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# Post-hurricane assessment (Hurricane Rita, September 2005) and recovery at the East Flower Garden Bank, Northwestern Gulf of Mexico

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**Abstract.** Hurricane Rita, a category 3 storm, passed within 83 km of the Flower Garden Banks (FGB) on September 23, 2005. Prior to that, in August 2005, Flower Garden Banks National Marine Sanctuary (FGBNMS) staff observed coral bleaching on the reef cap (18-23 m). In November 2005, we assessed hurricane damage and the effects of the bleaching event at the East Flower Garden Bank (EFGB) long-term monitoring site (Aronson et al. 2005). In June 2006, we conducted monitoring which included methods employed in November 2005. Hurricane Rita removed ~1.5% of coral colonies in repetitively photographed quadrats (mostly *Diploria strigosa*, *Porites astreoides*, and *Montastraea* spp.; sizes: 76 to 6,448 cm$^2$. Monospecific areas of *Madracis mirabilis* experienced catastrophic levels of breakage and toppling. Furthermore, ~10% of coral colonies (mostly *Montastraea annularis* species complex, *M. cavernosa*, and *Millepora alcicornis*) were bleached, an unprecedented bleaching level at the FGB since 1990 when ~5% of corals bleached (Hagman and Gittings 1992). Corals in deeper photo-quadrats (on the reef slope at 32-40 m) exhibited less bleaching than on the reef cap. The passage of Hurricane Rita caused water temperature to drop by 2-3°C, a hiatus in the prolonged thermal stress (> 30°C) which lasted 38 days. In June 2006, reef cap corals had largely recovered from the bleaching event of the previous summer, with bleaching closer to normal levels ~1%, while coral cover values and species relative abundance, remained stable.

**Key words:** Hurricane Rita, 2005, Gulf of Mexico, coral reef, damage, impact, bleaching, scouring, recovery.

## Introduction

Hurricane-force tropical cyclones have frequently entered the Gulf of Mexico and traversed the East and West Flower Garden Banks (EFGB: 27°54'N; 93°35'W; WFGB: 27°52'N; 93°48'W) (Scholten and Deslarzes 1988). During the 20th century, severe hurricanes (Categories 4 and 5 on the Saffir-Simpson Index) may have moved through the FGB region (within ~250 km of the FGB) in 1900, 1909, 1915, 1957, 1961 (Category [Cat] 5), 1964, 1974, 1979, and 1980 (Cat 5). In August of 1980, Hurricane Allen, with a >5-m surge and wind speeds of 96 km/hr, caused physical damage to the coral reefs of the FGB long-term monitoring site (C. Combs, pers. comm., 1990).

The 2005 hurricane season in the Atlantic was the most active to date, fueled by record high sea-surface temperatures. Eleven tropical cyclones entered the Gulf of Mexico in 2005. On September 23 Hurricane Rita passed within 83 km of the FGB as a Cat 3 hurricane (Fig. 1); the other 10 storms passed more than 500 km away (The Weather Underground 2005).

Preliminary assessments of the FGB coral reefs following Hurricane Rita included substantial mechanical impacts, evidence of fractured and displaced corals (one dislodged colony was 4 m across and 2 m in height), sediment-scoured corals bordering large sand flats, and corals gouged and damaged from water-borne projectiles (Fig. 2, 3, 4). Impacts of Hurricane Rita at the FGB were preceded and followed by other natural disturbances: extreme seawater warming from August through November 2005 causing coral bleaching (48% of coral colonies were either partially or totally bleached) and the offshore transport of river runoff from the Texas-Louisiana coast after the storm (NOAA CoastWatch 2005).

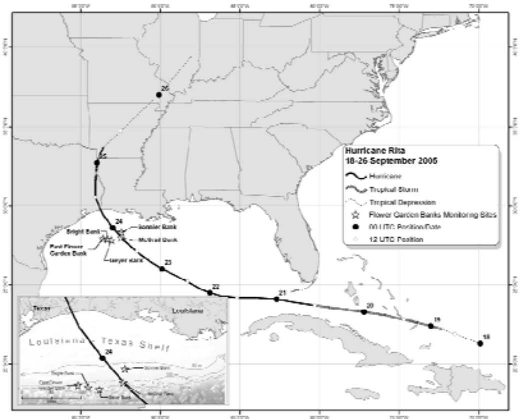


Figure 1: Track of Hurricane Rita, 18-26 September 2005 (National Hurricane Center 2006).

Figure 2: Sediment-scoured corals at the edge of a sand flat at the EFGB in October 2005. The scouring and sand removal were caused by the passage of Hurricane Rita on 23 September 2005. Photo by E. Hickerson, FGBNMS.

Figure 3: Coral colony gouged by waterborne projectiles during Hurricane Rita on 23 September 2005. Photo by E. Hickerson, FGBNMS.

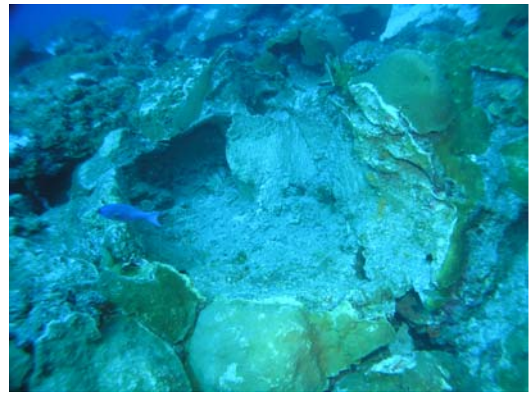

Figure 4: Footprint of a coral colony dislodged from the FGB reef cap by Hurricane Rita on 23 September 2005. Photo by E. Hickerson, FGBNMS.

In order to assess the impacts of both Hurricane Rita and the thermal stress on the benthic community at the EFGB, we made before-and-after comparisons of repetitive photographic quadrats, video footage of monitoring site perimeter lines, and of temperature and salinity data on the reef cap (turbidity, pH, DO, and Photosynthetically Available Radiation [PAR] data were lost to the storm).

**Material and Methods**

Repetitive Quadrats: To assess changes in the coral assemblage due to Hurricane Rita and bleaching, we photographed repetitive 8-m$^2$ quadrats within the 100 m x 100 m long-term monitoring site (18-23 m) and associated deep stations (32-40 m) in November 2005 (Gittings et al. 1992). The percent cover of benthic components was analyzed using CPCe® point-count software with Excel extensions (Kohler and Gill 2006) for repetitive photographs taken in June 2005, November 2005, and June 2006. Benthic components assessed included coral species cover, bleaching, paling, concentrated and isolated fish biting, and disease; as well as the cover of macroalgae, turf, and crustose, coralline and bare cover (CTB). We also used planimetry (Sigma Scan Pro 5®) to analyze selected corals within repetitive quadrats between June 2005 and November 2005. The goal of this analysis was to determine whether dominant framework-building corals of the FGB (*Montastraea annularis* species complex, *Diploria strigosa*, and *Colpophyllia natans*) grew or lost tissue laterally and to quantify the amount of coral cover lost due to the storm. Descriptive statistics were used to characterize the effects of Hurricane Rita within 8-m$^2$ repetitive quadrats.

Perimeter Lines: Perimeter lines around the 100 m x 100 m site were videotaped and a general sense of coral condition was obtained between June and November 2005. Divers videotaped two 100 m segments of the perimeter lines at the East Bank (north and east margins) in November 2005.

Perimeter lines were analyzed for hurricane effects such as toppling, removal, or breakage of coral heads, and thermal stress effects including coral disease, bleaching, paling, isolated and concentrated fish biting. These analyses were qualitative and therefore no statistical analyses were conducted.

Hydrological Data: We used YSI 6600 Series datasonde and a HoboTemp thermograph deployed on EFGB reef cap to examine temperature and salinity (specific conductance) data in June and November 2005. Storm damage done to the sensors prevented us from examining other data (turbidity, pH, DO, and PAR).

**Results**

Coral cover within repetitive quadrats on the EFGB remained high in November 2005 at approximately 61%, and species relative abundance showed continued stability with *Montastraea annularis* species complex, *Diploria strigosa*, *P. astreoides*, and *M. cavernosa* as the four dominant species (Fig. 5). Approximately 1.5% of coral colonies within repetitive quadrats were missing, most likely due to the effects of Hurricane Rita. This did not noticeably affect coral-cover estimates, which did not vary substantially from June 2005 (Fig. 5). *Diploria strigosa*, *Porites astreoides*, and *Montastraea* spp. comprised the majority of missing coral colonies with sizes ranging from 78 to 6,296 $cm^2$.

The most noticeable difference in the study site repetitive quadrats photographed at the East Bank in November 2005 compared to June 2005 was the level of bleaching: 9.74% (± 1.07 SE) in November and 0.57% (± 0.18 SE) in June. Most bleaching occurred on colonies of *Montastraea annularis* species complex, *M. cavernosa*, and *Millepora alcicornis*. Paling and fish biting measurements were low at 1.48% or less, and disease was not observed. In June 2006 bleached corals had recovered and bleaching levels were low (0.62% ± 0.24 SE), and little disease was documented consistent with November results.

From June 2005 to November 2005 algae group dominance changed. In June 2005 macroalgae was high at 24%, while crustose coralline and bare cover (CTB) was lower at 10%. After the hurricane, in November 2005 the inverse relationship between macroalgae and CTB was evident, with 24% CTB and 13% macroalgae (mostly turfs <3cm). Macroalgal cover is seasonally influenced and with the passage of Hurricane Rita it is likely that macroalgae were removed from the substratum (except short turfs). In June 2006 macroalgae and CTB were similar in cover (18 and 17% cover respectively), however, crustose coralline algae appeared to be higher in June 2006 (~11%) while the macroalgae group was dominated by *Lobophora lobata* instead of turfs.

Twenty-one coral heads from the 40 quadrats photographed within the 100 m x 100 m study site were removed between June 2005 and November 2005. Measurements of all missing corals were made from the June 2005 photographs to obtain a total area of coral cover loss. A total of ~3 $m^2$ of coral cover was removed from the 40 quadrats between June 2005 and November 2005; which amounted to a loss of 1.5% of the coral colonies in repetitive quadrats on the EFGB coral cap (18-23 m).

Among the nine reef slope (32-40 m) quadrats photographed in November 2005, 0.5% of coral colonies (2 colonies) were missing. There was also less bleaching (3.1%) compared to the reef cap quadrats. Coral cover remained high (74.5%) on the reef slope, and the dominant corals were *Montastraea annularis* complex, *M. cavernosa*, *Colpophyllia natans*, and *Diploria strigosa*.

Corals along the EFGB study site perimeter lines showed evidence of hurricane impacts, including the dislodgement, loss, or redeposition of entire coral heads as well as breaking of corals, and abrasion on the reef. There was evidence of bleaching and fish biting. Most distressed corals were affected by bleaching (6.4%), with slightly fewer incidences of fish biting (1.2%). As in June 2005, *Montastraea faveolata* and *M. franksi* were the most affected coral species. No evidence of disease was observed in November 2005. Physical damage was observed at several locations along the north perimeter line in November 2005. A partially bleached, dislodged colony of *Montastraea faveolata* was deposited along the perimeter line (Fig. 6). Several colonies of *Diploria strigosa* were either shattered or completely dislodged.

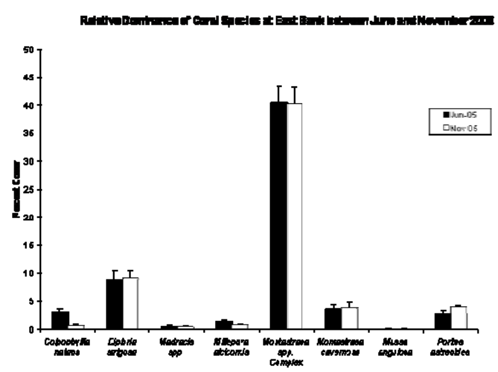


Figure 5: Relative dominance of coral species at EFGB between June and November 2005.

With the passage of Hurricane Rita, there was a sudden drop in temperature on the reef caps of the East and West Flower Garden Banks (Fig. 7). The temperature dropped from 29.6 °C at 0033 hours to 27.4 °C at 1933 hours on 23 September 2005. Temperature rose gradually after the passage of the hurricane. By 0733 hours on 24 September, the temperature on the reef cap had reached 28.4 °C. During the passage of Hurricane Rita, mean daily salinity at the East Bank was 35.7 NTU.

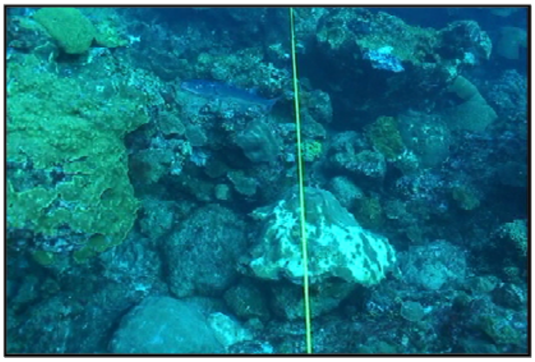

Figure 6: Photographs of a partially bleached *Montastraea faveolata* colony redeposited along the study site perimeter line.

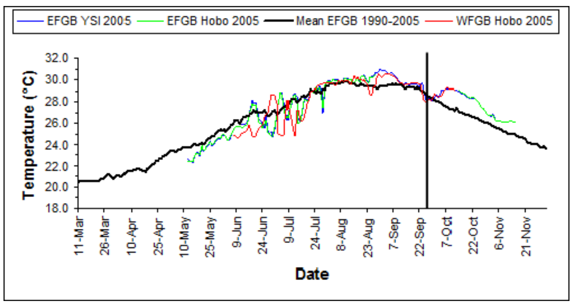


Figure 7: Water temperature at the Flower Garden Banks in 2005 and mean temperature at the EFGB from 1990 to 2005. Water temperature was measured using YSI 6600 Series datasondes (YSI) and HoboTemp recorders (Hobo). A vertical line drawn through the temperature profiles shows the timing of the passage of Hurricane Rita near the FGB (September 23, 2005). The 1990-2005 data are from Gittings et al. 1992, CSA 1996, and Dokken et al. 1999, Dokken et al. 2003, Precht et al. 2006, and Precht et al. 2008a.

**Discussion**

Mean daily significant wave height at NOAA data buoy 42019 was 4.5 m as Hurricane Rita passed by the EFGB. Depth, measured by the YSI instrument on the EFGB reef cap, rose from 23 to 25 m from 0300 hours on 23 September to 0400 hours on 24 September. The highest point of the storm took place at 2000 hours on September 23 when maximum wave height reached 5.9 m at buoy 42019. The intensity of Hurricane Rita at the FGB was evidenced by physical effects, including the large amounts of sediment removed from sand flats, the dislodgment of corals, and the gouging of corals. Current velocity and direction, measured by current meters placed near the sea surface on Texas Automated Buoy System (TABS) "Buoy V" located near the EFGB, and "Buoy N", located near the WFGB, provide another way to estimate the power of the storm. Buoy N recorded data up until 0830 hours on 23 September; current velocity at that time was 58.09 cm/sec. Current velocity was 57.6 cm/sec at 1100 hours at "Buoy V" (Bender et al., pers. comm., 2005). At the EFGB, water moved in a southeasterly and southerly direction at speeds ranging from 19.7 to 57.9 cm/sec from 23 to 24 September. The current direction recorded at the TABS buoys corroborates our observations at the EFGB of permanent stainless-steel station markers bent in a southerly direction.

In 2005, corals at the FGB were exposed to a prolonged period of thermal stress that was interrupted by the passage of Hurricane Rita. Thermal conditions on the reef cap were unquestionably more severe in 2005 than the average temperature at the FGB recorded to date. The temporary cooling of the reef cap as Hurricane Rita swept through the FGB region was likely the result of the mixing of cold deep water with the warm superficial water (the upper 50 m). At the foot of the FGB (~100 m), seawater temperatures average 19°C. Further down in the water column at 130 m, average water temperature is about 15°C (Nowlin et al. 1998).

Following Hurricane Rita 4 to 6 in of rainfall was recorded along the Mississippi and Atchafalaya rivers on 24 September 2005. Other areas along the coast of Louisiana experienced up to 12 in of rainfall on September 24. Satellite imagery of total suspended matter in the northwestern Gulf of Mexico showed that nearshore water associated with the high levels of precipitation was driven across the shelf and onto the shelf edge, including the area of the FGB. The discolored water seen reaching the FGB could have contained pollutants delivered directly into the northern Gulf of Mexico from industrial sites. Such pollutants include >0.14 $km^3$/yr of sewage effluent from municipalities, and routine discharges from petroleum refineries and petrochemical plants (Weber et al. 1992) and materials contained in 610 $km^3$/yr of discharge from the Mississippi and Atchafalaya Rivers (Dai and Trenberth 2002). Coastal and river-borne pollutants may include inorganic nutrients, organic carbon, insecticides and herbicides, and pathogens.

Hurricane Rita affected corals at the EFGB (18-23 m) in a number of ways. Approximately 1.5% of coral colonies photographed at the East Bank were missing from repetitive quadrat stations. *Diploria strigosa*, *Porites astreoides*, and *Montastraea* spp. comprised the majority of missing coral colonies, with sizes ranging from 0.95 to 80.61 $cm^2$. Approximately 0.5% of coral colonies at the deep stations (32-40 m) were missing. The field of *Madracis mirabilis*, which occurs at a similar depth to the deep stations, suffered severe breakage and damage during Hurricane Rita, but was recovering in June 2006 with new growth extending from the rubble. Corals within the deep repetitive quadrats are mainly plating morphologies and, therefore, may not be as susceptible to breakage as more fragile, branching morphologies, such as *M. mirabilis* (but see Aronson et al. 1994).

Regional warming in 2005 produced coral bleaching at locations throughout the western Atlantic including Trinidad and Tobago, the BVI, Florida, and the FGB. Sea temperatures at the EFGB were elevated above 30°C, the HotSpot bleaching threshold for the FGB, for 38 days from 30 July to 8 September 2005. Although bleaching events are a natural occurrence, the increased frequency and severity of bleaching events is of concern because the likelihood of bleaching-associated mortality increases with exposure (Hoegh-Guldberg 1999). Additionally, higher temperatures have been linked to increased virulence of marine pathogens implicated in coral diseases (Harvell et al. 2002). We documented unprecedented coral bleaching at the EFGB in November 2005. Repetitive quadrats photographed at that time showed ~10% bleaching of the coral population, a marked increase from June 2005 (Hagman and Gittings 1992). Video perimeter results showed similar bleaching rates and similar differences in relation to video perimeter data taken in June 2005.

Despite the loss of corals, coral cover remained high on the reef cap (61%) and at the deep stations (74.5%). A comparison of shallow study site quadrats with deep station quadrats showed different bleaching patterns and hurricane impacts related to depth. Shallow quadrats had higher levels of bleaching (10%) and experienced a loss of 1.5% of coral colonies. The deep quadrats had lower levels of coral bleaching (~3%) and approximately 0.5% of coral colonies were missing.

The comparison of June 2005 with post-hurricane assessment data collected in November 2005 and June 2006 at the EFGB showed that coral cover within the established long-term monitoring study site remained relatively constant and species relative abundance showed stability with *Montastraea annularis* species complex, *Diploria strigosa*, and *Porites* spp. as the dominant species (Precht et al. 2008). In June 2005 macroalgae was high at 24%, while CTB was lower at 10%. After the hurricane, in November 2005, the inverse relationship between macroalgae and CTB was evident, with 24% CTB and 13% macroalgae (Precht et al. 2008a). By June 2006 macrolagal populations were reestablished while crustose coralline algae increased (Deslarzes et al. unpublished data).

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