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9D Refuges for corals in time and space

Flower Garden Banks – A Refuge in the Gulf of Mexico?

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Abstract. The East and West Flower Garden Banks contain the northernmost coral reefs in the continental United States and are part of a discontinuous arc of reefs and banks along the outer continental shelf in the northwestern Gulf of Mexico. They are located approximately 204 kilometers south of the Texas/Louisiana coast, and are managed by NOAA's Office of National Marine Sanctuaries. These deep, remote reefs thrive in an unlikely area, near the physiological edge of conditions required by hermatypic corals. The coral reef caps are dominated by large boulder corals at over 50% coral cover and harbor relatively abundant populations of associated fish and invertebrates. Mesophotic coral reefs thrive at depths to 50 meters and display an extraordinary 80% coral cover. The latest data from a 20-year term-monitoring program of the Flower Garden Banks reflects a continued flourishing coral reef system, but warns of possible anthropogenic and natural stressors that may threaten the high level of health of these reefs. Recent long-term monitoring data from the Flower Garden Banks supports the stability and resilience of these coral reefs, while the coral community at Stetson Bank show decline. Anthropogenic and natural stressors including fishing, pollution, hurricanes, and bleaching have affected the health of the reef at Stetson Bank and pose a threat to the reefs of the Flower Garden Banks. Other coral reefs and coral communities in this region, such as McGrail Bank, harbor significant mesophotic coral reefs. In an era of global decline in coral reefs worldwide, the northern Gulf of Mexico may provide a refuge for coral reefs and communities in the Caribbean.

Key words: Coral reef, Gulf of Mexico, Flower Garden Banks National Marine Sanctuary, long-term monitoring, mesophotic, invasive species

Introduction

In a global trend of declining coral reef health and cover, the northwestern Gulf of Mexico continues to harbor sites that exhibit high cover of healthy, productive coral reefs (Zimmer et al. 2010).

The Flower Garden Banks National Marine Sanctuary (FGBNMS) is located between 140 and 190 kilometers southeast of Galveston, Texas in the northwestern Gulf of Mexico. It is one of fourteen designated sites under the jurisdiction of the Office of National Marine Sanctuaries (ONMS), within the National Oceanic and Oceanographic Administration (NOAA).

Two geographically separated sites - the East Flower Garden Bank (EFGB) and West Flower Garden Bank (WFGB), were designated as the FGBNMS in 1992. Twenty-two (22) kilometers of open ocean and deep water habitat separate the two coral reefs. Stetson Bank, which is located approximately 48 kilometers to the northwest of the WFGB, was added to the FGBNMS in 1996.

The coral reef caps of the EFGB and WFGB harbor 1.85 kilometers² of coral reefs exhibiting 50% to 80% coral cover dominated by massive boulders

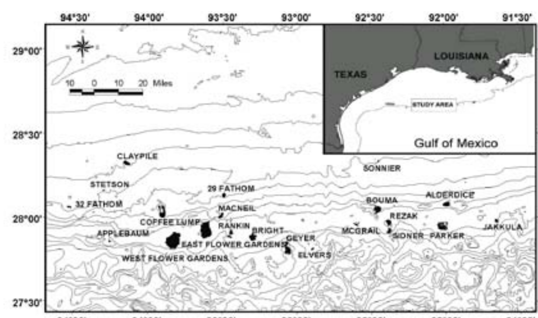

Figure 1: Reefs and banks along the continental shelf of the northwestern Gulf of Mexico

of star and brain corals (*Montastraea* spp., *Diploria strigosa*, *Colpophyllia natans*). The shallowest depth at the East and West FGB is 17 meters. They have been recognized as some of the healthiest coral reefs in the region (Lang et al. 2001).

The earliest recorded quantitative data for coral and other invertebrate cover were collected at the Flower Garden Banks in 1972 (Bright and Pequegnat (1974). The coral reefs of the EFGB and WFGB have been subject to frequent monitoring ever since, including annual evaluation since 1989 (Aronson et al. 2005).

Stetson Bank contains distinct claystone pinnacles running 457 meters on an east-west orientation that rise to depths of 17 meters. These pinnacles are dominated by sponges, algae, and *Millepora alcicornis*, but contain significant outcroppings of *Madracis decactis*, and scattered hermatypic corals. Beginning in 1993, the Gulf Reef Environmental Action Team (GREAT), comprised of researchers from Texas A&M University and the Department of Interior's Bureau of Ocean Energy Management (formerly Minerals Management Service) and volunteers, initiated a long-term monitoring program at Stetson Bank (DeBose et al. in review) and continues annually.

The banks of the FGBNMS are but three of dozens of reefs and banks spread across the outer continental shelf of the northwestern Gulf of Mexico (Rezak et al. 1985) (see Fig. 1). McGrail Bank, located 99 kilometers east of the EFGB, harbors a unique mesophotic coral reef dominated by blushing star coral (*Stephanocoenia intersepta*). The reefs and banks in the region harbor coral communities and deep coral habitats.

Naturally occurring stressors contributing to the overall level of health of the reefs include hurricanes that cause direct physical damage and increased coastal runoff. Invasive species, specifically the Indo-Pacific lionfish (*Pterois sp*.), is causing concern as a major stressor. Anthropogenic pressures include hook and line fishing, scuba diving, pollutant discharge, oil and gas activities, and illegal activities, such as spearfishing, and anchoring.

As natural and anthropogenic stressors threaten the future of coral reefs, discreet locations may be more resilient to the threats and emerge as important refugia worthy of elevated conservation and management. Monitoring can document the presence of intact ecosystems and has the potential for predicting refugia for coral reefs. Long-term monitoring at the Flower Garden Banks has been conducted since the early 1970s and has documented the stability of the reefs over time.

Material and Methods

Flower Garden Banks Long-Term Monitoring

As presented in Johnston et al. (in press), permanent 100 meter x 100 meter study sites have been established on the coral caps of both the EFGB and WFGB. The majority of the long-term monitoring data was collected within these areas on an annual basis. The monitoring program consists of a suite of techniques to evaluate the condition of the coral reef: repetitive photostations; random transects; fish surveys; invertebrate counts; measurement of coral growth rates; and water quality analysis. Forty repetitive quadrat photostations were originally established in 1989 at each bank and were selected to represent typical high cover of healthy coral features within the study site. These stations were photographed and analyzed at each study site to detect and evaluate long term changes in individual coral colonies. An additional nine repetitive photostations were installed in the mesophotic coral reef depths of between 30-40 meters. All repetitive photographs were assessed for substrate percent cover (coral, sponge, macroalgae, and CTB, consisting of crustose coralline algae, fine turf algae, and bare rock), using random points in the Coral Point Count program (CPCe) developed by Kohler and Gill (2006). Sixteen 10 meter randomly placed photographic and/or video transects were conducted at each study site. Random points using CPCe software were used to analyze percent cover, species composition, and dominance. A minimum of 24 Bohnsack-Bannerot (1986) fish surveys were conducted at each bank, and assessed for reef fish abundance, diversity, and biomass. These surveys were conducted in 15 meter diameter inferred cylinders from the seafloor to the surface. Fish species were listed in a five minute time period, after which the diver made one rotation per species and recorded abundance and total length. Spiny lobster (*Panularis argus* and *P. guttatus*) and sea urchin (*Diadema antillarum*) surveys were conducted at night in two 2 meter x 100 meter transects along the perimeter boundaries of the study site. Thirty (30) millimeter cores of mountainous star coral (*Montastraea faveolata*) were taken bi-annually for sclerochronology measurements. Cores were cut into 8 millimeter slabs along the longitudinal axis and x-rayed to reveal the low and high density band annual coupling. Ages were assigned by counting backwards from the most recently deposited colony surface toward older skeletal material. Extension distances were determined by measuring the distance between each annual high density band. Sea-Bird® temperature and salinity instruments were maintained on the coral cap at each site and collected measurements every 30 minutes.

Stetson Bank Long-Term Monitoring

As outlined in DeBose et al. (in review), permanent photostations, selected for their high coral cover and prominent positions at the site were established along the pinnacles of Stetson Bank. The photostations were photographed annually and analyzed for percent benthic cover (i.e. coral, sponge, algae, coralline algae, other), and species composition and dominance using random point counts in CPCe software. A Sea-Bird® temperature and salinity instrument was maintained at 23.5 meters depth at Stetson Bank which collects measurements every 30 minutes.

Additional Observations
The FGBNMS research team has conducted characterization of the reefs and banks of the northwestern Gulf of Mexico since 1998 using Remotely Operated Vehicle (ROV) surveys and scuba and has compiled a database of information of the regional resources. ROV transects were conducted at McGrail Bank. Stratified random surveys were conducted, during which photographs were taken of the substrate. Random points were used to determine coral cover and species composition. As part of their tasks conducted underwater, the FGBNMS research scuba divers record a variety of observations such as occurrences of bleaching, invasive species, new records, and notable sightings of rare species, or megafauna.

Results

Flower Garden Banks Long-Term Monitoring
Random transect results revealed high coral cover at both banks from 2009 to 2010, with coral cover ranging from 53% to 55% at the EFGB and from 54% in 2009 and 66% in 2010 at the WFGB.

From 2009-2010, macroalgae were more abundant than crustose coralline algae, fine turf algae, and bare rock (CTB), ranging from approximately 22-33%. The most abundant macroalgal taxa in terms of substratum cover were fleshy algae, thick turf algae, and *Dictyota spp*. Macroalgal cover was higher at the EFGB than the WFGB.

Annual accretionary extension of *M. faveolata* at the EFGB averaged 0.55 mm/year (range = 0.30-0.76). At the WFGB annual accretionary growth averaged 0.69 mm/year (range = 0.33-0.97). When compared to the past three coring events from WFGB (2003, 2005, and 2007), the 2010 data do not appear substantially different with respect to mean extension rates. However, there was a significant difference (α=0.05, p-value=0.0011) in the extension rate of cored colonies between the EFGB and the WFGB when comparable years (1998 to 2010) were analyzed. There was also a significant difference (α=0.05, p-value=0.0010) when all years (1991 to 2010) were analyzed.

In the deep repetitive quadrat photographs (30-40 meters), coral cover was high, averaging 82% between 2009 and 2010. The *Montastraea annularis* species complex and *M. cavernosa* were the dominant species in these quadrats. CTB averaged 7% at the deep stations from 2009 to 2010, while macroalgae averaged 10% during 2009-2010.

Fish surveys showed fish assemblages that were dominated by invertivorous fish, with healthy populations of herbivores, piscivores, and planktivores. A mean of 57 fish species were observed per bank per year in 2009 and 2010. From 2009 to 2010, the Pomacentridae, Labridae, and Serranidae were the dominant fish taxa at the EFGB and WFGB. Invertivores were the dominant fish guild, with Pomacentridae (damselfish) and Labridae (parrotfish and wrasses) representing the largest density. The size-frequency distributions of invertivores were non-normally distributed, with the majority of individuals occurring in the small size categories due to the dominant density of small damselfishes. Inter-annual comparisons of fish statistics indicated generally stable assemblages; however, diversity measures were significantly different at the WFGB between 2009 and 2010.

In 2009, surveys for *Diadema antillarum* documented 0.25 individuals/100 meter² and 0.5 individuals/100 meter² in 2010 at the EFGB. Higher densities were documented at WFGB from 2009-2010. In 2009 13.75 individuals/100 meter² were reported and 11.0 individuals/100 meter² in 2010. These populations have not recovered to pre-1984 levels which were approximately 140 individuals/100 meter² at EFGB and 50 individuals/100 meter² at WFGB (Gittings et al. 1988).

Bleaching affected the FGB coral reefs in 2005 (Eakin et al. 2010) and 2010. Both years experienced elevated water temperatures near or above 30°C for prolonged periods. The maximum temperature for EFGB in 2010 was 30.69°C and 30.64°C at WFGB. Preliminary qualitative 2011 observations suggest a full recovery for the EFGB and WFGB from the 2010 bleaching event.

Stetson Bank Long Term Monitoring
Benthic communities at Stetson Bank appeared relatively stable since monitoring began in 1993 until the early 2000s. In 2005, Stetson Bank was subjected to a Caribbean-wide bleaching event, impacts from Hurricane Rita, and increased nutrients in the water column from coastal runoff. As a result, from 2005-2008, the coral/sponge community of Stetson Bank has been in steady decline (Debose et al., in review). Total coral cover on the pinnacles at Stetson Bank, dominated by *Millepora alcicornis* and *Madracis decactis,* has fallen from a maximum of 32% in 1993 to a minimum of 7% in 2008. However, recent long term monitoring data suggests a small but gradual increase in total coral cover to 8% in 2009 and 11% in 2010. Mirroring the decline

in coral cover, macroalgae cover on these pinnacles has peaked since 2005, reaching a maximum of 63% in 2007 and declining to 53% in 2010.

The sponge community of Stetson Bank is dominated by *Ircina strobilina*, the percent cover of which has remained relatively stable over the duration of the long-term monitoring study. However, the historically dominant "chicken liver sponge", *Chondrilla nucula*, has undergone a steady decline from 15% in 1993 to <1% in 2010.

Additional Observations

At McGrail Bank, a series of unique mesophotic *Stephanocoenia* dominated reefs were documented. Living coral cover approached 28% of the benthic surface at depths of 44 to 52 meters in an area of at least 0.15 kilometers². Less prominent coral reef and coral communities have been verified at Bright, Geyer and Sonnier Banks, all located in the northwestern Gulf of Mexico. At Geyer Bank, 52 kilometers east of the EFGB, the invasive orange cup coral, *Tubastraea sp.*, has become well established, and has also been documented in surrounding reefs and banks outside of the sanctuary. In July 2011 the authors documented a large overhang at the WFGB with upwards of 75 *Tubastraea sp.* colonies. On July 21, 2011, the first lionfish, *Pterois sp.*, was documented within the boundaries of the FGBNMS. To date, 15 lionfish have been reported within the sanctuary boundaries, six of which have been removed through permitted activities.

Discussion

Consistently high living coral cover and other indicators of reef health continue to be reflected in monitoring investigations at the East and West Flower Garden Banks. While most coral reefs in the Caribbean region have undergone alarming deterioration, these isolated reefs in the northern Gulf of Mexico have yet to be significantly impacted. This may suggest that areas like the Flower Garden Banks could serve as refuges for coral communities in an era of global decline. It is of critical importance to coral reef science to identify and evaluate the conditions that have allowed these reefs to survive and thrive. Insulation from perturbations inherent to nearshore waters, and depth of the water column at the site have buffered the reefs from some impacts, and may lead to the continued prosperity of the reefs. The coral reefs of the EFGB and WFGB have demonstrated the ability to mostly recover from bleaching events that have resulted in devastating effects on reefs globally. Likewise, the mesophotic coral reefs of McGrail Bank have also demonstrated relative resilience due to their distance from shore and the depths of the coral communities.

Conversely, Stetson Bank, a mid-shelf reef much closer to shore than the EFGB and WFGB, has suffered a decline of important benthic components over the recent years, and may be moving towards an algae dominated state. The reasons for this phase shift are not well understood, but unlike the Flower Garden Banks, the site has not recovered from the bleaching events in 2005 and 2010. Hurricanes also appear to have more pronounced physical and coastal runoff impacts at Stetson Bank that may contribute to the decreased resilience of this site. This is probably due to the increased vulnerability of the substrate type (soft siltstone/claystone) and its closer proximity to shore. The lionfish invasion at Stetson Bank is of particular concern as this site harbors large populations of small and juvenile fish, which will be at risk of predation at a higher rate than pre-invasion conditions. This may exacerbate or accelerate the decline in the conditions at Stetson Bank (Albins and Hickson 2008, Lesser and Slattery 2011).

Other Caribbean reefs that have historically displayed high coral cover are now showing overall coral cover decreases mainly due to bleaching and/or coral disease. There are very few areas that have maintained high levels of coral cover in recent years. Curaçao still contains some reefs with up to 55% (ranging from 3% to 55% across 21 sites - Vermeij, Pers. Comm.). In contrast, Bonaire has reported a recent 10% decrease in coral cover to 38% in 2011 (Steneck et al. 2011), and the Florida Keys is maintaining an average of approximately 7% coral coverage, with ranges from about 3% to 20% across sites (ONMS 2011). The Cuban reefs within Jardin de la Reina range from 7-19% cover (Pina Amargós et al. 2008).

It is interesting to speculate that high latitude coral reef areas, such as the Flower Garden Banks, may act as a refuge for corals in space and time, as continued global climate change affects the historical range of coral ecosystems. However, for this to occur, conditions must be maintained at an optimal level. A combination of bleaching, coral disease, and two major hurricanes (Katrina and Rita) impacted the FGBNMS resources in 2005. The impacts to the reefs from these events and subsequent events such as Hurricane Ike in 2008 and the bleaching event of 2010, serve as warning signs to the scientists and managers.

The long-term monitoring of the reefs within the FGBNMS may provide a type of "sentinel" for the regional implications of climate change. Other shelf-edge locations in the region such as McGrail, Geyer, and Bright Banks, while not containing extensive coral reefs at this time, may provide additional refuge for future development of coral ecosystems. Recent declines at Stetson Bank may indicate that the mid-shelf banks will be more susceptible to impacts from hurricane activity, coastal runoff, and elevated water temperatures.

The coral reefs and coral communities of the FGBNMS have displayed remarkable health and stability since they were first surveyed in the 1970s. However, there are recent warning signs that indicate potential problems on the horizon regionally. Meanwhile, the FGBNMS will attempt to manage impacts that are subject to human control, so that hopefully reefs can maintain a level of health and resilience necessary to respond to events that are not controllable. It is critical that resource managers be able to take proactive actions in order to maintain the level of ecosystem health. Only time will tell whether or not the coral reefs and associated habitats of the Flower Garden Banks National Marine Sanctuary and shelf-edge reefs and banks of the northwestern Gulf of Mexico can maintain resilience and provide a refuge in this age of global reef decline.

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