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Reef Community Stability on the Flower Garden Banks, Northwest Gulf of Mexico

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Benthic cover and coral growth studies conducted on the coral reefs at the Flower Garden Banks since the early 1970s, as well as investigations on other aspects of biotic assemblages associated with the reefs, suggest fairly high community stability. Changes that have been observed indicate the community's resilience in response to periodic episodes of stress, which are caused primarily by natural factors (e.g., anomalously high temperatures, disease epidemics). There has been no indication of long-term environmental degradation following such events. On the whole, the reef communities appear to have remained unaltered by human activities, despite numerous isolated insults to the reefs, caused mostly by anchoring, lost or discarded debris, illegal fishing gear, and tow cables. Early recognition of the sensitivity of the reef communities on the banks led to implementation of protective measures related to hydrocarbon development by the Minerals Management Service. Regulations promulgated later by the National Oceanic and Atmospheric Administration addressed threats posed by other potentially destructive activities. Long-term research and monitoring programs have been instrumental in, and remain vital to, enabling resource managers to make science-based decisions concerning environmental protection at the Flower Gardens.

There is a widespread agreement that many coral reefs throughout the world are experiencing serious degradation. It has been estimated that of the world's reefs, which by some estimates cover an area of more than 600,000 km^2 (nearly as large as Texas; Smith, 1978), about 10% have already been degraded beyond recovery; another 30% are likely to be lost within 10–20 yr, and another 30% within 20–40 yr (Wilkinson, 1992). There is, however, a high degree of uncertainty associated with these estimates, partly due to the paucity of information available from most of the world's reefs (Eakin et al., 1997).

Furthermore, considerable disagreement exists as to the causes of many cases of coral reef deterioration. Although "anthropogenic stress" is commonly recognized as a principal cause of reef demise (Wilkinson et al., 1997), specific causes are generally difficult to isolate. Causes widely viewed as some of the most significant are excessive coastal development, resulting in poor water quality through excessive sedimentation, nutrient pollution, or sewage discharges; clearing of vegetation and its effects on water quality; over-fishing; and in certain cases, destructive fishing practices, such as dynamite fishing.

In the last 5–10 yr, scientists throughout the world have begun to advocate the establishment of mapping and habitat monitoring programs that will help determine the distribution of reefs, the level of natural temporal variability experienced by coral reef ecosystems, and their condition. Numerous initiatives have begun or are in development, such as the International Coral Reef Initiative, the Global Coral Reef Monitoring Network, Caribbean Coastal Marine Productivity Program, and ReefCheck (see Eakin et al., 1997).

For many coral reefs, however, these efforts come at a time after their deterioration has begun, making it difficult for researchers and resource managers to know what the healthy ecosystems might have looked like or how naturally variable the healthy ecosystems might have been. Few coral reefs in the world have been monitored for periods long enough to establish this fundamental information. Even in developed countries, long-term programs are not common. For example, several monitoring programs have been initiated in the Florida Keys, but comprehensive studies have only begun in the last 5 yr or so. In other places, monitoring has received inconsistent support, and discontinuous funding has been a significant problem for the program described herein, resulting in data gaps that make interpretation of some information difficult.

Coral communities that have been monitored quantitatively for substantial periods of time have generally been those that exist in shallow water (e.g., Porter and Meier, 1992) or those exhibiting considerable human impact (e.g., Liddell and Ohlhorst, 1992). Results from shallow reef studies have shown that substantial natural variation frequently occurs in periods as short as 1–5 yr, making generalizations regarding trends in coral reef condition difficult.

Coral community stability may be higher in deeper zones on less impacted coral reefs, at least with regard to parameters typically measured in monitoring programs (e.g., cover, diversity, growth rates). Dominant species in reef zones below about 10 m tend to be those that grow more slowly and are less frequently disturbed by storm events. Quantitative assessments in such zones may provide a clearer indication of trends in community condition than those in shallower, more highly variable habitats.

This paper focuses on quantitative assessments of benthic habitats between 18 and 25 m on the reefs of the East and West Flower Garden Banks, located about 175 km SSE of Galveston, Texas (Fig. 1). These banks contain tropical assemblages of comparatively low diversity, with around 20 hermatypic coral species, more than 250 invertebrate species, and 175 fish species. They occur on features caused by uplift of Jurassic age salt on the edge of the continental shelf in the northwest Gulf of Mexico and are 600 km from any other coral reefs. The northwest Gulf is highly industrialized, with nearly 4,000 hydrocarbon production facilities and more than 35,000 km of gas and oil pipelines. Considerable commercial fishing effort (primarily snapper and grouper) is focused on the deeper portions of the banks, and several thousand divers visit the reefs each year, most making multiday trips on live-aboard vessels.

A summary of the history of monitoring, which began in the mid-1970s, will be presented, along with a summary of the program's findings, as well as information from other investigations related to the condition of these isolated coral reefs. The objective is to evaluate information from published papers, monitoring and damage assessment reports, and unpublished observations that relate to community condition, natural and anthropogenic change, and reef community resilience. The paper will also describe the role scientific research has played in the development of protective regulations for these coral reefs and surrounding environs.

History of Assessment and Monitoring at the Flower Gardens

The earliest quantitative data on coral and other sessile invertebrate cover at the Flower Gardens was collected 26 yr ago (1972) in 27 quadrats, each measuring approximately 12 m^2 (Bright and Pequegnat, 1974). Although not formally part of a planned long-term monitoring study, it was recognized that the data could provide a baseline against which future information could be compared, particularly considering the anticipated placement of hydrocarbon production facilities and designation as a national marine sanctuary. This work was funded by the Flower Garden Ocean Research Center, a division of the Marine Biomedical Institute of the University of Texas Medical Branch at Galveston.

The first regularly collected data on benthic communities occurred in 1978 (Viada, 1980) and continued through 1983 (CSA, 1985). This work was prompted by the drilling activities of Mobil Exploration and Producing U.S., Inc., within 1.7 km of the coral reefs on the East Flower Garden Bank. Industry sponsorship of the monitoring program was required by the Minerals Management Service (MMS, which regulates offshore oil and gas activities) because the activity was within the "shunting and monitoring zone" established in 1974 by MMS (then part of the Bureau of Land Management). Within this zone, operators are required to shunt cuttings through a downpipe that terminates within 10 m of the seabed. At that time, they were also required to sponsor pre- and postdrilling surveys to evaluate the fate and effects of their discharges on the sensitive biological assemblages inhabiting the nearby banks.

With the commencement of production operations within this zone, also called the "1-Mile Zone" (the area within 1 mile of the reefs), MMS required operators to conduct regular monitoring of the fate of produced water discharges. This involved chemical analysis of sediments taken from the vicinity of the platforms but did not involve biological collections from either of the banks.

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Fig. 1. Location of the Flower Garden Banks (inset) and current regulatory boundaries relative to gas and oil pipelines, platforms, outer continental shelf lease blocks, and shipping lanes. Lease blocks are 4.8 km on a side.

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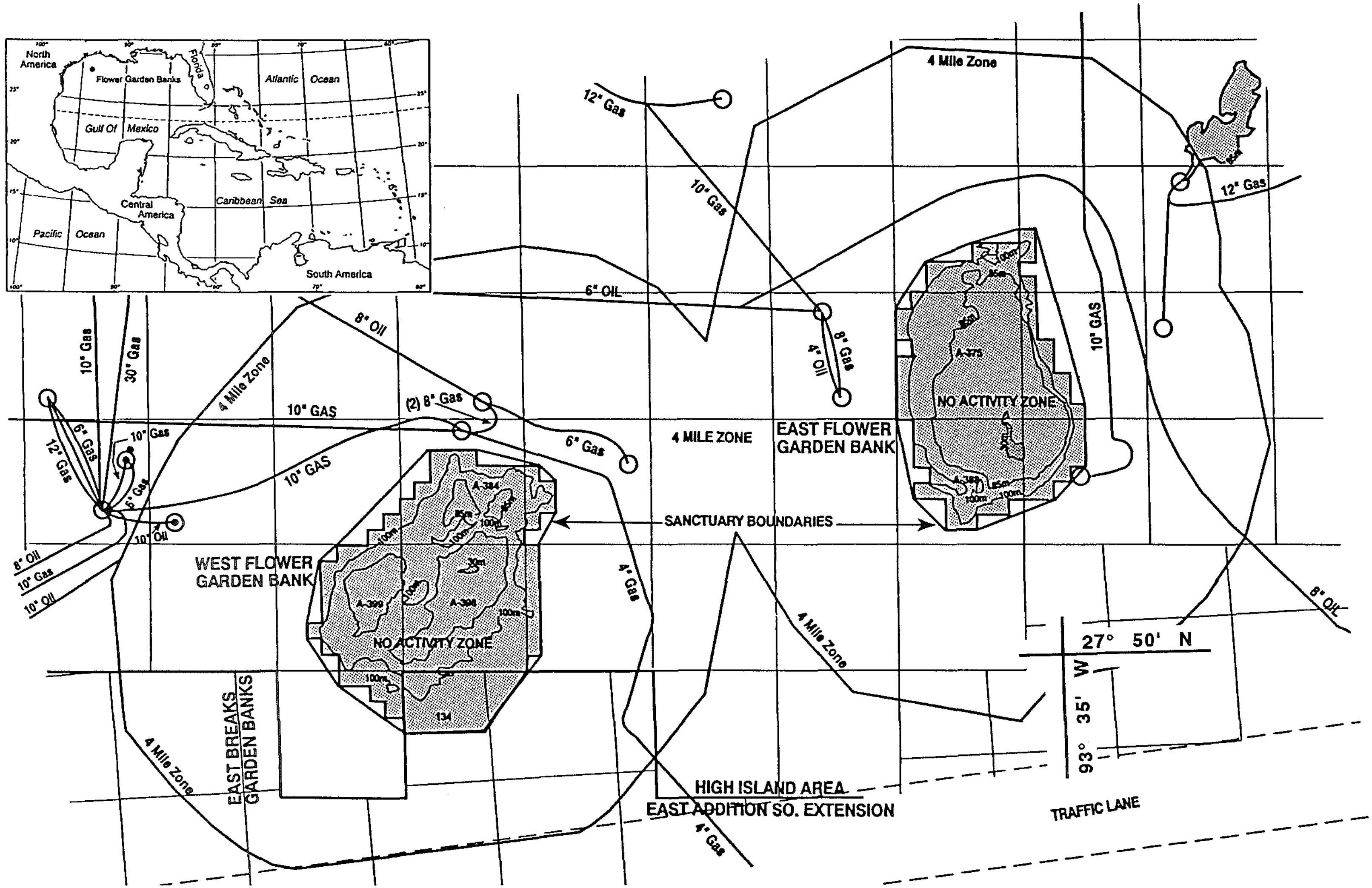
North America
Flower Garden Banks
Florida
Atlantic Ocean
Gulf Of Mexico
Central America
Caribbean Sea
Pacific Ocean
South America
4 Mile Zone
12" Gas
10" Gas
6" OIL
8" Gas
4" Oil
10" GAS
30" Gas
8" Oil
(2) 8" Gas
6" Gas
12" Gas
10" Oil
4 MILE ZONE
EAST FLOWER
GARDEN BANK
NO ACTIVITY ZONE
SANCTUARY BOUNDARIES
WEST FLOWER
GARDEN BANK
4" Gas
8" Oil
27° 50' N
93° 35' W
EAST BREAKS
GARDEN BANKS
HIGH ISLAND AREA
EAST ADDITION SO. EXTENSION
TRAFFIC LANE

Following the completion of the study by CSA for Mobil in 1983 and because no new activity was proposed for the 1-Mile Zone, no further benthic monitoring was conducted at the Flower Gardens for nearly 6 yr. There was, however, one sampling effort, funded by the National Oceanic and Atmospheric Administration (NOAA), to investigate the fate of an area of the East Flower Garden Bank damaged in 1983 by an anchored tug and barge (Gittings and Bright, 1986). The study documented the potential for damage to reef corals by large vessel anchors and the potential for recovery from damage of varying extents.

In consultation with academia and industry, MMS developed a comprehensive benthic monitoring program for the Flower Gardens in the late 1980s. Between 1988 and 1992, they issued a contract for the first 3 yr of work on this program. The sampling program has remained in place, with some modifications, ever since.

In 1993, the requirement for produced water monitoring around platforms was removed following consultation between MMS, other federal agencies, and academia. It was determined that the monitoring protocols were inadequate to provide useful information on the fate of this material. MMS decided to request that the Environmental Protection Agency (EPA) require discharge monitoring data from platforms rather than require separate monitoring by industry. They also initiated a 2-yr study called the "Gulf of Mexico Offshore Operations Monitoring Experiment," which would more accurately measure the areal extent of contamination in sediments and assess sublethal responses of benthic organisms to exposure in the vicinity of one production platform near the East Flower Garden Bank. The study would eventually demonstrate that shunting did in fact localize contamination to within about 75 m of the platform (Kennicutt, 1994).

Currently, MMS and NOAA share the cost of benthic monitoring at the Flower Gardens. Modifications to the program are made prior to each funding cycle and are based on consultation between MMS, NOAA, and the contractor. In partnership with other organizations, the Flower Gardens Sanctuary also supports additional monitoring efforts (e.g., reef fish) and other studies related to community condition. Through permitting authority under the National Pollutant Discharge Elimination System (NPDES), the EPA requires routine monitoring of produced water discharge levels and toxicity.

A variety of benthic data have been collected over the years at the Flower Gardens, including coral cover, relative abundance, diversity, evenness, relative abundance, and accretionary (upward) and encrusting (lateral) growth rates. Cover and abundance data have been collected along transects and at repetitive stations using a variety of different, though probably comparable, photographic methods. Repetitive photo stations are also used to monitor coral disease frequency and the fate of bleached corals (those that have lost or expelled symbiotic algae as a result of stress). Growth data have been collected using repetitive photography and using sclerochronology (growth ring measurement from coral cores). Monitoring conducted during drilling operations also included evaluations of sedimentation levels, analysis of sediments and drilling fluids, tissue burden measurements, vertical profiling, and current meter deployments (CSA 1985). In recent years, instruments have been installed to measure temperature (since 1990) and light (since 1995) on a continual basis, and water quality measurement devices (Semi-Permeable Membrane Devices; SPMDs) are currently being tested (since 1996).

Other studies that augment the MMS/NOAA monitoring program at the Flower Gardens include periodic reef fish censuses and trophic studies (Pattengill et al., 1997), elasmobranch surveys, sea turtle tagging and tracking, recruitment studies, annual observations and experiments related to mass coral spawning, and studies on historical water quality and paleoclimate (both using coral cores).

Benthic Cover and Coral Growth 1972–95

Figure 2 shows total coral cover at the East and West Flower Gardens and presents data from all benthic studies for which quantitative data on corals have been collected. It includes data from the 27 quadrats sampled in 1972 and 440 random transects photographed since 1978. Though variation is clear, it can probably be attributed primarily to spatial differences between study sites used over the years [Viada (1980) first documented significant spatial variation on the reef at the East Flower Garden Bank]. Cover averages 47.3% (45.4% at the West Bank; 49.0% at the East Bank) and has probably not changed significantly on the banks in over 25 yr. Gittings et al. (1992c) and data collected by CSA (USDOI/MMS, 1996) showed that cover for individual species of corals on the Flower Gardens did not change significantly between 1978 and 1995 (Fig. 3).

Figure 4 shows data on accretionary growth

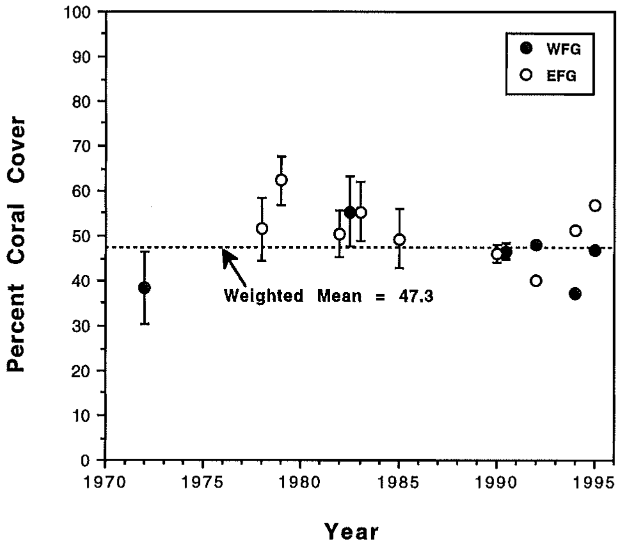

Fig. 2. Measurements of percent coral cover by various investigators since 1972. Data are from Bright and Pequegnat (1974); Viada (1980); Kraemer (1982); CSA (1985); Gittings and Bright (1986); Gittings et al. (1992b); and CSA (USDOI/MMS, 1996). Error bars represent 95% confidence intervals (not provided for data from 1992, 1994, and 1995).

at the Flower Gardens over the last 85 yr. Data are annual band widths taken from four cores of *Monstastraea faveolata.* There may have been a period of anomalous growth for a number of years after 1956. A similar anomalous period was noted for corals in the Florida Keys as well (Hudson et al., 1994), suggesting regional variation as opposed to local effects. Nevertheless, recent data suggest that corals have been growing at or above mean historic rates for the last decade or so.

Gittings et al. (1992c) and CSA (USDOI/MMS, 1996) presented coral encrusting (i.e., lateral) growth data for *Diploria strigosa* from the Flower Gardens. Growth over exposed substrates adjacent to noncompetitive margins (i.e., those without other corals within several inches of the margin) exceeded tissue loss by

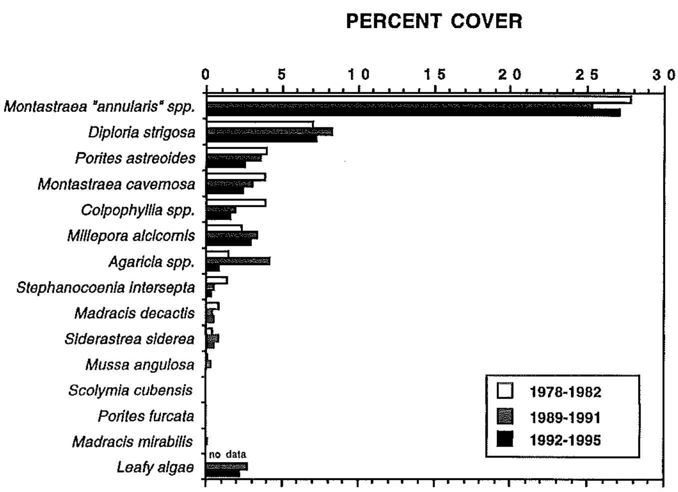

Fig. 3. Percent cover of the dominant reef coral species on the reefs of the Flower Garden Banks during three separate study periods (1978–1982 data from Kraemer, 1982; 1989–1991 data from Gittings et al., 1992b; 1992–1995 data from USDOI/MMS, 1996). All data were collected using transects. The *Montastraea "annularis"* group combines *M. franksi, M. faveolata,* and *M. annularis,* separate species recognized only recently, but which were called *M. annularis* during most of the period reported in this paper.

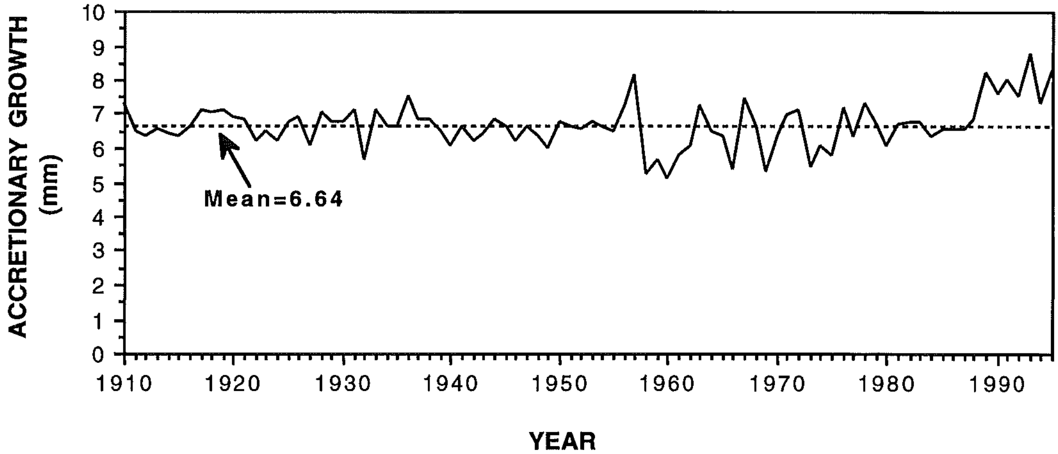

Fig. 4. Accretionary growth of corals measured by averaging sclerochronological data from four separate cores of *Montastraea faveolata* at the East and West Flower Garden Banks (data from Gittings et al., 1992b; USDOI/MMS, 1996).

a factor of 1.2 to 2.1 between 1989 and 1995 (Fig. 5). For *M.* "*annularis*" (primarily *M. faveolata*), Gittings et al. (1992c) reported a ratio of 1.8 between 1989 and 1991, compared to a value of 0.93 (a net tissue loss) for one reef in the Florida Keys between 1984 and 1987 (Gittings et al., 1988). It should be noted that the environments in which these studies were conducted are substantially different, both in terms of depth (more than 20 m at the Flower Gardens and 10 m in the Keys) and community structure, so direct comparisons may not be entirely appropriate.

Fifty-six percent of *D. strigosa* margins were advancing between 1989 and 1991, while only 26% were retreating (Gittings et al., 1992c). Percentages for *M.* "*annularis*" were 63% advancing and 22% retreating. The encrusting growth data suggest favorable growing conditions at the Flower Gardens and that tissue loss is controlled by natural factors, such as competition for space, rather than human-induced

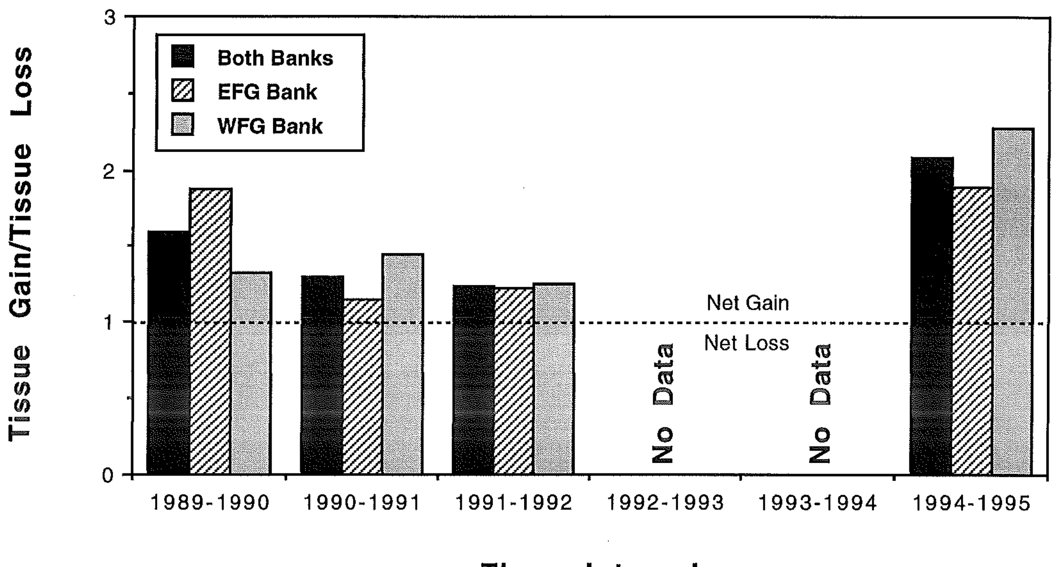

Fig. 5. Ratio of tissue gain to tissue loss along 20-cm marginal segments of approximately 30 colonies of *Diploria strigosa* annually between 1989 and 1995.

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stress. Other data supporting this include a low disease frequency among coral colonies, below 2%, between 1988 and 1992.

Status of the Flower Gardens Reefs

Neither coral community characteristics, based on data collected over the last 25 yr, nor growth data hint at significant upward or downward trends in environmental quality at the Flower Gardens. On the whole, the reef communities have remained largely unaltered by human activities. This is so despite numerous isolated insults to the reefs, including anchoring incidents (e.g., Gittings and Bright, 1986) and minor damage caused by illegal fishing gear and tow cables.

This is not to say the reefs have not exhibited temporal change or experienced destructive activities. In 1983 and 1984, nearly all long-spined sea urchins (*Diadema antillarum*) in the western Atlantic were killed by an unidentified pathogen that quickly spread through the region (Lessios et al., 1983). With the loss of this important herbivore, the Flower Gardens experienced an increase in algal cover to over 13% within 1–2 yr (Gittings and Bright, 1986), posing a significant threat to coral colonies [algal cover was less than 2.5% prior to the *D. antillarum* kill (CSA, 1985)]. But the ecosystem appeared to respond, apparently through increasing abundances of herbivorous fish, such as queen and stoplight parrotfish (*Scarus vetula* and *Sparisoma viride*, respectively; Gittings et al., 1992b). Leafy algal cover has remained below 3% since 1989 (Fig. 4).

Stress, indicated by coral bleaching, has also been reported on the banks (e.g., Hagman and Gittings, 1992), and is generally associated with anomalously warm summers when water temperatures rise above 30 C. In each case to date, however, recovery of symbiotic algae followed, without coral tissue mortality.

The reefs may also have experienced periodic invasion of nonnative species. Reef fish censuses conducted since 1994 (Pattengill et al., 1997) have documented the immigration of yellowtail snappers (*Ocyurus chrysurus*) and sergeant majors (*Abudefduf saxatilis*), species previously unknown or exceedingly rare on the banks. It is likely that the presence of production platforms on the shelf edge, as well as mooring buoy placement, has enhanced migration potential for these species. The long-term effects of these invasions remain to be determined.

Elasmobranch and turtle studies have demonstrated that the Flower Gardens may be critical habitat for scalloped hammerheads (*Sphyrna lewini*) and some other sharks, which annually school over the banks; for juvenile manta rays (*Manta birostris*), which frequent the banks and feed on plankton along the reef edges; and for loggerhead turtles (*Caretta caretta*), some of which may live on the banks as subadults (Childs et al., 1996).

Spawning studies have shown that, for seven coral species that broadcast larvae, the Flower Gardens may have the most predictable and prolific spawning of any reefs in the Caribbean Province (Gittings et al., 1992a). Species involved include *Montastraea franksi, M. faveolata, M. annularis, M. cavernosa, Diploria strigosa, Colpophyllia natans,* and *Stephanocoenia intersepta.* For these species, the reefs provide enormous numbers of larvae that become available for recruitment on other natural or artificial reefs in the northwest Gulf of Mexico. It is not known to what extent spawning reflects reef health, but it is likely that community longevity on these isolated banks can only be assured by persistent reproduction, which enhances resilience.

Discussion

With the exception of localized incidents that caused measurable changes in coral and algae cover at the Flower Gardens, very little change has been observed on these reefs.

Eakin et al. (1997) discussed the value of designing monitoring programs to accomodate the needs of both science and management and of involving managers and user groups in the development of such programs. Thanks to thorough surveys conducted prior to oil and gas exploration and production around the Flower Gardens and long-term research efforts designed to detect the impacts of such activities, more is known about the ecosystem of the Flower Garden Banks and its condition than most other geographically isolated coral reefs. Not only have these efforts demonstrated the continued health of the Flower Gardens reefs, but they have also ensured that resource managers have seldom had to rely on subjective criteria on which to base management decisions. In nearly all cases, regulations and other management actions have been based on interpretation of objective scientific data collected from the sites (see Gittings et al., 1997). For example, the requirement for shunting drill cuttings and fluids to the base of the rigs originated when it was discovered that currents in the region did not rise over the banks, but were steered around the features (see Rezak et al., 1985). Shunting to within 10 m of the bottom (80–100 m deep), therefore, would reduce the likelihood that sediment plumes would impinge on the coral reefs. It would also place the material in the nepheloid layer, a permanent, naturally turbid water mass on and around the base of the banks.

The Flower Garden reefs provide rare examples of the potential for compatibility between hydrocarbon development and resource protection. Hydrocarbon production has been occurring for nearly 20 yr in the immediate vicinity of the banks, yet the monitoring programs and related studies continue to attest to the apparent health of the ecosystem. Appropriate regulation by MMS in the early 1970s and vigilance by resource protection agencies and industry account for this success.

The level of production around the Flower Gardens has risen dramatically over the past decade or so. The 4-Mile Zone, depicted in Figure 1, currently contains 10 production platforms and approximately 161 km of pipeline (half of which are dedicated oil lines). There are 20 pipelines that either originate within, terminate within, or transit this zone. From 1984 to 1997, 13 pipelines were added to the 4-Mile Zone (K. Deslarzes, pers. comm.). Considering this, and the levels of visitation by dive charters and other users, it is vital that monitoring continue, first to alert resource managers and operators if conditions change, and second, so that scientists and managers can be in a position to determine the cause(s) of those changes, and aptly attribute responsibility.

Conclusion

The stability of benthic communities at the Flower Gardens, as well as their apparent resilience, is remarkable, particularly considering the low diversity of the community and the amount of industrial activity in surrounding waters. They attest to the lack of significant impacts by human activities to date, and perhaps to effective control by regulatory agencies. As pressures from industrial development, commercial fishing, and visitation continue to mount, however, it seems improbable that the condition of the reefs will remain robust without consequent modification of protective measures.

Reliance of management on science is the life-blood of effective resource protection. The concept is not new, but even resource management authorities as established as the National Park Service have had difficulty implementing it (National Research Council, 1992). It is critical that research and monitoring programs not only continue at the Flower Gardens, but that they evolve to address the challenges posed by changing patterns of use. It is only by continuing such efforts that objectivity and informed decision-making can be assured, and the goal of long-term protection can be realized.

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