden Banks. The only significant tissue mortality observed at repetitive stations occurred as a result of "ridge-mortality" (Abbott, 1979) or unidentified diseases. As shown in Section 5.4, 69% of the 67 diseased corals at repetitive stations eventually exhibited some level of mortality. The number of colonies on which disease was identified, however, was low compared to the 4,160 colonies analyzed (1.7% occurrence over a three-year period).

Unfortunately, rates of occurrence of disease and bleaching were not obtained in early surveys of reef corals on the Flower Garden Banks. It is widely thought that coral disease incidence increases with deteriorating environmental conditions (Antonius, 1981a). Therefore, continued monitoring of disease frequency and effects should be considered an important component of long-term monitoring. In addition, research on identification of diseases at the Flower Gardens should be conducted so that the occurrence of "exotic" infestations can be identified. These include "black band" and "white band" diseases (Antonius, 1981b), which occur elsewhere but have never been observed at the Flower Gardens.

6.7 Videography

The results obtained from video transecting were limited, but are useful for obtaining an impression of the condition of the coral reef habitat over a relatively large area. The two semi-repetitive video transects on each bank during each cruise, encompassing an area of 700 m^2, could be performed during a single 30 min dive. The repetitive still photographic stations were far superior for measuring changes in percent cover and mortality within their total area of 320 m^2 on each bank, but the video method offered additional information on reef fish densities over a continuous, uninterrupted sample area.

The variation in fish density data was apparently related mostly to season. Only one significant difference was observed between banks, this being the queen parrotfish, and this difference was probably due to a number of zero observations on one bank.

No significant temporal trends with respect to fish populations were observed in this study. Useful comparisons can be made, however, between this study and past work conducted at the Flower Gardens. Boland et al. (1983) conducted the only other fish study on the Flower Garden Banks that included similar documentation of reef fish densities. Appendix F presents dates of cruises and densities of selected species relevant to this report. The 1981-82 study was performed in habitats from the reef crest to the soft bottom surrounding the banks, but data were separated by depth as well as habitat type. Appendix F also includes density data from the upper coral reef and the depth zone surveyed during this study (20 to 24 m).

Table 6-1 compares densities of the top four reef fish found in this study with data presented by Boland et al. (1983). There were no significant seasonal differences between the studies. When seasonal data were combined, comparisons between data sets were not significantly different for creolefish or creole wrasse densities, but were different for both queen and stoplight parrotfish (*t* test p=0.033 and 0.032 respectively).

Table 6-1. Selected reef fish densities from this study (FGLTM) and Boland et al. (1983) by season (number/100 m^2).

	FGLTM		Boland et al., 1983	
	Summer	Winter	Summer	Winter
Creolefish	10.48	20.24	14.58	12.99
Creole wrasse	2.07	10.79	5.02	1.25
Queen parrotfish	0.74	0.95	0.26	0.10
Stoplight parrotfish	0.36	0.29	0.13	0.02

The increase in parrotfish density (by 10 to 14 times) may be related to the mass mortality of the algae-eating long-spine sea urchin *Diadema antillarum* in 1983 and 1984 (Lessios et al., 1984). The effects of *Diadema* grazing have been widely reported (e.g., Sammarco, 1982). Changes in algal abundance and community structure following the mass mortality have been observed here and elsewhere (Gittings and Bright, 1987; Hughes et al., 1987), and changes in fish community structure have been observed elsewhere (Gladfelter, pers. comm.). The sea urchin population at the

Flower Gardens has shown no indications of significant recovery since the mass mortality. Diver estimates of sea urchin density have remained less than one individual/100 m^2.

The dominant fish taxa at the Flower Gardens, the creole fish *Paranthias furcifer*, showed the most variation between cruises and seasons during this study. It was interesting that seasonal variation was detected only on the EFG (Figure 5-30a). A possible explanation is that creolefish are plankton feeders commonly observed to form large feeding aggregations on the up-current edges of reefs. The EFG study site was located very near the drop-off on the eastern margin of the bank. The WFG study site was more centrally located with respect to the edges of the coral reef zone. Average winds in winter are toward the southwest and the rest of the year are toward the northwest (McGrail et al., 1982). Bright et al. (1985) reported a prevailing east-to-west current in winter at the EFG, shifting toward the northeast in summer. Winter westerly currents on the EFG could account for increased abundances of creolefish in the area of the video transects. Thus, for creolefish, seasonal variations in video transect data may not represent reef-wide population changes, but are possibly caused by seasonal migratory patterns.

6.7.1 General Observations

Between Cruises 4 and 5, a long portion of cable (15-20 m visible on video) was lost or snagged on the EFG east transect. The cable was 2-3 cm in diameter and was most likely lost during seismic surveys which were being conducted over and around the Flower Garden Banks during that time. The lost cable did not appear to cause extensive damage to reef corals, but tissue mortality would obviously result on colonies contacted by the cable. A number of seismic and other cables are located throughout the study site on the East Flower Garden Bank. Other than the visual pollution to this otherwise pristine environment, the older cables appear to have little long-term impact and are heavily encrusted with calcareous algae as well as a variety of live coral.

Two large vase-type sponges (*Xestospongia* sp.) were observed along two transects. Both of these individuals remained intact and in good condition throughout the study. Changes in size could not be accurately

determined due to slight variations in camera altitude or angle of observation between cruises.

6.7.2 Evaluation of Technique

In general, the video transecting technique was a simple and useful tool for qualitative assessment of coral community condition and composition. There were a number of difficulties which made quantitative descriptions and comparisons difficult. Some could be corrected in future monitoring efforts.

The videotape format used during this study was regular 8 mm, which at the time the project started, was the logical choice for underwater videography with a limited budget. Since that time, high band 8mm video or HI 8 has become the state-of-the-art for low cost underwater use. The resolution of regular 8 mm format was not adequate to resolve the detail of small areas of change or to distinguish between small areas of dead coral substrate and small patches of live coral. A HI 8 system with color correcting filter would greatly improve this situation. In order to continue to collect information over large areas using video, this higher resolution system should be used in a manner similar to that used in this study.

Highly repetitive videography along the 100 m transect lines was not possible. This was because transect lines were secured only at their ends (0 and 100 m). Though attempts were made to secure lines as tightly as possible, variable currents caused significant displacement, particularly in the center of the lines. The addition of permanent anchor bolts at regular intervals (at least three additional) would help to minimize this problem.

It was also difficult to maintain the video camera at a consistent altitude over the characteristically rough coral reef terrain. A single diver should perform all transects to minimize variations caused by different swimming techniques. But even using a single diver, variations will result from effects of currents on swimming speed, from variation in camera angle, and from variations in proximity of the plumb guide to the bottom. Thus, without significant changes in methodology, this technique is likely to remain best suited for detection of gross habitat or community changes, large-bodied fish assessments, and potentially seasonal differences (e.g., algal blooms) and long-term qualitative comparisons.

For reef fish surveys, transecting techniques are not necessarily the best methods (Thresher and Gunn, 1986; Bortone et al., 1986). Numerous techniques have been evaluated and one of the more useful, efficient and powerful of these is the random point count (Bohnsack and Bannerot, 1983). Point counts have been shown in some situations to provide more consistent estimates of density than transects (Thresher and Gunn, 1986).

Videography would be well-suited to point count censuses. Repeated or random stations could be used. A diver would slowly pan the video camera in a circular manner around each point for a specified length of time. Duplicate samples at stations of specific radius could be used to establish the precision of the method. The angle of the video would be low, permitting an optimal view of individual fish. This would also allow census of more species than down-looking video.

While it may not be necessary to survey an area as large as the 402,000 m^2 used by Boland et al. (1983), the sample size needed to make temporal comparisons should be larger than two 100 m transects currently used to obtain reef fish density and diversity estimates. A minimum of thirty to forty point counts would probably be necessary.

6.8 Industrial Threats and the Flower Garden Banks

6.8.1 Oil Spills

Oil spills in the Gulf of Mexico generally occur as a result of accidents on production platforms, and during transportation of crude oil and petroleum products by pipelines, barges and tankers (Rainey, 1991). The three major transport operations within the Gulf of Mexico are: import-export activities, shipping between Gulf terminals, and pumping domestic OCS oil to onshore terminals and refineries.

Of the 2,609 million barrels (bbl) of petroleum products transported through the Gulf of Mexico annually, about 862 million bbl are imported, representing around 63% of the total amount of oil imported to the U.S. each year. The majority of coastal storage facilities and refineries which handle both imported and domestically produced crude oil are located in Texas and Louisiana. The Gulf's busiest tanker routes pass in close proximity to the Flower Garden Banks. The safety fairway running east-west along the

shelf break in the northwestern Gulf of Mexico is less than 6 km south of the WFG and less than 10 km south of the EFG.

The three oil and gas development activities responsible for most accidental oil spills are platform production, pipeline transport, and tanker and barge transport. The majority of accidents occur in the nearshore regions, in close proximity to terminals, and are usually due to tanker or barge accidents. Nearly 32,000 km (20,000 miles) of pipeline exist in the Gulf of Mexico, and 98% of Gulf of Mexico OCS produced oil is taken to shore by pipeline. Nevertheless, in 1989, five times as much oil was imported than was produced in the region. Thus, the sheer volume of oil transported by tanker and barge accounts for the disproportionate number of spills due to these modes of transport (Rainey, 1991).

Between 1974 and July 1990, the Gulf of Mexico suffered 91 major spills (1,000 bbl or more). Although most of these spills occurred nearshore, there were eight large offshore oil spills in domestic Gulf waters during this period. Two of the OCS incidents resulted from platform mishaps; one from a collision and the other from a storage tank leak. The others were pipeline spills, mostly caused by anchor damage. The average volume of major spills in the Gulf OCS region resulting from platform accidents is 18,000 bbl (median value 6,000 bbl), and from pipeline spills 25,000 bbl (median value 7,000 bbl) (Rainey, 1991).

In June of 1990, the Norwegian tanker *M/V Mega Borg* lost approximately 84,000 bbl of its total cargo of 745,000 bbl of light Angolan crude oil, 57 miles offshore Galveston, Texas. The fires resulting from explosions that caused the incident burned for six days, but did not spread through the majority of oil containing compartments. The fire consumed most of the spilled oil as it exited the ship. Firefighters worked to keep the ship intact by cooling the vessel's surface and controlling the spread of fire to other compartments; had the entire cargo been lost, a spill nearly three times the volume of the *Exxon Valdez* spill would have resulted. As a consequence of the consumption of large quantities of crude by the fire, cleanup efforts, the application of over 11,000 gallons of dispersant, and evaporation, only about 730 bbl of oil remained in the water following the incident (Kennicutt et al., 1991). Although the spill occurred about 50 miles to the north of the Flower Garden Banks, potential impact to these

communities was ultimately averted by northeastward transport of the slick by surface currents (Wieczynski, 1991).

Excluding tanker and barge accidents, there have been 20 major spills in the Gulf since 1964, the first year oil spill records were kept. Half of these spills were due to platform accidents; the other half resulted from ruptured pipelines. Of the 10 platform accidents in the Gulf resulting in spills, all causes including blowouts, ship collisions, storage tank spills, and weather related accidents pose realistic, however unlikely, threats to the Flower Garden Banks. There has not been a major spill resulting from a platform accident since 1980, probably due to improvements in platform production and storage technology, and heightened care by industry personnel.

Both oil and gas pipelines exist near the Flower Garden Banks. Several are within the "4-Mile Zone" surrounding each bank (a zone in which drilling operations are required to shunt discharges to the seabottom for disposal). One gas pipeline is several hundred meters from the EFG Bank. Pipeline ruptures have historically been caused mainly by anchor dragging, although one incident, in 1976, was caused by a shrimp trawl. Detailed nautical charts with pipeline routes are available and their use strongly urged by industry, the Coast Guard, MMS, and NOAA. Since the depths surrounding the Flower Garden Banks generally exceed practical anchoring depths and commercial fisheries trawl depths, the risk of a ruptured pipeline due to anchor or trawl damage in the region is probably minimal. The largest potential threat with respect to pipeline and platform activities in the vicinity of the Flower Garden Banks may be that of leaks caused by equipment failure.

Recently, decisions regarding pipeline placement in the vicinity of the banks have taken into account the nature of currents in the region as well as geologic criteria. A proposed oil pipeline which would have been routed between the EFG and WFG was rerouted to the east of the EFG Bank because of prevailing west-to-east currents. Though the revised pipeline route comes to within 2.5 km of the bank, the rerouting makes it likely that the oil would drift to the east and not affect the biota of the bank. An additional safety measure in the operation this pipeline was an agreement by the operator to set the "Pressure Safety Low" (PSL; the pressure drop shut-in threshold level) sensors at a 10% range of the low normal operating

pressure (revised downward 15%). Thus, a pressure drop of 10% below the normal operating range would require shut-in and evaluation of the cause of the drop.

6.8.2 Toxicity of Oil to Corals

Documented, catastrophic damage to marine ecosystems by major oil spills, such as the *Amoco Cadiz*, the *Torrey Canyon*, and the *Exxon Valdez*, have led to considerable concern regarding the potential impacts of oil pollution on coral reefs. It can be argued that reef-building corals are the most important organisms on the shallow portions of most reefs, as they provide the framework upon which the entire ecosystem depends (coralline algae are also important framework producers, but their relative contribution is probably greater on deeper portions of reefs). It follows, therefore, that an environmental assessment addressing the effects of oil on reef organisms and community structure should concentrate first on the acute and chronic effects of hydrocarbons on hermatypic corals. Yet, quantitative scientific data on the effects of hydocarbons on hermatypic corals are limited, and in certain cases contradictory (Loya and Rinkevich, 1980; Grigg and Dollar, 1990).

In 1986 a spill of about 50,000 bbl heavily oiled nearshore reefs, mangroves, seagrass beds, and other habitats along the Caribbean coast of Panama which had previously been well characterized ecologically (Jackson et al., 1989). This presented researchers with an unprecedented opportunity for the study of both acute and chronic impacts of crude oil on tropical marine communities in their natural setting (Keller and Jackson, 1991). For coral communities, pre- and post-impact data at individual, population, and community levels were compared (Guzmán and Jackson, 1991). Most field studies concerning the effects of hydrocarbons on coral reef communities are in agreement in their conclusion that oil imparts significant detrimental effects on shallow coral reefs, but such studies typically lack observations recorded prior to the onset of pollution (Lewis, 1971; Johannes et al., 1972; Loya, 1976; Reimer, 1975; Birkeland et al., 1976; Rinkevich and Loya, 1977, 1979; Loya and Rinkevich, 1980; Peters et al., 1981; Bak, 1987). In an unpublished paper by Tunnell and Dokken, qualitative observations of impacts of the 1979 IXTOC spill were recorded

following surveys of several patch reefs and coral islands in the southwestern Gulf of Mexico. Although the ecology of these reefs had been well characterized prior to the spill (Rigby and McIntyre, 1966; Rannefeld, 1972; Tunnell, 1974), no effects on corals could be attributed to the spill. The studies in Panama, however, indicated that growth rates, population levels, total coral cover, and species diversity decreased significantly, and tissue injury increased in shallow subtidal areas where reef corals were exposed to oil. Although the dominant massive taxa, *Montastraea annularis*, *Porites astreoides*, and *Diploria strigosa*, are common to both the Flower Garden Banks and the impacted Panamanian reefs, the habitats differ markedly with respect to physical parameters, including depth, distance from shore, and hydrography (Rezak et al., 1985; Jackson et al., 1989). Consequently, it is unlikely that Panama data represent a realistic model which might serve as a basis for the prediction of potential impacts of a spill of this magnitude at the Flower Garden Banks.

Petroleum products can be ranked according to their relative toxicities to marine organisms, determined through laboratory studies. From high to low relative toxicity, they are refined products, fresh crude, waste oil, and residual material (Neff, 1979). Experiments on the effects of oil and dispersants on corals conducted in the laboratory reveal considerable contradictions. Some studies suggest little or no mortality or discernable sub-lethal impacts of oil on corals (Reimer, 1975; Elgershuizen and de Kruijf, 1976; Cook and Knap, 1983; LeGore et al., 1983; Dodge et al., 1984; Knap et al., 1985; Wyers et al., 1986), while others suggest serious damage (Lewis, 1971; Birkeland et al., 1976; Rinkevich and Loya, 1977; Peters et al., 1981). In either case, there is considerable debate over the extrapolation of laboratory data to assessments of the threat of oil, chemical dispersants, or oil/dispersant mixtures to corals. This is primarily due to the fact that actual field behavior of these mixtures is not well understood and is likely to vary in unpredictable ways from laboratory manipulations.

Laboratory studies of the toxicity of petroleum products to both marine vertebrate and invertebrate species indicate that higher molecular weight polycyclic components (containing 1-3 rings) are the most toxic to marine organisms (Neff, 1979). These compounds, however, are generally less soluble in water than hydrocarbons with low or intermediate molecular

weights. Non-molluscan invertebrates have shown the highest hydrocarbon sensitivities, with larval crustaceans being the most sensitive (Neff, 1987).

The corals present at the Flower Garden Banks are submerged by a minimum of about 18 m of water (Rezak et al., 1985). Hydrocarbon spills generally form buoyant surface-bound slicks (Lee, 1980). But the potential for submerged pipeline spills to introduce hydrocarbons into the water column, and the use of chemical dispersants which cause surface slicks to mix downward into the water column create the possibility of direct oiling at depth. Cook and Knap (1983) showed that the application of crude oil (19 ppm) mixed with the chemical dispersant COREXIT 9527 (1 ppm) reduced photosynthetic activity of zooxanthellae by 85%. In this study, neither oil nor dispersant alone had any effect, and recovery occurred within 24 hours.

Stress responses shown by corals to direct exposure to oil and oil fractions are given in Table 6-2. (Fucik et al., 1984). At sublethal levels the effects of hydrocarbons on corals are difficult to measure in the field. Impacts due to sublethal levels may not be evident for some time following a spill. The monitoring of corals exposed to oil may, however, reveal elevated susceptibility to bleaching, infection, reduced growth rate, reduced reproductive ability, and mortality (Brown and Howard, 1985).

6.8.3 Produced Waters

Produced waters are those contained in hydrocarbon-bearing formations. Some are brought to the surface during extraction of petroleum reserves (crude, condensates, and natural gas). Produced waters are formed from water trapped within permeable sedimentary rock, and are also known as formation water, or oil field brine. Produced waters are generally hypersaline (50-200) and contain elevated levels of hydrocarbons, trace metals, elemental sulfur, and radionuclides (Kendall and Rainey, 1991). Studies indicate that the types of compounds found in these effluents are fairly constant, but their relative concentrations are variable (Rabalais, 1991; St. Pé et al., 1991). In coastal and marine environments the majority of produced water is discharged untreated directly at the surface.

A recent escalation of research into the environmental effects of produced water discharges has been largely due to the increased regulatory

Table 6-2. Stress responses of corals shown to result from exposure to oil.

Response	Reference
tissue death	Johannes et al.(1972); Reimer (1975); Neff and Anderson (1981)
impaired feeding	Reimer (1975); Lewis (1971)
impaired polyp retraction	Shinn (1976); Cohen et al. (1977); Elgershuizen and de Kruijf (1976); Neff and Anderson (1981)
impaired sediment clearance	Bak and Elgershuizen (1976)
increased mucus production	Mitchell and Chet (1975)
decreased calcification rates	Birkeland et al. (1976); Neff and Anderson (1981)
gonad damage	Rinkevich and Loya (1979); Peters et al. (1981)
extrusion of immature planulae	Loya and Rinkevich (1979); Cohen et al. (1977)
larval mortality	Rinkevich and Loya (1977)
impaired larval settlement	Rinkevich and Loya (1977)
coenosarc tissue damage	Peters et al. (1981); Burns et al. (1991)
expulsion of zooxanthellae (bleaching)	Birkeland et al. (1976); Neff and Anderson (1981)
decreased zooxanthellae production	Neff and Anderson (1981)
muscle atrophy	Peters et al. (1981)
effects on lipid biochemistry	Burns et al. (1991)

concerns of federal, state, and local agencies (Gibson, 1991; St. Pé et al., 1991). Produced water discharges have been shown to affect platform biofouling community structure (Gallaway and Lewbel, 1982). The most susceptible organisms have been shown to be microcrustaceans and barnacles. Due to dilution of the fluids, the impacts appeared to be restricted to within several meters of the point of discharge.

Field biological assessments using oysters have been conducted to examine impacts of organic and inorganic contaminants associated with the discharge of produced waters. Oysters serve as useful indicators of the presence of elevated levels of specific compounds due to their tendency to bioaccumulate. Studies of bioaccumulation of produced water contaminants in oyster tissues compared with concentrations of contaminants in ambient sediments show a clear potential for uptake and accumulation of these compounds both in close proximity to and at some distance from the source of discharge. One such study placed cages containing 75 oysters about 75 m from discharge sources in several nearshore regions in Louisiana (St. Pé et

al., 1991). In some cases, levels of hydrocarbons and petrogenic radionuclides in oyster tissues were several hundred times background concentrations. Reef-building corals, however do not occur in these nearshore habitats in the Gulf, and hydrological conditions at the Flower Garden Banks are vastly different from the shallow turbid regions characteristic of oyster reefs. In addition, hermatypic corals have not been shown to bioaccumule these compounds.

Toxic levels of produced water compounds are generally not observed in sediment samples taken from beyond 20 m from the source of discharge (Neff and Sauer, 1991). Sediment analyses conducted under a variety of conditions, including shallow semi-enclosed and open inner continental shelf habitats at discharge levels of about 1,600 bbl/day, have shown that produced water contamination of sediments, even in the most extreme cases examined, did not extend beyond 100 m from the point of discharge (Neff and Sauer, 1991). In addition, Neff and Sauer (1991) found that the low level of contamination of sediments with petroleum hydrocarbons, even at shallow (8.5 m) sampling stations 20 m from the point source, was not sufficient to cause hypoxia in either bottom water or surficial sediments. Benthic communities located between 100 and 1,000 m from the platforms exhibited no evidence of impacts attributable to platform discharges.

At present there are no production platforms near enough, or in appropriate positions relative to the Flower Garden Banks to have an impact from the discharge of produced waters. Monitoring studies conducted throughout the operational life of a platform less than 2 km from the high diversity reef on the EFG Bank have revealed no detrimental effects on the reef. In the case of this platform, however, it is possible that prevailing west-to-east currents have some effect on limiting the platform's influence on the bank. For other platforms in the vicinity, relatively deep water between the platforms and the banks and generally active currents enhance dilution, and further diminish the potential for impact on the banks. For platforms within the "4-Mile Zone" surrounding each bank, MMS requirements to shunt discharges to within 10 m of the seafloor prior to release further limit the potential for impact.

6.8.4 Drill Muds

During offshore drilling, plumes of turbid water are commonly seen trailing down-current from drilling platforms. These plumes consist primarily of drill muds, which are routinely discharged into the surrounding water at variable rates, and may be visible for up to 3 km from their source (Thompson et al., 1980). The most important functions of drilling muds include transport and removal of drill cuttings from the hole, lubrication and cooling of the bit and drill string, control of subsurface pressure, and prevention of corrosion of the drill pipe, casing, and other steel parts. Drilling muds are essentially suspensions of clays in water, plus organic and inorganic chemicals which control flow and filtration properties and minimize corrosion. The major component of drilling muds is barite, or barium sulfate ($BaSO_4$). Drilling muds generally contain up to 90% barite by dry weight. Barite is insoluble, inert, and nontoxic (Thompson et al., 1980). Other components of drilling muds include chromium, and biocides which prevent bacterial growth (which can produce corrosive metabolic waste products such as hydrogen sulfide; Monaghan et al., 1980).

Drill muds are notable for wide variations in toxicity from one mud to another (e.g., Powell et al., 1984a,b), though toxic agents are often difficult to determine conclusively and appear to vary between drill muds (Powell et al., 1984b). Demonstrated stress responses are given in Table 6-3. Heavy metals, hydrocarbons, and biocides have been suggested as toxic agents (Loya and Rinkevich, 1980; Kendall, 1983). However, discharge of even the least toxic muds can increase turbidity in the vicinity of the source due to increased levels of suspended particulates and may be expected to cause some effects as a result (Kendall et al., 1983, 1985). High turbidity decreases incident light levels, and has been shown to adversely affect coral growth rates (Hudson and Robbin, 1980). Direct contact of highly concentrated drill muds to live coral results in bleaching and tissue death (Kendall, 1983). Under most conditions, coral growth and other metabolic functions can recover from effects (Kendall et al., 1984; but see Powell et al., 1984b). Prediction of recovery capacity may depend on drill mud toxicity, and not simply exposure level (Kendall et al., 1984).

Dilution of discharged drill muds increases with distance from the source (Shinn et al., 1980; Thompson et al., 1980; St. Pé et al., 1991),

resulting in decreased toxicity and turbidity. Thus, the distance between platforms and sensitive communities influences the potential for effects on organisms. Regulatory measures also influence this potential. Production platforms in the vicinity of the Flower Garden Banks, as well as in other regions which are considered environmentally sensitive, are required by MMS to shunt discharges to within ten meters of the seafloor. This practice has been shown to limit the area of the discharge plume, and thus the range of potential environmental impact. Deepwater discharge, dilution of drilling muds, and lack of net upward transport of particles by deep currents (McGrail et al., 1982), are apparently sufficient to prevent fine particles released by offshore production from reaching the Flower Gardens. Monitoring studies on the reefs have not encountered sediments originating from drilling operations (Continental Shelf Associates, Inc., 1985).

Therefore, neither contamination by toxic components, nor turbidity or smothering by drill muds seem to pose realistic threats to the coral reefs at the Flower Garden Banks. It is likely that the boundaries of the Flower Garden Banks National Marine Sanctuary and protective zones established by MMS surrounding the sanctuary boundaries further diminish the potential threat posed by discharged materials released during offshore production.

Table 6-3. Potential effects of drilling fluids on reef corals.

Stress Response	Reference
tissue death	Thompson (1980)
impaired feeding	Szmant-Froelich et al. (1981)
impaired sediment clearance	Thompson and Bright (1977); Thompson (1980)
increased mucus production	Thompson (1980); Thompson et al. (1980); Thompson and Bright (1980);
decreased calcification rates	Szmant-Froelich et al. (1981); Dodge (1982); White et al. (1982); Kendall et al. (1983, 1984)
expulsion of zooxanthellae (bleaching)	Thompson (1980); Kendall et al. (1983, 1984)
decreased zooxanthellae production	Szmant-Froelich et al. (1981)
increased incidence of infection	White et al. (1982)
decreased soluble tissue protein	Kendall et al. (1983, 1984); Powell et al. (1984b)
change in free amino acid pool	Kendall et al. (1983); Powell et al. (1984a,b)

7.0 Conclusions

Virtually no significant long-term changes have been detected in coral reef populations, cover, or diversity at the Flower Garden Banks since quantitative surveys of the reefs began. Those differences that have been identified are not considered to represent trends or evidence of deterioration of habitat quality. Differences between study sites on the banks should not, without further study, be considered as representative of differences between the banks in general.

Coral bleaching was observed every summer during the study. The most significant episodes were associated with sea water temperatures that exceeded 30°C, generally in early to mid-August. Mortality was seldom associated with bleaching, as only 7% of bleached colonies exhibited any tissue loss; where it did occur, loss was limited to small portions of the bleached colonies.

Diseases occurred on less then 2% of all corals analyzed at repetitive stations. Compared to coral bleaching, however, relatively high levels of tissue mortality occurred; 69% of diseased colonies exhibited tissue loss.

Conditions for accretionary and encrusting growth on the banks appear to be favorable for *Montastrea annularis* and *Diploria strigosa*, the two dominant coral species. Accretionary growth rates comparable to those found elsewhere in the Atlantic, relatively high encrusting growth rates, net tissue gain during the study period, and high proportions of advancing margins on these corals all indicate a lack of effects from factors other than those which naturally control coral growth.

While barium incorporation rates in a coral core analyzed from the West Flower Garden Bank appeared to be higher than those reported from the Florida Keys, the data were preliminary. A possible elevation in levels of barium related to drilling activity could not be verified, but requires further investigation. Regardless, elevated levels would not necessarily imply detrimental effects of industrial activity.

The observations of mass spawning by three coral species on the East Bank in 1991 constitutes the first documented observation of synchronous spawning by multiple species in the Atlantic Ocean region. Data from these observations, from studies of recruitment, and observations of reef corals on petroleum platforms imply that the Flower Garden Banks harbor wholly

functional coral communities. This suggests that the reefs are capable of self-seeding, and may not require gene flow from outside sources for recovery following natural or human-induced disturbance.

Reef fish populations exhibited considerable seasonal variation. Differences between banks for one species (the creolefish, *Paranthias furcifer*) may be a result of behavioral variations related to feeding and the locations of study sites relative to the banks' peripheries. Parrotfish abundances appeared to have increased since the early 1980's. This may be a result of the 1983-1984 mass mortality of the long-spine sea urchin, *Diadema antillarum*, and consequent changes in benthic algae availability on the banks.

Potential threats to the Flower Garden Banks from hydrocarbon exploration and development include tanker oil spills, accidental spills from platforms and pipelines, spill clean-up efforts, and the discharge of produced waters and drilling fluids. Accidents on platforms, and those occurring during tanker transport of oil through the Gulf may pose the most realistic threats, since platforms occur in the vicinity and traffic routes pass nearby. Subsequent clean-up efforts, if they utilize dispersants, pose an uncertain, but possibly substantial, threat to reef corals, even at the depths of the Flower Gardens. Material discharge is largely regulated by shunting in areas close enough to the Flower Gardens to otherwise preclude effective dilution.

The remote location of the Flower Garden Banks has left them, for the most part, undisturbed. Resource monitoring has demonstrated no substantial long-term changes in reef coral populations or growth rates. Potential industrial effects caused by offshore development in the northwest Gulf have been monitored, but never detected. It is anticipated that the designation of the Flower Garden Banks National Marine Sanctuary will foster continued resource protection and encourage increased research on important functional attributes of these unique and pristine coral reefs.

8.0 Literature Cited

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

Antonius, A. 1981a. Coral reef pathology: a review. Proc. 4th Int. Coral Reef Symp. (Manila) 2:3-6.

Antonius, A. 1981b. The "band" diseases in coral reefs. Proc. 4th Int. Coral Reef Symp. (Manila) 2:7-14.

Babcock, R.C., G.D. Bull, P.L. Harrison, A.J. Heyward, J.K. Oliver, C.C. Wallace, and B.L. Willis. 1986. Synchronous spawnings of 105 scleractinian coral species on the Great Barrier Reef. Mar. Biol. 90:379-394.

Baggett, L.S. 1985. Patterns of coral recruitment at the East Flower Garden bank. M.S. Thesis, Texas A&M University, Dept. of Oceanography, College Station, TX. 55 pp.

Baggett, L.S. and T.J. Bright. 1985. Coral recruitment at the East Flower Garden Reef (northwestern Gulf of Mexico). Proc. 5th Int. Coral Reef Cong. 4:379-384.

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

Bak, R.P.M. and J.H.B.W. Elgershuizen. 1976. Patterns of oil sediment rejection in corals. Mar. Biol. 37:105-113

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

Bohnsack, J.A. and S.P. Bannerot. 1983. A random point census technique for visually assessing coral reef fishes. Pp. 5-7 *In:* Barans, C.A. and S.A. Bortone (eds.) The visual assessment of fish populations in the southeastern United States. South Carolina Sea Grant Consortium Tech. Rept. No. 1, 52 pp.

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

Bortone, S.A., R.W. Hastings, and J.L. Oglesby. 1986. Quantification of reef fish assemblages: A comparison of several *in situ* methods. N.E. Gulf Sci. 8(1):1-22.

Boto, K. and P. Isdale. 1985. Fluorescent bands in massive corals result from terrestrial fulvic acid inputs to the nearshore zone. Nature 315:396-397.

Bright, T.J. 1986. A survey of the topography and biological communities of Bright Bank, northwestern Gulf of Mexico. Rept. to Amarada Hess Corp. 1200 Milam, Houston, TX, 77002. 22 pp.

Bright, T.J. 1991. First direct sighting of star coral spawning. Texas Shores (Texas A&M University Sea Grant Program) 24(1):2.

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

Bright, T.J., J.W. Tunnell, L.H. Pequegnat, T.E. Burke, C.W. Cashman, D.A. Cropper, J.P. Ray, R.C. Tressler, J. Teerling, and J.B. Wills. 1974. Biotic zonation on the West Flower Garden Bank. pp. 5-54 *In* T.J. Bright and L.H. Pequegnat (eds.) Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division, Houston, TX. 435 pp.

Bright, T.J., S. 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 U.S. Dept. of Interior, Bureau of Land Management. Gulf of Mexico OCS Office, New Orleans, LA. Contract No. AA551-CT8-35. Texas A&M Dept. of Oceanography Tech. Rep. 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 U.S. Dept. of 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. Dept. of Interior Minerals Management Service, Gulf of Mexico OCS Region Office, New Orleans, LA. OCS Studies/MMS 85-0024. 103 pp.

Bright, T.J., S.R. Gittings, A. Choi, and R.R. Barnett. 1987. Coral recovery following the grounding of the freighter M/V WELLWOOD on Molasses Reef, Key Largo National Marine Sanctuary. Final Report to NOAA Office of Coastal and Estuarine Systems, Washington, D.C. Contract No. NA85AA-H-CZ015. 202 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

Bull, G. 1986. Distribution and abundance of coral plankton. Coral Reefs 4:197-200.

Burns, K.A., J. MacPherson, J. Tierney, and G. Kananan. 1991. Hydrocarbon Analyses. Chapter 9 *In:* B.D. Keller and J.B.C. Jackson (eds.) Long-term assessment of the oil spill at Bahía Las Minas, Panama. Interim Report. OCS Study MMS-90-0031. U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 450 pp.

Carpenter, J.H. 1965. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method. Limnol. Oceanogr. 10: 141-143.

Chamberlain, C.K. 1966. Some Octocorallia of Isla los Lobos, Veracruz, Mexico. Brigham Univ. Geol. Stud. 13:47-54.

Church, T.M. and K. Wolgemuth. 1972. Marine barite saturation. Earth and Planetary Science Letters 15:35-44.

Cohen, Y., A. Nissenbaum, and R. Eisler. 1977. Effects of Iranian crude oil on the Red Sea octocoral *Heteroxenia buscesens*. Env. Poll. 12:173-185.

Coles, S.L. and P.L. Jokiel. 1978. Synergistic effects of temperature, and light on the hermatypic coral *Montipora verucosa.* Mar. Biol. 49: 187-195.

Continental Shelf Associates, Inc. 1984. Impact assessment following an anchoring incident at the East Flower Garden Bank coral reef. Rep. 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. Rept. to Mobil Producing Texas and New Mexico, Inc., The Woodlands, TX. 353 pp. + appendices.

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. Rept. to Union Oil Company of California, Houston, TX. 35 pp. + appendices.

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

Dennis, G.D. 1985. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. M.S. Thesis, Texas A&M University, College Station, TX. 184 pp.

Dennis, G.D. and T.J. Bright. 1988. Reef fish assemblages on hard banks in the northwestern Gulf of Mexico. Bull. Mar. Sci. 43(2):280-307.

Deslarzes, K.J.P. in prep. Long-term monitoring of reef corals at the Flower Garden Banks (northwest Gulf of Mexico): reef coral population changes and historical incorporation of barium in *Montastrea annularis*. Ph.D. Dissertation, Texas A&M University, College Station, TX.

Dodge, R.E. 1982. Effects of drilling fluids on the reef building coral *Montastrea annularis*. Mar. Biol. 71:141-147.

Dodge, R.E. and J.C. Lang 1983. Environmental correlates of hermatypic coral (*Montastrea annularis*) growth on the East Flower Garden Bank, northwest Gulf of Mexico. Limnol. Oceanogr. 28(2):228-240.

Dodge, R.E. and J. Thompson. 1974. The natural radiochemical and growth records in contemporary corals from the Atlantic and Caribbean. Earth Planetary Sci. Lett. 23:313-322.

Dodge, R.E., R.C. Aller, and J. Thompson. 1974. Coral growth related to resuspension of bottom sediments. Nature 274:574-577.

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.

Edwards, G.S. 1971. Geology of the West Flower Garden Bank. Texas A&M Sea Grant Publ., TAMU-SG-71-215. 199 pp.

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.

Endean, R. 1976. Destruction and recovery of coral reef communities. pp. 215-254 *In:* O.A. Jones and R. Endean (eds.) Biology and Geology of Coral Reefs. Vol. III. Biology 2. Academic Press, New York.

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., A.L. Buikema, Jr. (eds.) Restoration of Habitats Impacted by Oil Spills. Butterworth Publishers, Boston. 182 pp.

Gallaway, B.J. and G.S. Lewbel. 1982. The ecology of petroleum platforms in the northwestern Gulf of Mexico: a community profile. U.S. Fish and Wildlife Service, Off. Biol. Services, Washington, DC. FWS/OBS-82-27. Bureau of Land Management, Gulf of Mexico OCS Regional Office, Open File Report 82-03. xiv + 92 pp.

Gibson, L.B. 1991. Overview of current federal environmental regulations regarding produced waters. pp. 180-182. *In:* Proc.: eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Gittings, S.R. 1988. The recovery process in a mechanically damaged coral reef community. Ph.D. Dissertation, Texas A&M University, Dept. 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. and T.J. Bright. 1987. Mass mortality of *Diadema antillarum* at the Flower Garden banks, northwest Gulf of Mexico: effect on algae and coral cover. Benthic Ecology Meetings, Raleigh, North Carolina (abstract).

Gittings, S.R., T.J. Bright, A. Choi, and R.R. Barnett. 1988. The recovery process in a mechanically damaged coral reef community: recruitment and growth. Proc. 6th Int. Coral Reef Symp. 2:225-230.

Gittings, S.R. and T.J. Bright. 1990. Coral recovery following grounding of the freighter M/V *Wellwood* on Molasses Reef, Key Largo National Marine Sanctuary. Draft Final Report to NOAA Office of Ocean and Coastal Resource Management. Contract No. NA88AA-H-CZ037. 73 pp.

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

Glynn, P.W. 1988. El Niño-Southern Oscillation 1982-1983: near-shore, population, community and ecosystem responses. Ann. Rev. Ecol. Syst. 19: 309-345.

Grigg, R.W. and S.J. Dollar. 1990. Natural and anthropogenic disturbance on coral reefs. pp. 439-452 *In* Z. Dubinsky (ed.) Ecosystems of the World Vol. 25: Coral Reefs. Elsevier Science Publishers. Amsterdam, The Netherlands.

Guzmán, 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.

Harrison, P.L. and C.C. Wallace. 1990. Reproduction, dispersal and recruitment of scleractinian corals. pp. 133-207 *In* Z. Dubinsky (ed.) Ecosystems of the World Vol. 25: Coral Reefs. Elsevier Science Publishers. Amsterdam, The Netherlands.

Harrison, P., R. Babcock, G.D. Bull, J. Oliver, C. Wallace and B. Willis. 1984. Mass spawning in tropical reef corals. Science 223:1186-1189.

Hudson, J.H. 1981. Growth rates in *Montastrea annularis*: a record of environmental change in Key Largo Coral Reef Sanctuary, Florida. Bull. Mar. Sci. 31:444-459.

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, Vol. 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York. 591 pp.

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

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

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. Guzmán, 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. 1975. Pollution and degradation of coral reef communities. pp. 13-51 *In:* E.J. Ferguson-Wood and R.E. Johannes (eds.) Tropical Marine Pollution. Elsevier, Amsterdam.

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 Bahía Las Minas, Panama. Interim Report. OCS Study MMS-90-0031. U.S. Dept. of Interior, Minerals Management Service, Gulf of Mexico OCS Regional Office, New Orleans, LA. 450 pp.

Kendall, J.J. 1983. The effects of drilling fluids (muds) and turbidity on the metabolic state of the coral *Acropora cervicornis*: calcification rate and protein concentration. Ph.D. Dissertation, Texas A&M University, College Station, TX. 110 pp.

Kendall, J.J. and G. Rainey. 1991. Produced waters: Findings of recent studies in the coastal waters of Louisiana: Session introduction. p.161 *In:* Proc. eleventh annual Gulf of Mexico information transfer meeting. Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Kendall, J.J., Jr., E.N. Powell, S.J. Conner, and T.J. Bright. 1983. The effects of drilling fluids (muds) and turbidity on the growth and metabolic state of the coral *Acropora cervicornis*, with comments on methods of normalization for coral data. Bull. Mar. Sci. 33(2):336-352.

Kendall, J.J., Jr., E.N. Powell, S.J. Conner, T.J. Bright, and C.E. Zastrow. 1984. The importance of monitoring metabolic recovery in the coral *Acropora cervicornis* after short-term exposure to drilling muds: calcification rate and protein concentration. Coral Reefs 2:215-225.

Kendall, J.J., Jr., E.N. Powell, S.J. Conner, T.J. Bright, and C.E. Zastrow. 1985. Effects of turbidity on calcification rate, protein concentration and the free amino acid pool of the coral *Acropora cervicornis*. Mar. Biol. 87:33-46.

Kennicutt, M.C., II, T.L. Wade, N.L. Guinasso Jr., J.M. Brooks, and J. Payne. 1991. A comparison of response, mitigation, and impact. pp. 239-247 *In:* Proc. 23rd Annual Offshore Technology Conference, Houston, TX.

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:* Proc. 1985 Oil Spill Conference, Amer. Petrol. Inst., Washington, D.C.

Knowlton, N., E. Weil, L.A. Weigt, and H.M. Guzmán. 1992. Sibling species in *Montastraea annularis*, coral bleaching, and the coral climate record. Science 255:330-333.

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

Kornicker, L.S., F. Bonet, R. Cann, and C.M. Hooker. 1959. Alacran Reef, Campeche Bank, Mexico. Publ. Inst. Mar. Sci. (Univ. Texas) 6:1-22.

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 Univ., College Station, TX. 138 pp.

Lang, J.C. 1973. Interspecific aggression by scleractinian corals 2. Why the race is not only to the swift. Bull. Mar. Sci. 23:952-959.

LaPointe, B.E. and M.W. Clark. 1990. Final Report: Spatial and temporal variability in trophic state of surface waters in Monroe County during 1989-1990. Florida Keys Land and Sea Trust Final Report. Monroe County.

Lea, D.W. 1990. Foraminiferal and coralline barium as paleoceanographic tracers. Ph.D. Thesis. MIT/WHOI-90-06.

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

Lee, R.F. 1980. Processes affecting oil in the sea. pp. 337-351 *In:* R.A. Geyer (ed.) Marine Environmental Pollution, Volume 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York. 591 pp.

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

Lessios, H.A., D.R. Robertson, and J.D. Cubit. 1984. Spread of *Diadema* mass mortality through the Caribbean. Science 226:335-337.

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

Lewis, J.B. 1989. The ecology of *Millepora*. Coral Reefs 8:99-107.

Livingston, H.D. and G. Thompson. 1971. Trace element concentrations in some modern corals. Limnol. Oceanogr. 16:786-796.

Logan, B.W. 1969. Carbonate sediments and reefs, Yucatan shelf, Mexico: part 2, Coral Reefs and Banks, Yucatan shelf, Mexico (Yucatan Reef Unit). AAPG Mem. 11:129-198.

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. 1979. Abortion effect in corals induced by oil pollution. Mar. Ecol. Prog. Ser. 1:77-80.

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

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

Marszalek, D.S. 1987. Sewage and eutrophication. pp. 77-90 *In* B. Salvat (ed.) Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Museum E.P.H.E., French Polynesia.

McConnaughey, T. 1989. ^{13}C and ^{18}O isotopic disequilibrium in biological carbonates: I. Patterns. Geochim. Cosmochim. Acta. 53:151-162.

McGrail, D.W., M. Carnes, D. Horne, T. Cecil, J. Hawkins, and F. Halper. 1982. Water and sediment dynamics at the Flower Garden Banks. pp. 103-226 *In:* D.W. McGrail, R. Rezak, and T.J. Bright (eds.) Environmental studies at the Flower Gardens and selected banks. Final Report to MMS. Contract #AA851-CT0-25 NTIS Order No. PB83-101303.

Minerals Management Service. 1989. Public Borehole (PUBBH) tape data set.

Mitchell, R. and I. Chet. 1975. Bacterial attack of corals in polluted seawater. Microbiol. Ecol. 2:227-233.

Monaghan, P.H., C.D. McAuliffe, and F.T. Weiss. 1980. Environmental aspects of drilling muds and cuttings from oil and gas operations in offshore and coastal waters. pp. 413-432 *In:* R.A. Geyer (ed.) Marine Environmental Pollution, Volume 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York.

Moore, D.R. 1958. Notes on Blanquilla Reef, the most northerly coral formation in the western Gulf of Mexico. Publ. Inst. Mar. Sci. (Univ. Texas) 5:151-155.

Moore, M.D., L.E. Wells, R.J. Silva, and G.L. Klunder. 1991. Evaluation of fluorescence banding in reef corals as a paleodischarge proxy. International Society for Reef Studies. Annual Meeting, Berkley, CA. p. 44. (abstract).

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

Neff, J.M. 1987. Biological effects of oil on the marine environment. Chem. Engin. Prog. pp. 27-33

Neff, J.M. and J.W. Anderson. 1981. Response of Marine Animals to Petroleum and Specific Petroleum Hydrocarbons. John Wiley & Sons, 177 pp.

Neff, J.M. and T.C. Sauer. 1991. Review: findings of the American Petroleum Institute study on produced waters. pp. 171-176 *In:* Proc.: eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Nelson, T.J., T.L. Stinnett, and J.W. Tunnell. 1988. Quantitative assessment of an unusually dense octocoral community in the southwestern Gulf of Mexico. Proc. 6th Int. Coral Reef Symp. 2:791-796.

Olsen, C. 1991. The Florida Keys environmental summit report 1991. Florida Keys Land and Sea Trust, Key West, Marathon, FL. 54 pp.

Pearson, R.G. 1981. Recovery and recolonization of coral reefs. Mar. Ecol. Prog. Ser. 4:105-122.

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.

Powell, E.N,, S.J. Conner, J.J. Kendall, Jr., C.E. Zastrow, and T.J. Bright. 1984a. Recovery of the coral Acropora cervicornis after drilling mud exposure. The free amino acid pool. Arch. Environ. Contam. Toxicol. 13:243-258.

Powell, E.N,, J.J. Kendall, Jr., S.J. Conner, C.E. Zastrow, and T.J. Bright. 1984b. Effects of eight outer continental shelf drilling muds on the calcification rate and free amino acid pool of the coral *Acropora cervicornis*. Bull. Environ. Contam. Toxicol. 33:362-372.

Rabalais, N.N. 1991. Introduction to the Minerals Management Service-funded study on produced waters and study site descriptions. pp. 161-165 *In:* Proc.: eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Rainey, G. 1991. The risk of oil spills from transportation of petroleum in the Gulf of Mexico. pp. 298-317 *In:* Proc.: eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Rannefeld, J.W. 1972. The stony corals of Enmedio Reef off Veracruz, Mexico. M. S. Thesis, Dept. of Oceanography, Texas A&M University. 104 pp.

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

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

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

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

Rigby, J.K. and W.G. McIntyre. 1966. The Isla de Lobos and associated reefs. B.Y.U. Geol. Stud., 13:1-46.

Rinkevich, B and Y. Loya. 1977. Harmful effects of chronic oil pollution on a Red Sea coral population. Proc. 3rd Int. Coral Reef Symp. (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.

Sammarco, P.W. 1982. Effects of grazing by *Diadema antillarum* Philippi (Echinodermata: Echinoidea) on algal diversity and community structure. J. Exp. Mar. Biol. Ecol. 65:83-105

Salvat, B. (ed). 1987. Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Museum E.P.H.E., French Polynesia. 253 pp.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics, Version 5. SAS Institute, Inc., Cary, NC. 958 pp.

Shen, G.T. and E.A. Boyle. 1988. Determination of lead, cadmium and other trace metals in annually-banded corals. Chem. Geol. 67:47-62.

Shinn, E. 1976. Coral reef recovery in Florida and the Persian Gulf. Env. Geol. 1:241-254.

Shinn, E.A., J.H. Hudson, D.M. Robbin, and C.K. Lee. 1980. Drilling mud plumes from offshore drilling operations: Implications for coral survival. pp. 471-496 *In:* R.A. Geyer (ed.) Marine Environmental Pollution, Volume 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York, NY. 591 pp.

Simpson, C.J. 1985. Mass spawning of scleractinian corals in the Dampier archipelago and the implications for management of coral reefs in Western Australia. West. Aust. Dep. Conserv. Environ. Bull. 244, 35 pp.

St. Pé, K.M., P. Breaux, E.J. Eues, Jr., R. Guidry, J.C. Means, C. Milan, M. Schlenker, and S. Courtney. 1991. An assessment of produced water impacts in Louisiana. pp. 176-180 *In:* Proc. eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Stoddart, D.R. 1969. Ecology and morphology of recent coral reefs. Biol. Rev. 44:433-498.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Bd. Canada 167. 310 pp.

Szmant, A.M. 1986. Reproductive ecology of Caribbean reef corals. Coral Reefs 5(1):43-53.

Szmant-Froelich, A. 1985. The effect of colony size on the reproductive ability of the Caribbean coral *Montastrea annularis* (Ellis and Solander). Proc. 5th Int. Coral Reef Symp. 4:295-300.

Szmant-Froelich, A., V. Johnson, T. Hoen, J. Battey, G.J. Smith, E. Fleishmann, J. Porter, and D. Dallmeyer. 1981. The physiological effects of oil drilling fluids on the Caribbean coral *Montastrea annularis*. Proc. 4th Int. Coral Reef Symp. (Manila) 1:163-168.

Thompson, J.H., Jr. 1980. Responses of selected scleractinian corals to drilling fluids used in the marine environment. Ph.D. Dissertation. Texas A&M University.

Thompson, J.H., Jr. and T.J. Bright. 1977. Effects of drilling fluids on sediment clearing rates on certain hermatypic corals. pp. 495-498 *In:* Oil Spill Conference. Washington D. C. American Petroleum Institute.

Thompson, J.H., Jr. and T.J. Bright. 1980. Effects of an offshore drilling fluid on selected corals. pp. 1044-1078 *In:* Proceedings of a Symposium on Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Washington, D.C. Courtesy Associates.

Thompson, J.H., Jr., E.A. Shinn, and T.J. Bright. 1980. Effects of drilling mud on seven species of reef-building corals as measured in the field and laboratory. pp. 433-453 *In:* R.A. Geyer (ed.) Marine Environmental Pollution, Volume 1: Hydrocarbons. Elsevier Scientific Publishing Company, New York, NY. 591 pp.

Thresher, R.E. and J.S. Gunn. 1986. Comparative analysis of visual census techniques for highly mobile, reef-associated piscivores (Carangidae). Environ. Biol. Fishes 17(2):93-116.

Tilmant, J.T. 1987. Impacts of recreational activities on coral reefs. pp. 195-214. *In* B. Salvat (ed.) Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Museum E.P.H.E., French Polynesia.

Tilmant, J.T. and G.P. Schmahl. 1983. A comparative analysis of coral damage on recreationally used reefs within Biscayne National Park, Florida, U.S.A. Proc. 4th Int. Coral Symp. 1:187-192.

Tressler, R.C. 1974. Corals. pp. 116-139 *In:* T.J. Bright and L.H. Pequegnat (eds.) Biota of the West Flower Garden Bank. Gulf Publishing Company, Book Division, Houston, TX.

Tunnell, J.W., Jr. 1974. Ecological and geographical distribution of Mollusca of Lobos and Enmedio coral reefs, Southwestern Gulf of Mexico. Ph.D Dissertation Dept. of Oceanography, Texas A&M University, College Station, TX. 158pp.

van Moorsel, G.W.N.M. 1983. Reproductive strategies in two closely related corals (Agaricia, Scleractinia). Mar. Ecol. Prog. Ser. 13:273-283.

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

Villalobos, A. 1971. Estudios ecologicos en un arrecife coralino en Veracruz, Mexico. pp. 532-545 *In:* Symposium on Investigations and Resources of the Caribbean Sea and Adjacent Regions. Preparatory to CICAR, organized jointly by UNESCO and FAO.

Weil, E. and N. Knowlton. in prep. *Montastraea cascata* and *Montastraea inaequalis*, two new coral species for the Caribbean. A multy-assay approach to scleractinian coral taxonomy.

White, D.C., J.S. Nickels, M.J. Gehron, J.H. Parker, and R.F. Richards. 1982. Effect of well-drilling fluids on the physiological status and microbial infection of the reef-building coral *Montastrea annularis*. Arch. Environ. Contam. Toxic.

Wieczynski, P. 1991. Response for *Mega Borg* and Galveston Bay oil spills. pp. 317-319 *In:* Proc.: eleventh annual Gulf of Mexico information transfer meeting, Nov. 1990. U. S. Dept. of the Interior. Minerals Management Service. New Orleans, La. MMS Contract No. 14-35-0001-30499. OCS Study MMS 91-0040. 524 pp.

Williams, E.H., C. Goenaga, and V. Vincente. 1987. Mass bleaching on Atlantic coral reefs. Science 237:877-878.

Willis, B.L. and J.K. Oliver. 1988. Inter-reef dispersal of coral larvae following the annual mass spawning on the Great Barrier Reef. Proc. 6th Int. Coral Reef Symp. 2:853-859.

Willis, B.L., R.C. Babcock, P.L. Harrison, J.K. Oliver, and C.C. Wallace. 1985. Patterns in the mass spawning of corals on the Great Barrier Reef from 1981 to 1984. Proc. 5th Int. Coral Reef Cong. 4:343-348.

Wyers, S.C. 1985. Sexual reproduction of the coral *Diploria strigosa* (Scleractinia, Faviidae) in Bermuda: research in progress. Proc. 5th Int. Coral Reef Cong. 4:301-306.

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

Zihua. 1991. Harbor master; a Macintosh® application to predict ocean tides and tidal currents. Zihua, Pacific Grove, CA. 24 pp.

Appendix A.

(Statistical Analyses - Stratified Random Transects)

Table A-1. Specific percent cover comparisons between study sites (cruises combined). Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent Cover				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,234	97.50	**0.0001**	**East > West**
Colpophyllia spp.	1,180	1.28	0.2592	ns
D. strigosa	1,234	8.55	**0.0038**	**West > East**
M. decactis	1,126	0.68	0.4112	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,224	1.52	0.2191	ns
M. annularis	1,236	1.11	0.2922	ns
M. cavernosa	1,195	0.52	0.4698	ns
M. angulosa	1,91	1.25	0.2664	ns
P. astreoides	1,236	172.01	**0.0001**	**East > West**
P. furcata	1,13	0.02	0.8914	ns
S. cubensis	1,112	0.14	0.7091	ns
S. siderea	1,41	9.56	**0.0036**	**West > East**
S. michelini	1,177	0.03	0.8744	ns

Table A-2. Specific percent cover comparisons between study sites on Cruise 1. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs. WFG Cruise 1				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,36	10.64	**0.0024**	**East > West**
Colpophyllia spp.	1,34	5.47	**0.0254**	**West > East**
D. strigosa	1,37	1.55	0.2209	ns
M. decactis	1,15	0.22	0.6456	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,34	1.00	0.3253	ns
M. annularis	1,37	0.06	0.8042	ns
M. cavernosa	1,32	9.90	**0.0036**	**East > West**
M. angulosa	1,19	2.48	0.1315	ns
P. astreoides	1,37	3.33	0.0763	ns
P. furcata	1,1	0.00	1.0000	ns
S. cubensis	1,19	1.87	0.1877	ns
S. siderea	1,5	0.00	1.0000	ns
S. michelini	1,27	0.27	0.6095	ns

Table A-3. Specific percent cover comparisons between study sites on Cruise 2. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs. WFG Cruise 2				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	17.25	**0.0002**	**East > West**
Colpophyllia spp.	1,32	4.32	**0.0458**	**West > East**
D. strigosa	1,38	1.00	0.3232	ns
M. decactis	1,21	0.06	0.8120	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,37	0.08	0.3756	ns
M. annularis	1,38	2.11	0.1542	ns
M. cavernosa	1,27	0.02	0.8986	ns
M. angulosa	1,14	0.53	0.4806	ns
P. astreoides	1,38	45.01	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,18	0.02	0.8846	ns
S. siderea	1,6	3.95	0.0941	ns
S. michelini	1,32	2.17	0.1501	ns

Table A-4. Specific percent cover comparisons between study sites on Cruise 3. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs WFG Cruise 3				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,37	16.96	**0.0002**	**East > West**
Colpophyllia spp.	1,25	0.53	0.4751	ns
D. strigosa	1,37	0.80	0.3756	ns
M. decactis	1,13	0.06	0.8048	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,36	0.20	0.6571	ns
M. annularis	1,38	0.01	0.9155	ns
M. cavernosa	1,31	0.01	0.9157	ns
M. angulosa	1,7	0.05	0.8247	ns
P. astreoides	1,38	66.17	**0.0001**	**East > West**
P. furcata	1,2	3.00	0.2254	ns
S. cubensis	1,17	0.80	0.3843	ns
S. siderea	1,6	0.10	0.7663	ns
S. michelini	1,19	0.04	0.8389	ns

Table A-5. Specific percent cover comparisons between study sites on Cruise 4. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs. WFG Cruise 4				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,37	42.04	**0.0001**	**East > West**
Colpophyllia spp.	1,19	0.04	0.8344	ns
D. strigosa	1,37	4.19	**0.0477**	**West > East**
M. decactis	1,23	1.00	0.3285	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,34	0.12	0.7333	ns
M. annularis	1,37	0.34	0.5622	ns
M. cavernosa	1,31	0.02	0.8877	ns
M. angulosa	1,12	0.04	0.8506	ns
P. astreoides	1,37	31.68	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,15	0.00	1.0000	ns
S. siderea	1,3	0.27	0.6376	ns
S. michelini	1,30	0.29	0.5923	ns

Table A-6. Specific percent cover comparisons between study sites on Cruise 5. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs. WFG Cruise 5				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	12.83	**0.0010**	**East > West**
Colpophyllia spp.	1,30	0.00	0.9851	ns
D. strigosa	1,38	0.00	0.9577	ns
M. decactis	1,22	1.29	0.2678	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,38	1.00	0.3232	ns
M. annularis	1,38	8.99	**0.0048**	**West > East**
M. cavernosa	1,32	0.43	0.5145	ns
M. angulosa	1,15	0.15	0.7011	ns
P. astreoides	1,38	101.77	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,20	0.37	0.5520	ns
S. siderea	1,4	0.83	0.4144	ns
S. michelini	1,33	0.07	0.7942	ns

Table A-7. Specific percent cover comparisons between study sites on Cruise 6. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Percent cover EFG vs. WFG Cruise 6				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	10.40	**0.0026**	**East > West**
Colpophyllia spp.	1,30	0.59	0.4479	ns
D. strigosa	1,37	5.84	**0.0207**	**West > East**
M. decactis	1,22	0.05	0.8207	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,35	0.72	0.4025	ns
M. annularis	1,38	2.47	0.1246	ns
M. cavernosa	1,32	1.15	0.2917	ns
M. angulosa	1,14	1.46	0.2472	ns
P. astreoides	1,38	19.31	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,13	6.86	**0.0212**	**West > East**
S. siderea	1,7	7.74	**0.0272**	**West > East**
S. michelini	1,26	0.17	0.6873	ns

Table A-8. Specific percent cover comparisons between cruises (study sites combined). Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

Percent Cover				
Species	**df**	**F**	**P-value**	**Tukey Groups**
Agaricia spp.	5,230	1.38	0.2333	ns
Colpophyllia spp.	5,176	0.88	0.4947	ns
D. strigosa	5,230	1.02	0.4040	ns
M. decactis	5,122	2.68	**0.0245**	**1 2 6 4 3 5**
M. mirabilis	-	-	-	-
Millepora sp.	5,220	1.00	0.4195	ns
M. annularis	5,232	1.44	0.2096	ns
M. cavernosa	5,191	0.38	0.8603	ns
M. angulosa	5,87	1.59	0.1717	ns
P. astreoides	5,232	2.04	0.0736	ns
P. furcata	5,9	1.21	0.3782	ns
S. cubensis	5,108	2.05	0.0771	ns
S. siderea	5,37	0.49	0.7785	ns
S. michelini	5,173	0.47	0.7976	ns

Table A-9. Specific relative dominance comparisons between study sites (cruises combined). Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,234	80.85	**0.0001**	**East > West**
Colpophyllia spp.	1,180	1.65	0.2003	ns
D. strigosa	1,234	6.70	**0.0103**	**West > East**
M. decactis	1,126	0.84	0.3612	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,224	1.99	0.1602	ns
M. annularis	1,236	0.95	0.3309	ns
M. cavernosa	1,195	0.52	0.4729	ns
M. angulosa	1,91	0.51	0.4758	ns
P. astreoides	1,236	130.91	**0.0001**	**East > West**
P. furcata	1,13	0.18	0.6813	ns
S. cubensis	1,112	0.51	0.4759	ns
S. siderea	1,41	8.78	**0.0051**	**West > East**
S. michelini	1,177	0.02	0.8857	ns

Table A-10. Specific relative dominance comparisons between study sites on Cruise 1. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance **EFG vs. WFG** **Cruise 1**				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,36	9.32	**0.0042**	**East > West**
Colpophyllia spp.	1,34	7.30	**0.0107**	**West > East**
D. strigosa	1,37	1.02	0.3182	ns
M. decactis	1,15	0.08	0.7831	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,34	1.13	0.2950	ns
M. annularis	1,37	0.00	0.9561	ns
M. cavernosa	1,32	11.63	**0.0018**	**East > West**
M. angulosa	1,19	2.48	0.1315	ns
P. astreoides	1,37	3.21	0.0813	ns
P. furcata	1,1	0.00	1.0000	ns
S. cubensis	1,19	1.29	0.2706	ns
S. siderea	1,5	0.00	1.0000	ns
S. michelini	1,27	0.05	0.8318	ns

Table A-11. Specific relative dominance comparisons between study sites on Cruise 2. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance EFG vs. WFG Cruise 2				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	18.46	**0.0001**	**East > West**
Colpophyllia spp.	1,32	4.49	**0.0420**	**West > East**
D. strigosa	1,38	0.00	0.9577	ns
M. decactis	1,21	0.13	0.7210	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,37	1.02	0.3182	ns
M. annularis	1,38	0.61	0.4399	ns
M. cavernosa	1,27	0.02	0.8986	ns
M. angulosa	1,14	0.92	0.3531	ns
P. astreoides	1,38	35.98	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,18	0.20	0.6624	ns
S. siderea	1,6	3.95	0.0941	ns
S. michelini	1,32	3.61	0.0665	ns

Table A-12. Specific relative dominance comparisons between study sites on Cruise 3. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance EFG vs. WFG Cruise 3				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,37	14.7	**0.0005**	**East > West**
Colpophyllia spp.	1,25	0.23	0.6349	ns
D. strigosa	1,37	0.97	0.3320	ns
M. decactis	1,13	0.14	0.7104	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,36	0.20	0.6571	ns
M. annularis	1,38	0.09	0.7703	ns
M. cavernosa	1,31	0.18	0.6714	ns
M. angulosa	1,7	0.51	0.4996	ns
P. astreoides	1,38	55.7	**0.0001**	**East > West**
P. furcata	1,2	3.00	0.2254	ns
S. cubensis	1,17	0.53	0.4783	ns
S. siderea	1,6	0.10	0.7663	ns
S. michelini	1,19	0.04	0.8389	ns

Table A-13. Specific relative dominance comparisons between study sites on Cruise 4. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance EFG vs. WFG Cruise 4				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,37	31.68	**0.0001**	**East > West**
Colpophyllia spp.	1,19	0.18	0.6752	ns
D. strigosa	1,37	4.06	0.0512	ns
M. decactis	1,23	0.88	0.3566	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,34	0.04	0.8526	ns
M. annularis	1,37	0.05	0.8256	ns
M. cavernosa	1,31	0.01	0.9157	ns
M. angulosa	1,12	0.10	0.7533	ns
P. astreoides	1,37	22.02	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,15	0.01	0.9270	ns
S. siderea	1,3	0.27	0.6376	ns
S. michelini	1,30	0.10	0.7540	ns

Table A-14. Specific relative dominance comparisons between study sites on Cruise 5. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance EFG vs. WFG Cruise 5				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	11.43	**0.0017**	**East > West**
Colpophyllia spp.	1,30	0.00	0.9552	ns
D. strigosa	1,38	0.01	0.9366	ns
M. decactis	1,22	1.29	0.2678	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,38	1.72	0.1980	ns
M. annularis	1,38	8.99	**0.0048**	**West > East**
M. cavernosa	1,32	0.53	0.4709	ns
M. angulosa	1,15	0.63	0.4392	ns
P. astreoides	1,38	60.61	**0.0001**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,20	0.55	0.4663	ns
S. siderea	1,4	0.83	0.4144	ns
S. michelini	1,33	0.09	0.7691	ns

Table A-15. Specific relative dominance comparisons between study sites on Cruise 6. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Relative Dominance EFG vs. WFG Cruise 6				
Species	**df**	**F**	**P-value**	**Results**
Agaricia spp.	1,38	5.33	**0.0264**	**East > West**
Colpophyllia spp.	1,30	0.15	0.6985	ns
D. strigosa	1,37	8.54	**0.0059**	**West > East**
M. decactis	1,22	0.03	0.8651	ns
M. mirabilis	-	-	-	-
Millepora sp.	1,35	1.20	0.2801	ns
M. annularis	1,38	1.87	0.1795	ns
M. cavernosa	1,32	1.86	0.1824	ns
M. angulosa	1,14	0.71	0.4143	ns
P. astreoides	1,38	13.44	**0.0008**	**East > West**
P. furcata	-	-	-	-
S. cubensis	1,13	3.57	0.0815	ns
S. siderea	1,7	7.74	**0.0272**	**West > East**
S. michelini	1,26	0.02	0.8934	ns

Table A-16. Specific relative dominance comparisons between cruises (study sites combined). Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

Relative Dominance				
Species	**df**	**F**	**P-value**	**Tukey Groups**
Agaricia spp.	5,230	1.27	0.2772	ns
Colpophyllia spp.	5,176	0.74	0.5949	ns
D. strigosa	5,230	0.79	0.5604	ns
M. decactis	5,122	2.55	**0.0314**	**1 2 4 6 3 5**
M. mirabilis	-	-	-	-
Millepora sp.	5,220	1.03	0.4004	ns
M. annularis	5,232	2.10	0.0659	ns
M. cavernosa	5,191	0.46	0.8030	ns
M. angulosa	5,87	2.00	0.0868	ns
P. astreoides	5,232	1.81	0.1110	ns
P. furcata	5,9	1.04	0.4489	ns
S. cubensis	5,108	2.89	**0.0172**	**2 6 3 1 5 4**
S. siderea	5,37	0.53	0.7491	ns
S. michelini	5,173	0.27	0.9292	ns

Table A-17. Comparisons between cruises (study sites combined) of species diversity, species evenness, and percent coral cover. Kruskal-Wallis Tests compare Shannon-Weaver diversity based on coral cover, Shannon-Weaver diversity based on coral counts, evenness based on coral cover, evenness based on coral counts, and percent coral cover. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at $\alpha = 0.05$.

	df	F	P-value	Tukey Groups
H' Diversity (cover)	5,232	3.41	**0.0054**	**6 1 2 5 4 3**
H' Diversity (counts)	5,232	1.64	0.1490	ns
Evenness (cover)	5,232	2.72	**0.0205**	**6 2 1 4 5 3**
Evenness (counts)	5,232	2.33	**0.0436**	**3 2 1 4 6 5**
Percent Coral Cover	5,232	1.62	0.1565	ns

Appendix B.

(Coral Accretionary Growth Data)

Table B-1. *Montastrea annularis* accretionary growth data (spike length in mm), project day on which the measurements were made (i.e., number of days since the start of the project), and growth rates (mm/6 months) measured along growth spikes at the East Flower Garden study site. Data are shown only for stations and time periods that were used for analysis of growth rates.

Station #	Length (mm)	Project Day	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)
	Cruise 1		Cruise 2		Cruise 2 - 1	Cruise 3		Cruise 3 - 2
	Winter		Summer		Spring/Summer	Winter		Fall/Winter
1			97	303		93	498	4
9	100	76	96	303	3	95	498	1
11						95	498	
12			105	303		96	498	8
13	100	76				99	498	
16						91	498	
17						110	498	
23						99	498	
27						93	498	
30	101	76	99	303	2	95	498	4
34	102	76	99	303	2	100	498	
99	99	130	99	303	0	97	498	2
38	102	76	99	303	2	92	498	7
39			96	303		95	498	1
44	99	76	95	303	3	96	498	
54			103	304		97	498	6
55			104	303		100	498	4
57	105	116	111	303		95	498	15
60	102	116	101	303	1	97	498	4
62			110	303		104	498	6
71						107	498	
102			101	303		100	498	1
107	102	118	101	303	1	94	498	7
				Mean Growth Cr 1 to 2=	2		Mean Growth Cr 2 to 3=	5
				Std. Dev. Cr1to 2=	1.2		Std. Dev. Cr 2 to 3=	3.7
				N =	8		N =	14

Table B-1 (cont'd). *Montastrea annularis* accretionary growth data (spike length in mm), project day on which the measurements were made (i.e., number of days since the start of the project), and growth rates (mm/6 months) measured along growth spikes at the East Flower Garden study site. Data are shown only for stations and time periods that were used for analysis of growth rates.

Station #	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)
	Cruise 4		Cruise 4 - 3	Cruise 5		Cruise 5 - 4	Cruise 6		Cruise 6 - 5
	Summer		Spring/Summer	Winter		Fall/Winter	Summer		Spring/Summer
1	88	688	5	84	835	5	81	993	3
9									
11	89	688	6	84	835	6	84	993	0
12	89	688	7	82	835	9	81	993	1
13	89	688	10						
16	86	688	5				81	993	
17	105	688	5	102	835	4	95	993	8
23	93	688	6						
27	89	688	4	85	835	5	81	993	5
30	94	688	1	90	835	5	88	993	2
34	93	688	7						
99	92	688	5	93	835		87	993	7
38									
39	94	688	1	90	835	5	85	993	6
44	92	688	4	94	835		89	993	6
54	98	688							
55	95	688	5	91	835	5	90	993	1
57	92	688	3	90	835	3	84	993	7
60	87	688	10	91	835		82	993	10
62	102	688	2						
71	105	688	2	102	835	4	102	993	0
102	93	688	7						
107	93	688	1	93	835	0	91	993	2
		Mean Growth Cr 3 to 4=	5		Mean Growth Cr 4 to 5=	5		Mean Growth Cr 5 to 6=	4
		Std. Dev. Cr 3 to 4=	2.6		Std. Dev. Cr 4 to 5=	2.1		Std. Dev. Cr 5 to 6=	3.2
		N =	20		N =	11		N =	14

Table B-2. *Montastrea annularis* accretionary growth data (spike length in mm), project day on which the measurements were made (i.e., number of days since the start of the project), and growth rates (mm/6 months) measured along growth spikes at the West Flower Garden study site. Data are shown only for stations and time periods that were used for analysis of growth rates.

Station #	Length (mm)	Project Day	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)
	Cruise 1		Cruise 2		Cruise 2 -1	Cruise 3		Cruise 3 - 2
	Winter		Summer		Spring/Summer	Winter		Fall/Winter
7M	100	190	97	315	4	97	496	0
78			103	315		100	496	3
116			100	315		97	496	3
128	104	189	100	315	6	98	496	2
129	103	189	100	315	4	97	496	3
158	104	189	102	315	3	100	496	2
197	105	189	101	315	6	100	496	1
202	105	189	101	315	6			
205	103	189	99	315	6	100	496	
220?			102	315		101	496	1
293						103	496	
294	106	189				95	496	
307	102	189	100	315	3	95	496	5
316	100	189	99	315	1	97	496	2
317	96	189				90	496	
325						103	496	
347	97	189				89	496	
352			102	315		99	496	3
354	100	189	97	315	4	95	497	2
356			98	315		97	496	1
357			104	315		100	496	4
359			119	315		115	496	4
363	91	190	90	315	1			
371			100	315		96	496	4
376	99	189	97	315	3	95	496	2
380	98	189	94	315	6	89	496	5
				Mean Growth Cr 1 to 2=	4		Mean Growth Cr 2 to 3=	3
				Std. Dev. Cr 1to 2=	1.7		Std. Dev. Cr 2 to 3=	1.4
				N=	13		N=	18

Table B-2 (cont'd). *Montastrea annularis* accretionary growth data (spike length in mm), project day on which the measurements were made (i.e., number of days since the start of the project), and growth rates (mm/6 months) measured along growth spikes at the West Flower Garden study site. Data are shown only for stations and time periods that were used for analysis of growth rates.

Station #	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)	Length (mm)	Project Day	Growth (mm)
	Cruise 4		Cruise 4 - 3	Cruise 5		Cruise 5 - 4	Cruise 6		Cruise 6 - 5
	Summer		Spring/Summer	Winter		Fall/Winter	Summer		Spring/Summer
7M	86	686	11	89	832		80	992	10
78	99	686	1	100	832		98	991	2
116	95	686	2	94	832	1	93	991	1
128	93	686	5	90	832	4	86	992	5
129	98	686		97	832	1	95	992	2
158	100	686	0	100	832	0	98	991	2
197	98	686	2						
202	89	686		84	832	6	88	992	
205	98	686	2	96	832	3	96	992	0
220?	94	686	7	93	832	1			
293	99	686	4	94	832	6	94	991	0
294	92	686	3	86	832	8			
307	93	686	2						
316	92	686	5	90	832	3	90	991	0
317	83	686	7						
325	100	686	3	100	832	0	96	991	5
347	93	686		93	832	0	83	991	11
352	96	686	3						
354	90	686	5						
356	89	686	8	92	832		84	991	9
357	95	686	5	93	832	3	90	991	3
359	108	686	7	110	832		105	991	6
363	80	686		76	832	5	76	991	0
371	95	686	1	90	832	6	87	991	3
376	91	686	4	89	832	3	88	991	1
380	83	686	6	79	832	5			
		Mean Cr 3 to 4=	4		Mean Cr 4 to 5=	3		Mean Growth Cr 5 to 6=	4
		Std. Dev. Cr 3 to 4=	2.6		Std. Dev. Cr 4 to 5=	2.5		Std. Dev. Cr 5 to 6=	3.7
		N=	22		N=	17		N=	17

Table B-3. *Montastrea annularis* accretionary growth rates (mm) from 1910 to 1989 measured by sclerochronology at the East and West Flower Garden Banks (two cores analyzed on each bank).

Year	WFG1	WFG2	EFG1	EGF2	EFG Mean	WFG Mean	Mean
1989	10.2	7.7	7.4	7.5	7.5	9.0	8.2
1988	7.0	6.3	6.0	8.0	7.0	6.7	6.8
1987	7.1	6.3	5.9	6.8	6.4	6.7	6.5
1986	6.4	5.7	7.0	7.1	7.1	6.1	6.6
1985	9.7	4.8	4.8	7.0	5.9	7.3	6.6
1984	9.1	4.8	5.0	6.6	5.8	7.0	6.4
1983	8.2	5.3	4.5	9.1	6.8	6.8	6.8
1982	7.8	6.6	5.4	7.1	6.3	7.2	6.7
1981	9.8	4.5	5.6	6.8	6.2	7.2	6.7
1980	7.2	4.3	5.8	7.0	6.4	5.8	6.1
1979	9.5	4.7	5.7	6.8	6.3	7.1	6.7
1978	9.2	6.4	5.4	8.2	6.8	7.8	7.3
1977	7.1	8.3	4.7	5.4	5.1	7.7	6.4
1976	8.2	4.9	6.9	8.6	7.8	6.6	7.2
1975	7.5	5.0	4.9	5.8	5.4	6.3	5.8
1974	5.9	10.0	4.1	4.4	4.3	8.0	6.1
1973	6.7	5.0	4.7	5.3	5.0	5.9	5.4
1972	8.2	7.3	6.2	6.7	6.5	7.8	7.1
1971	7.8	7.2	5.7	7.1	6.4	7.5	7.0
1970	8.2	6.4	5.4	5.3	5.4	7.3	6.3
1969	6.8	4.7	4.6	5.1	4.9	5.8	5.3
1968	9.4	4.8	6.5	5.7	6.1	7.1	6.6
1967	9.5	6.7	6.8	6.8	6.8	8.1	7.5
1966	8.0	3.8	3.5	6.1	4.8	5.9	5.4
1965	8.1	6.3	5.0	5.9	5.5	7.2	6.3
1964	7.5	5.3	6.1	7.0	6.6	6.4	6.5
1963	9.5	6.4	6.2	6.9	6.6	8.0	7.3
1962	9.0	5.1	4.7	5.4	5.1	7.1	6.1
1961	8.5	4.2	4.7	5.7	5.2	6.4	5.8
1960	5.7	3.9	5.4	5.3	5.4	4.8	5.1
1959	8.0	4.2	4.1	6.2	5.2	6.1	5.6
1958	7.4	3.7	4.0	5.9	5.0	5.6	5.3
1957	9.9	6.6	7.8	8.3	8.1	8.3	8.2
1956	8.9	6.0	6.1	7.9	7.0	7.5	7.2
1955	9.1	5.2	5.1	6.6	5.9	7.2	6.5
1954	7.5	5.8	5.0	8.1	6.6	6.7	6.6
1953	8.4	5.9	4.6	8.2	6.4	7.2	6.8
1952	8.7	5.5	4.5	7.5	6.0	7.1	6.6
1951	8.9	5.0	5.1	7.5	6.3	7.0	6.6
1950	6.8	6.3	5.2	8.8	7.0	6.6	6.8
1949	4.7	6.0	5.7	7.7	6.7	5.4	6.0
1948	7.4	6.3	5.0	6.6	5.8	6.9	6.3
1947	9.2	5.6	4.9	6.8	5.9	7.4	6.6
1946	7.4	5.4	4.2	7.9	6.1	6.4	6.2
1945	8.5	5.8	4.5	7.8	6.2	7.2	6.7
1944	6.2	6.6	6.1	8.4	7.3	6.4	6.8

Table B-3 (cont'd). *Montastrea annularis* accretionary growth rates (mm) from 1910 to 1989 measured by sclerochronology at the East and West Flower Garden Banks (two cores analyzed on each bank).

Year	WFG1	WFG2	EFG1	EGF2	EFG Mean	WFG Mean	Mean
1943	5.2	5.8	6.2	8.5	7.4	5.5	6.4
1942	6.6	5.5	5.2	7.6	6.4	6.1	6.2
1941	8.2	5.5	4.9	7.9	6.4	6.9	6.6
1940	7.2	5.6	3.1	8.5	5.8	6.4	6.1
1939	7.4	5.9	4.5	8.0	6.3	6.7	6.5
1938	9.4	5.8	4.3	7.8	6.1	7.6	6.8
1937	7.6	6.0	5.1	8.5	6.8	6.8	6.8
1936	9.1	5.6	7.9	7.5	7.7	7.4	7.5
1935	7.8	5.3	5.3	8.0	6.7	6.6	6.6
1934	8.1	5.6	5.2	7.5	6.4	6.9	6.6
1933	9.2	6.5	6.6	6.2	6.4	7.9	7.1
1932	6.6	5.7	5.6	4.6	5.1	6.2	5.6
1931	7.4	6.4	7.5	7.0	7.3	6.9	7.1
1930	7.3	6.8	5.8	7.2	6.5	7.1	6.8
1929	7.5	7.6	5.1	6.8	6.0	7.6	6.8
1928	8.1	5.7	6.7	7.7	7.2	6.9	7.1
1927	7.5	5.0	5.8	6.1	6.0	6.3	6.1
1926	6.6	7.4	5.0	8.5	6.8	7.0	6.9
1925	7.5	5.9	5.4	8.3	6.9	6.7	6.8
1924	6.1	5.3	5.9	7.6	6.8	5.7	6.2
1923	7.5	5.4	5.5	7.6	6.6	6.5	6.5
1922	5.7	6.3	4.8	8.1	6.5	6.0	6.2
1921	8.2	5.9	4.3	8.8	6.6	7.1	6.8
1920	6.9	6.2	5.7	8.9	7.3	6.6	6.9
1919	7.7	6.2	5.0	9.6	7.3	7.0	7.1
1918	7.9	6.8	5.3	8.0	6.7	7.4	7.0
1917	9.0	7.1	4.4	7.8	6.1	8.1	7.1
1916	8.6	6.3	5.1	6.4	5.8	7.5	6.6
1915	6.4	7.1	4.5	7.4	6.0	6.8	6.4
1914	7.0	6.8	4.0	7.9	6.0	6.9	6.4
1913	7.5	6.4	4.7	7.5	6.1	7.0	6.5
1912	7.5	6.7	3.8	7.4	5.6	7.1	6.4
1911	7.1	6.8	5.3	6.6	6.0	7.0	6.5
1910	7.5	6.6	6.9	8.2	7.6	7.1	7.3
1910-1989							6.6

Appendix C.

(Statistical Analyses - Encrusting Growth Stations)

Table C-1. Growth rates of *D. strigosa* and *M. annularis* between cruises, study sites combined. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at a = 0.05.

Net Growth (banks combined)	df	F	P-value	Tukey Groups
D. strigosa	4,635	0.92	0.4507	ns
M. annularis	5,519	3.70	**0.0056**	**6 4 5 2 3**

Table C-2. Net growth rates of *D. strigosa* and *M. annularis* between study sites, cruises combined. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Net Growth (cruises combined)	df	F	P-value	Results
D. strigosa	1,638	6.24	**0.0127**	**East > West**
M. annularis	1,522	0.11	0.7359	ns

Table C-3. Net growth rates of *D. strigosa* and *M. annularis* between cruises at the East and West Flower Garden Banks. Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at a = 0.05.

Net Growth	Bank	df	F	P-value	Tukey Groups
D. strigosa	East	4,312	1.98	0.0967	ns
D. strigosa	West	4,318	0.62	0.6481	ns
M. annularis	East	4,229	0.39	0.8169	ns
M. annularis	West	4,285	5.09	**0.0006**	**6 4 3 5 2**

Table C-4. Kruskal-Wallis Test results of comparison of net growth rates of *Diploria strigosa* and *Montastrea annularis* between study sites on each of six project cruises. Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Net Growth	Cruise	df	F	P-value	Results
D. strigosa	2	1,114	0.11	0.7431	ns
D. strigosa	3	1,120	3.63	0.0590	ns
D. strigosa	4	1,124	8.55	**0.0041**	**East > West**
D. strigosa	5	1,132	0.02	0.8848	ns
D. strigosa	6	1,140	1.18	0.2783	ns
M. annularis	2	1,121	0.91	0.3416	ns
M. annularis	3	1,117	0.01	0.9183	ns
M. annularis	4	1,99	1.37	0.2446	ns
M. annularis	5	1,92	0.89	0.3475	ns
M. annularis	6	1,85	4.30	**0.0411**	**West > East**

Table C-5. Advance and retreat rates of *D. strigosa* and *M. annularis* between cruises, study sites combined. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented. Tukey Multiple Range Test groupings present cruises with means ranked from highest to lowest, and those underlined together are not significantly different at a = 0.05.

Banks Combined	Species	df	F	P-value	Tukey Groups
Advance	*D. strigosa*	4,362	1.50	0.2006	ns
	M. annularis	4,303	7.21	**0.0001**	**6 4 5 2 3**
Retreat	*D. strigosa*	4,268	0.65	0.6243	ns
	M. annularis	4,211	2.27	0.0625	ns

Table C-6. Comparison between cruises of retreat of *D. strigosa* and *M. annularis* at the East and West Flower Garden Banks. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented ("no groups" indicates that multiple range test was not able to provide groupings of cruises).

Retreat	Species	df	F	P-value	Tukey Groups
EFG	*D. strigosa*	4,124	1.16	0.3299	ns
WFG	*D. strigosa*	4,139	0.85	0.4971	ns
EFG	*M. annularis*	4,93	1.11	0.3563	ns
WFG	*M. annularis*	4,113	3.59	**0.0086**	no groups

Table C-7. Comparison of advance rates of *D. strigosa* and *M. annularis* between study sites on each cruise. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Advance	Cruise	df	F	P-value	Results
D. strigosa	2	1,63	0.21	0.6478	ns
D. strigosa	3	1,70	4.38	**0.0400**	**East > West**
D. strigosa	4	1,73	17.94	**0.0001**	**East > West**
D. strigosa	5	1,69	0.66	0.4210	ns
D. strigosa	6	1,82	5.96	**0.0168**	**East > West**
M. annularis	2	1,66	0.07	0.7881	ns
M. annularis	3	1,66	0.89	0.3478	ns
M. annularis	4	1,57	2.36	0.1302	ns
M. annularis	5	1,52	0.05	0.8244	ns
M. annularis	6	1,57	2.94	0.0917	ns

Table C-8. Comparison of retreat rates of *D. strigosa* and *M. annularis* between study sites. Kruskal-Wallis Test values (F), degrees of freedom (df), and associated probability values (P-value) are presented.

Retreat	Cruise	df	F	P-value	Results
D. strigosa	2	1,49	1.52	0.2235	ns
D. strigosa	3	1,48	1.73	0.1941	ns
D. strigosa	4	1,49	0.17	0.6800	ns
D. strigosa	5	1,61	0.08	0.7846	ns
D. strigosa	6	1,56	1.67	0.2011	ns
M. annularis	2	1,53	9.25	**0.0037**	**West > East**
M. annularis	3	1,49	0.86	0.3597	ns
M. annularis	4	1,40	0.21	0.6459	ns
M. annularis	5	1,38	1.96	0.1701	ns
M. annularis	6	1,26	3.04	0.0930	ns

Appendix D.

(Repetitive Quadrat Data)

Table D-1. Observations of growth, retreat, coral bleaching, and disease at repetitively photographed 8 m^2 quadrats at the Flower Garden Banks. Data are given in number of observations without regard to the sizes of areas affected. Data are given by cruise for each bank, then with banks combined by cruise.

Repetitive 8 m^2 Stations
West Flower Garden Bank
Cruise 2

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1	-	
Retreat, Bleaching, and Disease	unknown cause	12	12	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	9	1	eventual mortality - 8
	pre-existing disease	0	0	
	bleaching	4	0	
	TOTAL	25	13	

Repetitive 8 m^2 Stations
West Flower Garden Bank
Cruise 3

Change	Cause	Occurrence	Mortality	Notes
Growth	-	24	-	
Retreat, Bleaching, and Disease	unknown cause	232	232	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	11	1	eventual mortality - 5
	pre-existing disease	7	4	
	bleaching	0	0	
	TOTAL	250	237	

Repetitive 8 m^2 Stations
West Flower Garden Bank
Cruise 4

Change	Cause	Occurrence	Mortality	Notes
Growth	-	451	-	
Retreat, Bleaching, and Disease	unknown cause	319	319	generally minor
	algae mediated	1	1	
	algae/sediment	0	0	
	new disease	7	7	eventual mortality - 7
	pre-existing disease	8	3	
	bleaching	32	4	
	TOTAL	363	334	

Repetitive 8 m^2 Stations
West Flower Garden Bank
Cruise 5

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1049	-	
Retreat, Bleaching, and Disease	unknown cause	727	727	generally minor
	algae mediated	4	4	
	algae/sediment	0	0	
	new disease	12	1	eventual mortality - 2
	pre-existing disease	14	11	
	bleaching	0	0	
	TOTAL	757	743	

Repetitive 8 m^2 Stations
West Flower Garden Bank
Cruise 6

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1166	-	
Retreat, Bleaching, and Disease	unknown cause	350	350	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	1	1	eventual mortality - 1
	pre-existing disease	10	10	
	bleaching	15	0	
	TOTAL	376	361	

Repetitive 8 m^2 Stations
East Flower Garden Bank
Cruise 2

Change	Cause	Occurrence	Mortality	Notes
Growth	-	5	-	
Retreat, Bleaching, and Disease	unknown cause	11	11	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	10	3	eventual mortality - 9
	pre-existing disease	0	0	
	bleaching	18	2	
	TOTAL	39	16	

Repetitive 8 m^2 Stations
East Flower Garden Bank
Cruise 3

Change	Cause	Occurrence	Mortality	Notes
Growth	-	76	-	
Retreat, Bleaching, and Disease	unknown cause	140	140	generally minor
	algae mediated	2	2	
	algae/sediment	8	8	
	new disease	12	3	eventual mortality - 12
	pre-existing disease	7	6	
	bleaching	0	0	
	TOTAL	169	159	

Repetitive 8 m^2 Stations
East Flower Garden Bank
Cruise 4

Change	Cause	Occurrence	Mortality	Notes
Growth	-	272	-	
Retreat, Bleaching, and Disease	unknown cause	236	236	generally minor
	algae mediated	4	4	
	algae/sediment	3	3	
	new disease	2	0	eventual mortality - 1
	pre-existing disease	12	10	
	bleaching	91	8	
	TOTAL	348	261	

Repetitive 8 m^2 Stations
East Flower Garden Bank
Cruise 5

Change	Cause	Occurrence	Mortality	Notes
Growth	-	725	-	
Retreat, Bleaching, and Disease	unknown cause	348	348	generally minor
	algae mediated	9	9	
	algae/sediment	7	7	
	new disease	2	0	eventual mortality - 1
	pre-existing disease	18	14	
	bleaching	6	0	
	TOTAL	390	378	

Repetitive 8 m^2 Stations
East Flower Garden Bank
Cruise 6

Change	Cause	Occurrence	Mortality	Notes
Growth	-	797	-	
Retreat, Bleaching, and Disease	unknown cause	151	151	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	1	0	eventual mortality - 0
	pre-existing disease	7	4	
	bleaching	28	0	
	TOTAL	187	155	

Repetitive 8 m^2 Stations
Both Banks
Cruise 2

Change	Cause	Occurrence	Mortality	Notes
Growth	-	6	-	
Retreat, Bleaching, and Disease	unknown cause	23	23	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	19	4	eventual mortality - 17
	pre-existing disease	0	0	
	bleaching	22	2	
	TOTAL	64	29	

Repetitive 8 m^2 Stations
Both Banks
Cruise 3

Change	Cause	Occurrence	Mortality	Notes
Growth	-	100	-	
Retreat, Bleaching, and Disease	unknown cause	372	372	generally minor
	algae mediated	2	2	
	algae/sediment	8	8	
	new disease	23	4	eventual mortality - 17
	pre-existing disease	14	10	
	bleaching	0	0	
	TOTAL	419	396	

Repetitive 8 m^2 Stations
Both Banks
Cruise 4

Change	Cause	Occurrence	Mortality	Notes
Growth	-	723	-	
Retreat, Bleaching, and Disease	unknown cause	551	551	generally minor
	algae mediated	5	5	
	algae/sediment	3	3	
	new disease	9	7	eventual mortality - 8
	pre-existing disease	20	13	
	bleaching	123	12	
	TOTAL	711	591	

Repetitive 8 m^2 Stations
Both Banks
Cruise 5

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1772	-	
Retreat, Bleaching, and Disease	unknown cause	1075	1075	generally minor
	algae mediated	13	13	
	algae/sediment	7	7	
	new disease	14	1	eventual mortality - 3
	pre-existing disease	32	25	
	bleaching	6	0	
	TOTAL	1147	1121	

Repetitive 8 m^2 Stations
Both Banks
Cruise 6

Change	Cause	Occurrence	Mortality	Notes
Growth	-	1963	-	
Retreat, Bleaching, and Disease	unknown cause	501	501	generally minor
	algae mediated	0	0	
	algae/sediment	0	0	
	new disease	2	1	eventual mortality - 1
	pre-existing disease	17	14	
	bleaching	43	0	
	TOTAL	563	516	

Table D-2. Pecent coral cover at West Flower Garden Bank repetitive 8 m^2 stations during Cruises 2 and 6, the first and last cruises on which these stations were photographed using precise repetitive photography. Shaded areas were not used in calculations of mean cover, standard deviation, etc., because slides were missing or not useful in one of the two cruises. "Gain/Loss" indicates change in coral cover between Cruises 2 and 6. Also shown is the cover of bleached corals at repetitive stations during the three summer cruises (2, 4, and 6), and the average cover and number of bleached colonies on each of the cruises.

Station	Cr 2 Cover	Cr 6 Cover		gain/loss		Bleaching 2	Bleaching 4	Bleaching 6
31M	69	76		7		0	0	0
32M	24	23		-1		0	2	0
119	27	32		5		0	6	0
149	57	55	Parrotf.1.3%	-2		0	0	0
185	62	65		3		0	0	0
189	47	54		7		0	0	0.3
214	39	41		2		0	0	0
215	55	59		4		0	1	0
226	62	67		5		0	6	0
229	28	30		2		0	0	0
230	45	49		4		2	5	0
231	39	40		1		0	0	0
232	34	33	Cr3 and Cr6	-1		0	1	0
239	52	54		2		0	6	0
240	41	47		6		0	0	0.3
243	51	51		0		0	12	0
246	51	51		0		0	0.3	0
247	28	28		0		0	0	0
249	48	50		2		0	0	0
266	31	36		5		0	0	0
279	57	51	Disease 2.7%	-6		0	0	0
285	28	35		7		0	0	0
147	44	45		1		0	0	0.3
310	51	59		8		5	2	0
311	50	51		1		0	0	0
329	55	55		0		0	2	1
332	32	32		0		0	0	0
333	47	48		1		0	0.3	0
341	59	57		-2		0	2	0
346	45	50		5		0	0	0
349	43	41		-2		0	0	0
350	58	52	Dis. & Bleach.	-6		0	7	4
366M	53	50	Cr2 and Cr5	-3		0	0	0
368	48	53		5		0	0	0
373	59	60		1		0	0	0
375	45	48		3		5	1	0
386	34	36		2		0	1	1
397	41	39		-2		0	0	0
New 2	32	36		4		0	0	0
mean=	*45.5*	*47.5*	*avg increase*	*1.9*	*Bleached Cvr*	*0.3*	*1.4*	*0.2*
std dev.=	*11.5*	*11.6*	*num (+)=*	*25*	*Bleach. Obs.*	*3*	*16*	*6*
n=	*37*	*37*	*num (-)=*	*7*	*n*	*40*	*40*	*40*
max=	*69*	*76*	*num (0)=*	*5*				
min=	*24*	*23*	*n>2% gain=*	*15*				
			n>2% loss=	*2*				
			x>=-2, x<=2	*20*				

Table D-3. Pecent coral cover at East Flower Garden Bank repetitive 8 m^2 stations during Cruises 2 and 6, the first and last cruises on which these stations were photographed using precise repetitive photography. Shaded areas were not used in calculations of mean cover, standard deviation, etc., because slides were missing or not useful in one of the two cruises. "Gain/Loss" indicates change in coral cover between Cruises 2 and 6. Also shown is the cover of bleached corals at repetitive stations during the three summer cruises (2, 4, and 6), and the average cover and number of bleached colonies on each of the cruises.

Station	Cr 2 Cover	Cr 6 Cover		gain/loss		Bleaching 2	Bleaching 4	Bleaching 6
4	57	59		2		0	0	0
5	68	76		8		0	0.3	1.7
7	83	85		2		0	0	0
8	70	72		2		0	1.7	1
14	60	61		1		0	3.7	4.3
18	50	53		3		6.7	7.7	3
19	70	70		0		0	0	0
21	36	40		4		0	2	0.3
22	67	67	Cr2 and Cr5	0		0	1	0
26	26	25		-1		0	0.7	0.3
28	44	44		0		0	0	0
31	33	37		4		0	3.3	2
33	45	44		-1		0	1	0.3
36	28	27		-1		0	0	8.3
36M	46	47	Dis. minimal	1		0	0.3	0
37	41	45		4		0	7	0
39M	60	60		0		0	0	0
41	62	68		6		0	0	6
43	67	69		2		5.3	9.7	0
47	49	52		3		0	5	0.3
49	24	28		4		0	3.4	0
50	14	14		0		0	3	0
51	61	60	Disease	-1		0	4.7	0
52	63	64		1		0.3	0	0.7
58	41	47		6		0	7.3	0
61	56	55		-1		0	7	5
67	36	33	Disease	-3		0	(Cr 5) 0.7	0
70	51	53		2		0	0.3	0
75	49	57		8		0	1	0.3
81	22	22		0		0	0	1
82	42	39		-3		0	1	0
101	31	30		-1		0	0.7	0.3
106	64	65		1		0	15.8	15.1
112	29	28		-1		0	0.7	0
134	76	76		0		0.7	0	0
150	46	44	Disease	-2		1	1	0
151	54	55		1		0	1.3	0.3
155	61	60		-1		0	0.7	0
156	67	70		3		0	0	0
173	61	66		5		0	1	1
mean=	*49.8*	*51.3*	*avg increase*	*1.5*	*Bleached Cvr*	*0.4*	*2.4*	*1.3*
std dev.=	*16.4*	*17.2*	*num (+)=*	*22*	*Bleach. Obs.*	*5*	*29*	*19*
n=	*39*	*39*	*num (-)=*	*11*	*n*	*40*	*40*	*40*
max=	*83*	*85*	*num (0)=*	*6*				
min=	*14*	*14*	*n>2% gain=*	*12*				
			n>2% loss=	*2*				
			x>=-2, x<=2	*25*				

Appendix E.

(Ancillary Data)

Table E-1. Ancillary Data: light, oxygen, salinity, and temperature data collected on the six project cruises, along with temperature data collected during the project period on cruises other than those conducted on the project.

Date	Location	Depth (m)	Quanta/s/cm^2 (time)	Oxygen (ml/l) (time)	Salinity (time)	Temperature (°C) (time)
12/13/88	EFG	1	7.509E16 (1320)	7.036 (1315)	36.418 (1315)	23.5 (1219)
		21	1.946E16 (1218)	7.775 (1211)	36.427 (1211)	23.7 (1219)
12/14/88	EFG	1	-	-	-	23.4 (1212)
		18	0.499E16 (1500)	6.279 (1500)	36.426 (1500)	22.2 (1500)
12/15/88	EFG	1	8.724E16 (1220)	5.809 (1220)	36.464 (1220)	23.5 (1220)
		21	3.008E16 (1300)	10.53 (1300)	36.432 (1300)	22.2 (1300)
2/25/89	EFG	Air	9.849E16 (1400)	-	-	20.2 (1226)
		1	7.921E16 (1400)	5.466 (1226)	36.447 (1226)	21.1 (1226)
		20	0.947E16 (1345)	5.212 (1345)	36.443 (1345)	21.1 (1230)
2/26/89	EFG	1	2.481E16 (1140)	5.414 (1140)	36.430 (1140)	21.7 (1140)
2/26/89	EFG	Air	6.131E16 (1217)	-	-	20.9 (1225)
		1	2.443E16 (1240)	-	-	-
		20	-	5.231 (1345)	36.431 (1345)	21.0 (1230)
4/7/89	EFG	Air	1.703E17 (1228)	-	-	-
		1	9.826E16 (1239)	-	-	-
		17	2.124E16 (1530)	3.295	36.584	-
4/8/89	EFG	Air	1.706E17 (1430)	-	-	22.8 (1501)
		1	1.200E17 (1440)	5.988 (1445)	36.468 (1445)	21.9 (1445)
		17	-	5.932 (1541)	36.454 (1541)	22.5 (1600)
4/9/89	EFG	Air	1.611E17 (1500)	-	-	-
		1	1.201E17 (1430)	5.385 (1400)	36.398 (1400)	22.3 (1400)

Table E-1. Continued.

Date	Location	Depth (m)	Quanta/s/cm^2 (time)	Oxygen (ml/l) (time)	Salinity (time)	Temperature (°C) (time)
4/9/89	EFG	17	3.819E16 (1330)	5.173 (1350)	36.449 (1350)	21.5 (1350)
4/17/89	EFG	Air	1.774E17 (1455)	-	-	25.1 (1450)
		1	9.243E16	6.267 (1445)	36.342 (1445)	22.4 (1445)
		19	2.426E16	5.552 (1445)	36.401 (1445)	21.7 (1445)
4/18/89	EFG	Air	1.303E17	-	-	24.5 (1400)
		1	7.948E16 (1450)	5.524 (1500)	36.329 (1500)	23.5 (1505)
		19	2.495E16 (1330)	5.472 (1330)	36.380 (1330)	21.7 (1330)
4/19/89	WFG	Air	9.494E16 (1615)	-	-	23.8 (1600)
		1	3.058E16 (1550)	5.521 (1550)	36.323 (1550)	22.5 (1550)
		21	1.823E16 (1509)	5.270 (1509)	36.407 (1509)	22.0 (1510)
4/20/89	WFG	Air	-	-	-	27.5 (1530)
4/20/89	WFG	1	6.570E16 (1403)	4.940 (1400)	36.296 (1400)	-
		21	-	5.238 (1400)	36.383 (1400)	22.1 (1900)
6/3/89	WFG	Air	1.367E17 (1445)	-	-	28.3 (1449)
		1	9.821E16 (1451)	6.315 (1452)	33.459 (1452)	27.2 (1100)
		21	1.986E16 (1418)	5.401 (1416)	35.960 (1416)	27.2 (1417)
10/11/89	EFG	Air	1.299E17	-	-	27.0 (1400)
		1	7.805E16 (1309)	4.986 (1300)	36.549 (1300)	27.2 (1327)
		21	2.737E16 (1225)	4.923 (1220)	36.563 (1220)	27.4 (1226)
10/12/89	EFG	Air	7.643E16 (1220)	-	-	27.0 (1500)
		1	4.500E16 (1210)	5.002 (1200)	36.562 (1200)	27.3 (1200)
		21	1.956E16 (1200)	4.958 (1230)	36.570 (1230)	27.5 (1200)

Table E-1. Continued.

Date	Location	Depth (m)	Quanta/s/cm^2 (time)	Oxygen (ml/l) (time)	Salinity (time)	Temperature (°C) (time)
10/23/89	WFG	Air	1.260E17 (1230)	-	-	27.5 (1222)
		1	7.025E16 (1223)	5.010 (1215)	36.386 (1215)	25.9 (1225)
		20	1.082E16 (1245)	5.128 (1245)	36.454 (1245)	25.9 (1245)
10/24/89	WFG	Air	1.768E17	-	-	-
		1	8.279E16 (1430)	5.108 (1230)	36.449 (1230)	26.0 (1235)
		20	2.011E16 (1145)	5.058 (1211)	36.472 (1211)	26.1 (1145)
4/22/90	WFG	Air	1.533E17 (1150)	-	-	27.7 (1140)
		1	6.259E16 (1200)	5.667 (1200)	35.414 (1200)	23.4 (1200)
		23	1.136E15 (1250)	5.892 (1250)	36.282 (1250)	22.1 (1250)
4/23/90	WFG	Air	1.135E17 (1200)	-	-	-
		1	9.584E16 (1250)	7.026 (1245)	35.496 (1245)	23.4 (1300)
		23	1.912E16 (1310)	5.436 (1230)	35.919 (1230)	22.2 (1230)
4/24/90	WFG	1	-	-	-	23.4 (1300)
		23	1.383E16 (1300)	5.379 (1300)	36.103 (1300)	22.2 (1300)
4/25/90	EFG	1	-	-	-	-
		20	3.473E16 (1255)	5.555 (1250)	36.044 (1250)	22.4 (1300)
7/5/90	WFG (diver rept)	1	-	-	-	30.0 (computer)
		20	-	-	-	28.9 (computer)
7/25/90	WFG (diver rept)	1	-	-	-	28.9 (computer)
		20	-	-	-	27.2 (computer)
8/7/90	WFG	24	-	-	-	28.3 (0913)
	EFG	19	-	-	-	28.3 (1406)
8/8/90	EFG	19	-	-	-	29.5 (0910)

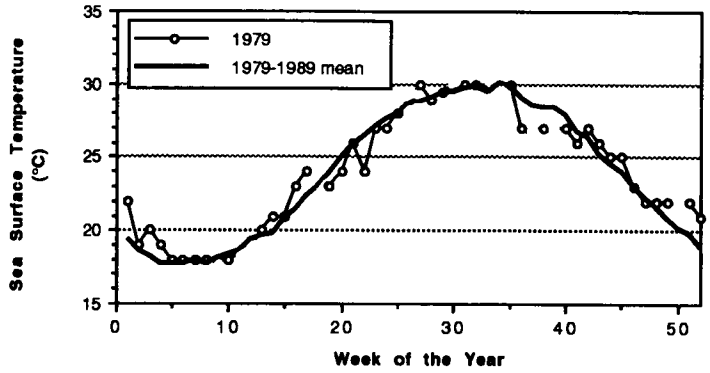
Table E-1. Continued.

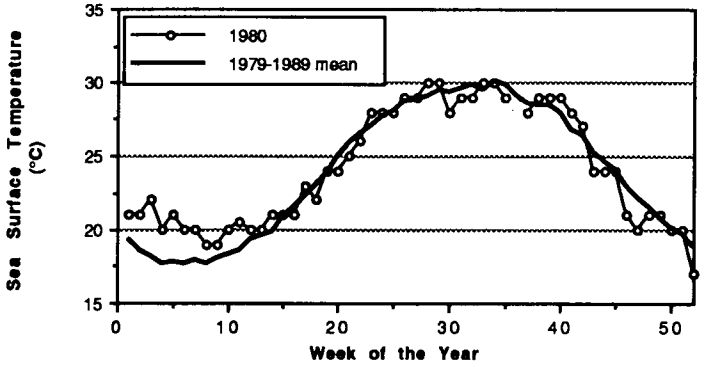
Date	Location	Depth (m)	Quanta/s/cm^2 (time)	Oxygen (ml/l) (time)	Salinity (time)	Temperature (°C) (time)
10/29/90	WFG	Air	1.321E17 (1306)	-	-	24.3 (1245)
		1	8.630E16 (1253)	5.754 (1257)	35.727 (1257)	25.8 (1240)
		21	1.655E16 (1200)	5.959 (1200)	36.110 (1200)	25.6 (1200)
10/30/90	WFG	Air	1.314E17 (1149)	-	-	22.6 (1234)
		1	9.312E16 (1248)	6.828 (1155)	36.096 (1155)	25.8 (1145)
		21	1.136E16 (1200)	7.490 (1225)	36.104 (1225)	25.8 (1137)
10/31/90	EFG	Air	1.145E17 (1215)	-	-	27.2 (1230)
		1	7.237E16 (1200)	5.418 (1230)	35.421 (1230)	25.6 (1254)
		20	2.317E16 (1235)	6.510 (1230)	35.909 (1230)	25.9 (1239)
11/1/90	EFG	Air	1.315E17 (1225)	-	-	26.9 (1215)
		1	3.828E16 (1208)	5.860 (1212)	35.800 (1212)	25.6 (1212)
		21	2.104E16 (1148)	5.944 (1148)	36.097 (1148)	26.0 (1152)
11/24/90	EFG	20	-	-	-	23.3
	WFG	21	-	-	-	25.0
11/25/90	STETSON	21	-	-	-	23.9
3/24/91	WFG	Air	1.21E17 (1242)	-	-	21.1 (1252)
		1	5.31E16 (1234)	6.077 (1202)	36.300 (1202)	21.3 (1235)
		24	2.17E16 (1200)	5.601 (1134)	36.238 (1134)	20.4 (1134)
3/25/91	WFG	Air	1.73E17 (1255)	-	-	-
		1	1.16E17 (1329)	5.637 (1156)	36.283 (1156)	22.2 (1256)
		24	2.20E16 (1158)	5.856 (1158)	36.287 (1158)	21.1 (1200)
3/26/91	EFG	Air	1.65E17 (1222)	-	-	24.1 (1222)
		1	9.72E16 (1340)	5.884 (1242)	36.723? (1242)	21.3 (1330)
		24	2.59E16 (1240)	6.028 (1250)	36.303 (1250)	20.9 (1250)

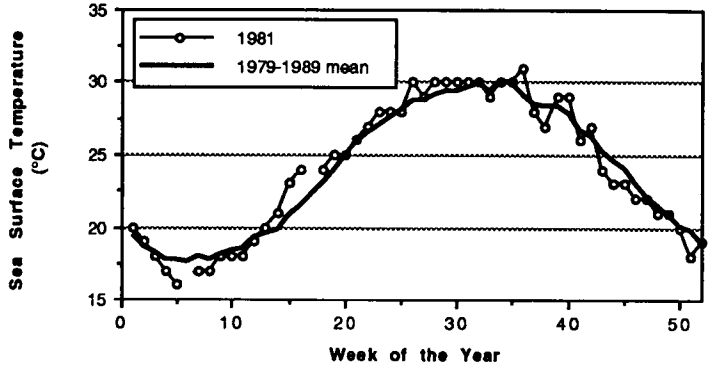
Table E-1. Continued.

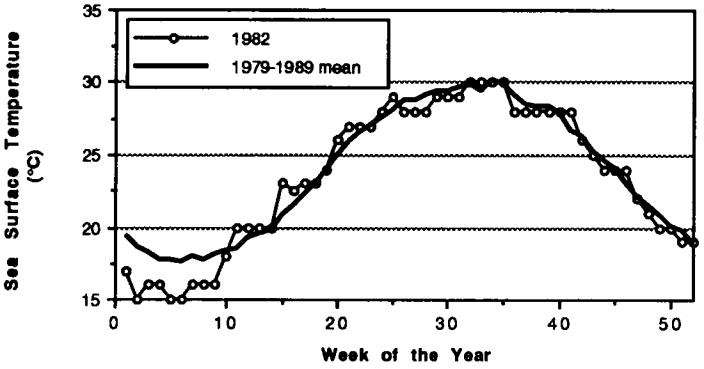
Date	Location	Depth (m)	Quanta/s/cm^2 (time)	Oxygen (ml/l) (time)	Salinity (time)	Temperature (°C) (time)
8/30/91	WFG	Air	1.141E17 (1325)	-	-	27.4 (1345)
		1	5.869E16 (1335)	5.835 (1340)	36.046 (1340)	29.4 (1335)
		25	2.020E16 (1211)	5.959 (1245)	36.593 (1245)	29.3 (1248)
8/31/91	WFG	Air	1.706E17 (1320)	-	-	26.9 (1300)
		1	8.803E16 (1330)	5.899 (1330)	36.029 (1330)	29.1 (1320)
		24	1.828E16 (1422)	bottle broken	36.017 (1416)	29.4 (1416)
9/1/91	EFG	Air	1.529E17 (1425)	-	-	26.3 (1420)
		1	1.227E17 (1306)	5.314 (1410)	36.056 (1410)	29.3 (1300)
		20	4.080E16 (1229)	5.235 (1223)	36.215 (1223)	29.3 (1223)
9/2/91	EFG	Air	1.880E17 (1339)	-	-	-
		1	1.309E17 (1348)	6.948 (1354)	35.459 (1354)	29.8 (1354)
		20	4.752E16 (1214)	5.418 (1515)	35.980 (1515)	29.0 (1207)

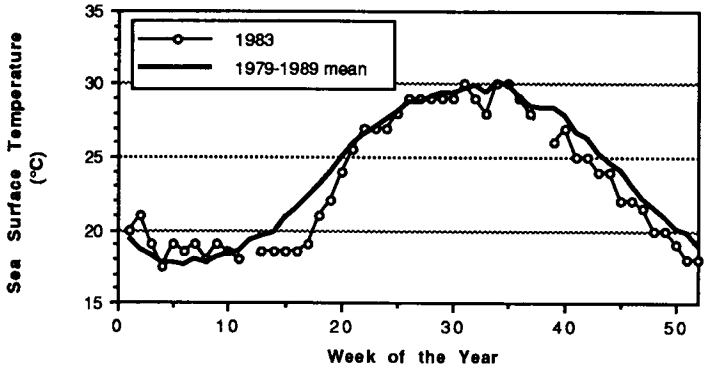
Figure E-1. AVHRR sea surface temperatures (°C) for each week of the year from 1979 through 1989 plotted against the 11-year (1979-1989) mean sea surface temperature for each week.

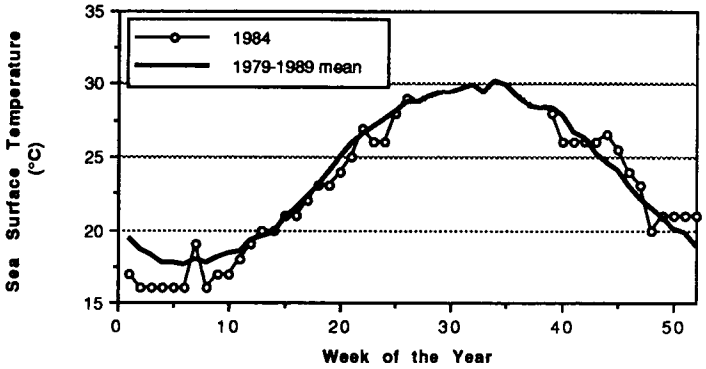

1979
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

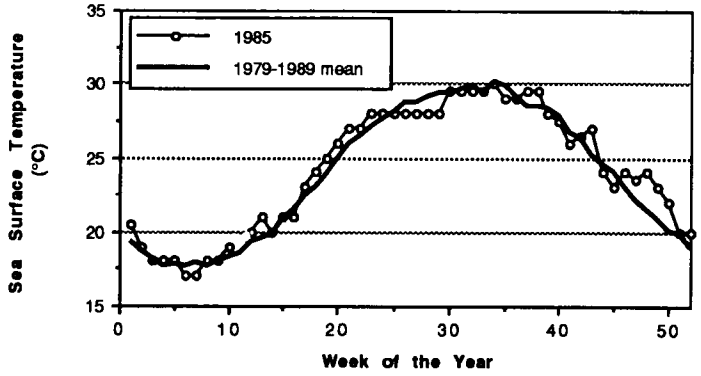

1980
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

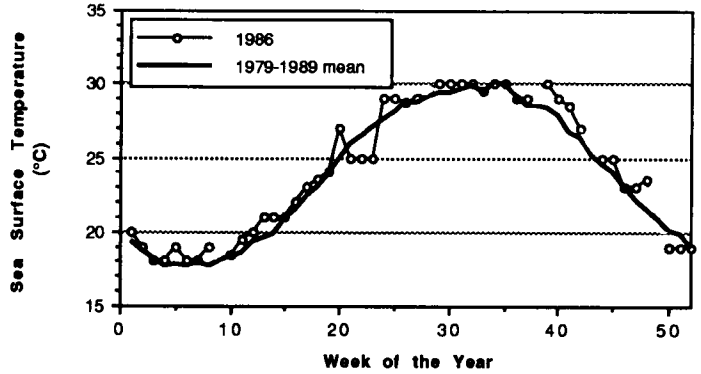

1981
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

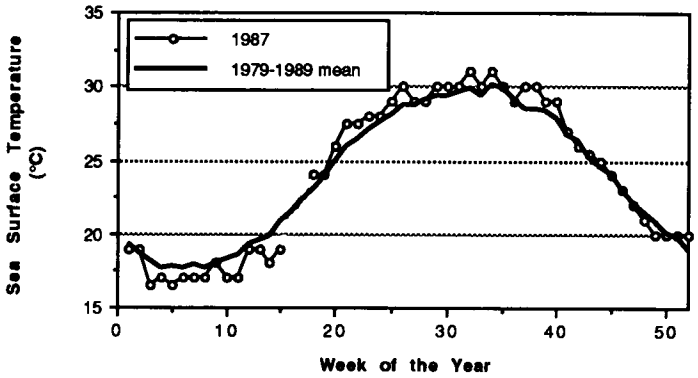

1982
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

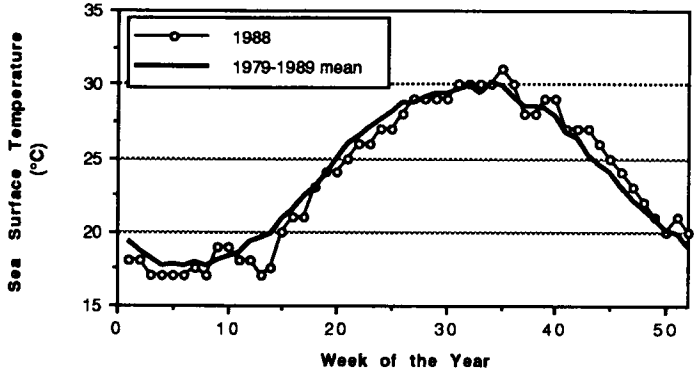

1983
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

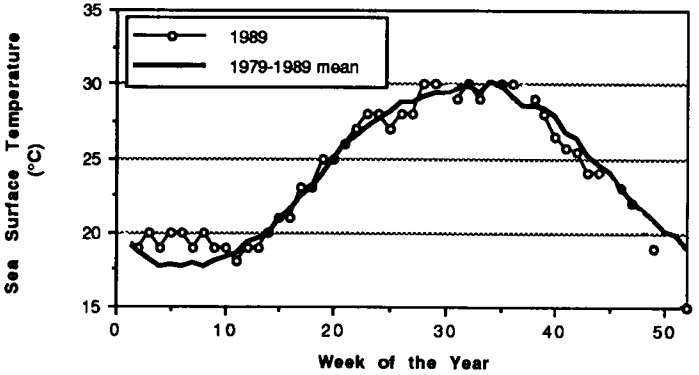

1984
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year


1985
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year


1986
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year


1987
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year


1988
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year


1989
1979-1989 mean
Sea Surface Temperature (°C)
Week of the Year

Appendix F.

(Video Transect Data)

Table F-1. Summary of reef fish species density (number/100m sq) at the Flower Garden sites

	Cruise 1				Cruise 2				Cruise 3			
	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG
Fish Taxa	North	East	South	West	North	East	South	West	North	East	South	West
Creolefish	13.7	43.1	0.6	2.6	6.6	1.7	37.4	28.9	30.0	37.7	11.1	5.4
Creole Wrasse	2.9	0.3	3.1	2.6		0.3	14.6	6.6	2.0	17.7	45.4	0.3
Queen Parrot	1.4	1.1	1.1	2.6			1.1	0.9			1.7	2.6
Stoplight Parrot	0.3			0.3			0.6	0.6			1.1	0.9
Red Band Parrot	0.3		0.3				0.6	0.3				0.6
Princess Parrot							0.3					
Unknown Parrot												
Black Durgon		0.3			0.6	0.6	0.3	0.3		0.3		0.3
Rock Beauty			0.3	0.3							0.9	0.3
Queen Angel	0.3							0.3				
Reef Butterfly	0.3	0.6	0.6						1.1		0.3	
Surgeon fish	0.6	0.3	0.3		0.9	0.3	0.3	0.3			0.3	0.6
Blue Tang	0.3	0.6					0.3	0.3			0.6	0.6
Mycteroperca spp.					0.3				0.3			
Tiger grouper					0.3							
Spanish Hogfish						0.3						
Spotfin Hogfish												0.3
Orange spotted filefish											0.3	0.3
Smooth Trunkfish								0.3				
Yellow goatfish												
French Angel												
Total Density	20.0	46.3	6.3	8.3	8.6	3.2	55.4	38.6	33.4	55.7	61.7	12.0
by Transect												
Mean Density by Bank	33.2		7.3		5.9		47.0		44.6		36.9	
Cruise Mean		20.2				26.4				40.7		
Seasonal mean Cr 1,3,5		Winter	33.7									
vs. Cr 2,4,6 all species		Summer	15.1									

Table F-1. Summary of reef fish species density (number/100m sq) at the Flower Garden sites

	Cruise 4				Cruise5				Cruise 6				Winter Total	Sum Total
	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG		
Fish Taxa	North	East	South	West	North	East	South	West	North	East	South	West		
Creolefish	4.9	0.3	0.9	1.4	27.4	59.1	6.0	6.0	10.3	6.9	12.3	14.3	20.2	10.5
Creole Wrasse			0.3		1.7	2.6	44.0	6.9	0.6		1.1	1.4	10.8	2.1
Queen Parrot	0.3		1.4	2.6				0.9	0.3		0.9	1.4	1.0	0.7
Stoplight Parrot	0.3		0.6	0.6		0.3	0.3	0.3	0.6	0.3	0.9		0.3	0.4
Red Band Parrot											0.3		0.1	0.1
Princess Parrot				0.3			0.3		0.3		0.3	0.6	0.0	0.1
Unknown Parrot	0.3							0.3					0.0	0.0
Black Durgon	0.3			0.3				1.1	0.6	0.6	1.7	0.6	0.2	0.5
Rock Beauty								0.6					0.2	0.0
Queen Angel			0.3										0.0	0.0
Reef Butterfly													0.2	0.0
Surgeon fish	0.3			0.3			0.3	0.3	0.6	0.3	0.3	0.3	0.2	0.3
Blue Tang								0.9	0.3	0.3			0.2	0.1
Mycteroperca spp.		0.3											0.0	0.0
Tiger grouper						0.9							0.1	0.0
Spanish Hogfish	0.3												0.0	0.0
Spotfin Hogfish													0.0	0.0
Orange spt filefish													0.0	0.0
Smooth Trunkfish												0.3	0.0	0.0
Yellow goatfish											0.3		0.0	0.0
French Angel					0.3								0.0	0.0
Total Density	6.6	0.6	3.4	5.4	29.4	62.9	50.9	17.2	13.4	8.3	18.0	18.9	33.7	15.1
by Transect														
Mean Density	3.6		4.4		46.1		34.0		10.9		18.4			
by Bank														
Cruise Mean		4.0				40.1				14.7				

Table F-2. Summary of abundance and percent composition for three dominant fish taxa at the Flower Garden sites.

	Cruise 1				Cruise 2				Cruise 3			
	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG
Fish Species	North	East	South	West	North	East	South	West	North	East	South	West
Creolefish	48	151	2	9	23	6	131	101	105	132	39	19
Creole Wrass	10	1	11	9	0	1	51	23	7	62	159	1
Queen Parrot	5	4	4	9	0	0	4	3	0	0	6	9
Total top 3	63	156	17	27	23	7	186	127	112	194	204	29
Total Number												
All Species	70	162	22	29	30	11	191	135	117	195	216	42
Percent top 3	90%	96%	77%	93%	77%	64%	97%	94%	96%	99%	94%	69%
Percent of total - top 3 speci			93.05%									
Percent of total for												
Creolefish	68.6%	93.2%	9.1%	31.0%	76.7%	54.5%	68.6%	74.8%	89.7%	67.7%	18.1%	45.2%
Creole Wrass	14.3%	0.6%	50.0%	31.0%	0.0%	9.1%	26.7%	17.0%	6.0%	31.8%	73.6%	2.4%
Queen Parrot	7.9%	2.6%	23.5%	33.3%	0.0%	0.0%	2.2%	2.4%	0.0%	0.0%	2.9%	31.0%
Total counted												
top 3 species	**1901**											
Total all	**2043**											

Table F-2. Summary of abundance and percent composition for three dominant fish taxa at the Flower Garden sites.

	Cruise 4				Cruise5				Cruise 6				
	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG	EFG	EFG	WFG	WFG	Total %
Fish Species	North	East	South	West	North	East	South	West	North	East	South	West	By species
Creolefish	17	1	5	3	96	207	21	21	36	24	43	50	63.1%
Creole Wrasse	0	0	0	1	6	9	154	24	2	0	4	5	26.4%
Queen Parrot	1	0	9	5	0	0	0	3	1	0	3	5	3.5%
Total top 3	18	1	14	9	102	216	175	48	39	24	50	60	93.0%
Total Number													
All Species	23	2	19	12	103	220	178	60	47	29	63	67	100.0%
Percent top 3	78%	50%	74%	75%	99%	98%	98%	80%	83%	83%	79%	90%	
Percent of total for													
Creolefish	73.9%	50.0%	26.3%	25.0%	93.2%	94.1%	11.8%	35.0%	76.6%	82.8%	68.3%	74.6%	
Creole Wrasse	0.0%	0.0%	0.0%	8.3%	5.8%	4.1%	86.5%	40.0%	4.3%	0.0%	6.3%	7.5%	
Queen Parrot	5.6%	0.0%	64.3%	55.6%	0.0%	0.0%	0.0%	6.3%	2.6%	0.0%	6.0%	8.3%	

Table F-3. Selected reef fish densities (number/100 m sq; W= West Flower Garden, E= East; from Boland et al., 1983).

Cruise #	2W	3W	3E	4W	4E	5E	6E	7E	8E
Date	Jan '81	Apr '81	Apr '81	Jul '81	Jul '81	Oct '81	Apr '82	Aug '82	Oct '82
A. Total density in coral high diversity zone									
Species					**Cruise**				
	2W	**3W**	**3E**	**4W**	**4E**	**5E**	**6E**	**7E**	**8E**
Creolefish	23.3	11.8	6.8	23.5	21.0	9.7	9.3	10.2	16.8
Creole wrasse	0.1	0.5	1.0	3.8	5.6	1.9	3.1	3.6	5.0
Queen parrotfish	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1
Stoplight parrotfish	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1
		Seasonal all depths							
		Winter		**Summer**					
Creolefish		12.8		16.3					
Creole wrasse		1.2		4.0					
Queen parrotfish		0.0		0.1					
Stoplight parrotfish		0.0		0.1					
B. Density in the 20 to 24 m depth zone									
Species					**Cruise**				
	2W	**3W**	**3E**	**4W**	**4E**	**5E**	**6E**	**7E**	**8E**
Creolefish	25.8	11.4	7.2	23.4	19.7	7.9	7.6	9.8	12.2
Creole wrasse	0.2	0.7	1.7	2.5	2.3	3.1	2.5	1.6	15.5
Queen parrotfish	0.5	0.5	0.0	0.1	0.0	0.0	0.1	0.3	0.1
Stoplight parrotfish	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Seasonal 20-24 m							
		Winter		**Summer**					
Creolefish		13.0		14.6					
Creole wrasse		1.3		5.0					
Queen parrotfish		0.3		0.1					
Stoplight parrotfish		0.1		0.0					

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 the wisest use of our land and water resources, protecting our fish and wildlife, 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 assure that their development is in the best interest of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.