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Post hurricane dynamics and status of coral reefs St. Croix, US Virgin Islands

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Abstract. To protect the vitality of Caribbean reefs, it is important to understand the physical and biological factors affecting the status of corals. Hurricane Hugo caused extensive damage on the island of St. Croix, US Virgin Islands in 1989. Underwater transects were set up on Tague forereef in 1989 and 2007 to study the coral species. The data show that there was an increase in both overall live coral species richness and total live coral present on Tague forereef eighteen years after Hurricane Hugo. These data were also compared with those collected on the south forereef of Buck Island Reef National Monument to assess the state of a protected reef after the hurricane. No significant difference was found between the percentage of live coral cover on Buck Island south forereef and Tague forereef in 2007. This suggests that marine protected areas alone cannot prevent the degradation of Caribbean coral reefs, and more effort must be placed on large-scale prevention of tidally transported coral-damaging factors.

Key Words: Caribbean, Hurricane, Marine Protected Area

Introduction

Hurricanes are acute physical factors that have immediate effects on the dynamics of coral reefs (Bythell et al. 1993b; WS1 2008). The intensity of hurricanes is escalating (Lugo 2000; Aronson and Precht 2006; WS1 2008)—under doubled CO_2 conditions they are estimated to be 10-20% stronger (Kleypas et al. 2001). Strong currents, large tidal ranges and transported debris can knock over large branches, roll heads of coral and smother live coral polyps (Bythell et al. 2000). According to the Intermediate Disturbance Hypothesis (Connell 1978) hurricanes can have positive effects—when of intermediate frequency—on coral reefs by clearing suitable substrata for new coral recruits that might have otherwise been outcompeted for space (Bythell et al. 2000). However, the analysis of the long-term consequences of major physical effects of storms is complicated by chronic biological factors (Bythell et al. 1993a; Bythell et al. 1993b; Bythell et al. 2000; Humann and DeLoach 2002; Aronson et al. 2005; WS1 2008).

On September 17-18, 1989, Hurricane Hugo raged over St. Croix for more than 12 hours (Hubbard et al. 1991; Bythell et al. 1993a). The category 4 storm was the first hurricane since 1928 to directly hit the island of St. Croix (Hubbard et al. 1991; Bythell et al. 1993a; Bythell et al. 2000). The near-shore reefs on St. Croix endured large waves, estimated at 6-7 m in height on Tague Reef, which caused erosion and increased sediment transfer (Hubbard et al. 1991). This study aims to analyze the effects of a major disturbance on the reefs of St. Croix.

Caribbean coral reefs have undergone a phase shift from coral to algal dominance since the late 1970s (Aronson and Precht 1997; Graham et al. 2006). These shifts have primarily been attributed to over-fishing as well as the Caribbean-wide disease related die-off of the echinoid, *Diadema antillarum* in 1983-1984 (Humann and DeLoach 2002; Aronson and Precht 2006; Mumby et al. 2006). Without the presence of the dominant algal grazer, *D. antillarum,* on Caribbean reefs, herbivorous fish such as parrotfish and surgeonfish, have become the dominant macroalgal grazers. Most marine protected areas (MPAs), such as Buck Island Reef National Monument (BIRNM), are primarily established to protect over-fished populations of tropical fish (Hughes et al. 2002). By restoring the abundance of herbivorous fish, MPAs are proposed to protect corals by increasing the grazing pressures on the macroalgal communities thus allowing colonization space for coral recruits (see Aronson and Precht 2006 for a review of related studies). Comparison of data from protected and unprotected reef sites on St. Croix suggests that the protection of a reef alone does not allow for a higher colonization of hard corals.

Materials and Methods

St. Croix Island is located in the Caribbean Sea and is a part of the USVI (Fig. 1A). Tague forereef protects the northeast shore of the mainland in an east-west orientation.

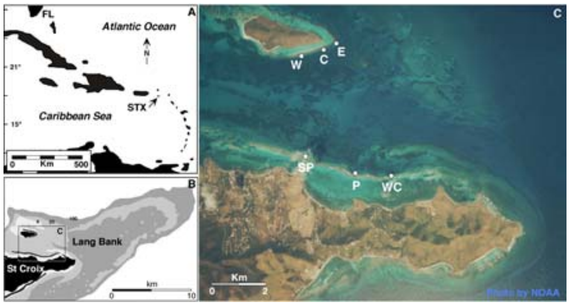

Figure 1: Map showing study localities: A) Island of St. Croix . B) Buck Island Reef National Monument and Tague Reef. C) Three study sites on Tague Reef and Buck Island south forereef. Tague Reef localities are Whaler Cut (WC); Platform (P); and Solar Panel (SP). Sites on Buck Island south forereef are West (W), Center (C), and East (E).

BIRNM is located 2.5 km off the northeast coast of St. Croix. Established as a National Monument in 1961, the continuous barrier reef forms an arc on the north and south-east side and protects the island from a primarily easterly wave action (Hubbard 1991). The southern forereef (Fig. 1C) has been monitored since 1988. The south forereef is usually protected from 'near-miss' hurricanes due to its proximity to the mainland of St. Croix, but when Hurricane Hugo passed directly over the island, BIRNM south forereef was hit harder than any other on St. Croix (Hubbard et al. 1991; Bythell et al. 1993a).

In the winter of 1989-1990, about three months after Hurricane Hugo struck St. Croix, data were collected at three locations on Tague forereef (Fig 1C) (Hubbard 1991; Hubbard et al. 1991; Hubbard pers. comm. 2007).

New data collections during the summer of 2007 were performed at the same three locations on Tague forereef—located by GPS—and at an additional three locations on Buck Island south forereef (Fig. 1C) (Fisco 2008). A meter tape was used to measure every contour and type of substrate—live coral, dead coral, coral rubble, sand and pavement—along the horizontal chain transects. The species of live coral, dead coral and coral rubble was recorded.

An assessment of the total live coral of each species was performed between 1989 and 2007, and differences in species richness and dominant species were noted. The species composition and total percent live coral cover of the substrate were compared between Buck Island south forereef and Tague forereef to assess the differences between a protected reef and one that is not.

Results

The results of this research are of two kinds. The first set of data analyzes the trends in species richness at the three Tague forereef locations between 1989 and 2007. This includes an analysis of low relief vs. high relief species. Low relief species are smaller species of coral which form encrusting colonies, up to 0.6 m in diameter, and therefore are not significant reef builders (Humann and DeLoach 2002). High relief species are those which grow to be as big as 4 m in diameter and add significantly to the structure of the reef (Humann and DeLoach 2002). The second set of data shows trends in total live coral cover between 1989 and 2007 at the three Tague forereef locations as well as a comparison of live coral between Tague forereef and Buck Island south forereef.

Trends in Species Richness

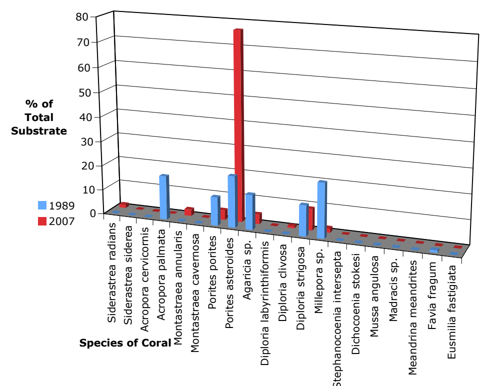

Figure 2: Comparison graph showing the percentage of total live coral of each species between 1989 and 2007 at 3 m depth, averaged between the three locations: Solar Panel, Whaler Cut and Platform.

The 3 m depth transects did not display a large species number influx in the eighteen years between Hurricane Hugo and the 2007 survey. On average, only one more species was found at the 3 m depth (Fig. 2). *Favia fragum* died out completely, as did *Acropora palmata*. *Siderastrea radians, Montastraea annularis,* and *Diploria clivosa* are three smaller, low-relief coral species that were not represented in the 3 m assemblages in 1989 but were present on the reef in 2007.

With a total of four species, the number of species of corals at 6 m was relatively low in 1989, this number more than doubled by 2007 with thirteen species present in the three locations (Fig. 3). In both 1989 and 2007, *Porites porites* represents the highest proportion of live coral present at 6 m on Tague forereef. In 2007, the low relief species *Agaricia* sp. (22.5%), *Siderastrea radians* (15.7%) and *P. asteroides* (15.4%) were relatively dominant. All of the species present at the 6 m depths are considered low relief, non-framework building corals. Although no species had died out, eight new species had colonized the 6 m depth of Tague forereef by 2007.

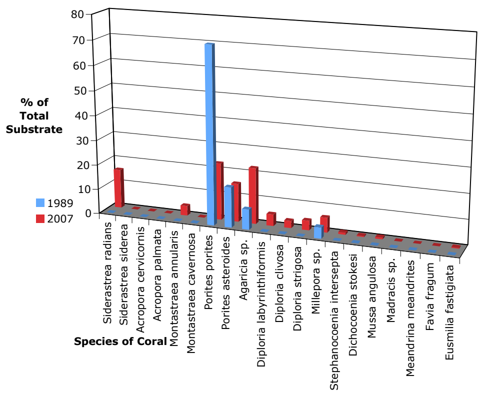

Figure 3: Comparison graph showing the percentage of total live coral of each species between 1989 and 2007 at 6 m depth, averaged between the three locations: Solar Panel, Whaler Cut and Platform.

The 9 m depth also showed an overall trend of increasing species richness. While only four species were recorded in 1989, the 9 m depth experienced a threefold jump in number of species to twelve species in 2007 (Fig. 4). In one of the transects, Whaler Cut 6 m, 100% of the live coral assemblage was composed of *M. annularis* in 1989. In 2007, at this same transect, the *M. annularis* population accounted for only 8.3%, while *Porites porites*, a smaller branching coral, dominated the assemblage with 32.2% of the live coral cover.

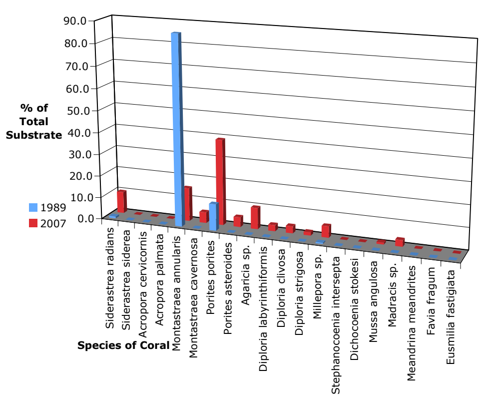

Figure 4: Comparison graph showing the percentage of total live coral of each species between 1989 and 2007 at 9 m depth, averaged between the three locations: Solar Panel, Whaler Cut and Platform

Trends in Live Coral Cover

Table 1: Total percent of the reef composed of live coral cover in 1989 and 2007.

Year	Total % Live Coral
1989	10.5%
2007	12.3%

On average, the total amount of live coral present on Tague forereef increased by 2.3% in the eighteen years after Hurricane Hugo (Table 1). Although an increase was observed, the percent of live coral present on the reefs in both studies was very low.

Table 2: Percent live coral cover of total substrate by location and depth on Tague forereef. Depths that experienced an increase in coral cover over the 18-year period are underlined.

Depth	Year	Location		
		Solar Panel	Whaler Cut	Platform
3 m	1989	6.6%	2.6%	3.2%
	2007	*22.3%*	*6.2%*	*7.7%*
6 m	1989	9.0%	26.8%	10.9%
	2007	*16.1%*	9.0%	7.2%
9 m	1989	0.0%	18.4%	17.3%
	2007	*1.9%*	7.6%	9.1%
Average	1989	5.2%	15.9%	10.5%
	2007	*13.4%*	7.6%	8.0%

Though there was a general trend towards increasing species richness in all but one transect between 1989 and 2007 (Fig. 2-Fig. 4), the Whaler Cut and Platform transects showed a decrease in the average percent of live coral cover (Table 2). The Whaler Cut 6 m transect showed the greatest change in coral cover—a 16.8% *decrease* in live coral cover occurred between 1989 and 2007. All of the depths at the Solar Panel transect showed a relatively large increase (an average increase of 8.2%) in live coral.

Table 3: Average total live coral measured between Buck Island south forereef and Tague forereef in 2007. The percent of the substrate covered by live coral cover is listed in parentheses.

	Average total live coral measured (m)	
Depth	Buck Island	Tague Reef
3 m	2.15 (15.7%)	1.60 (14.2%)
6 m	1.71 (10.9%)	1.64 (12.9%)
9 m	1.67 (10.4%)	1.21 (9.8%)
Average	1.84 (12.3%)	1.48 (12.3%)

In 2007, there is almost no difference (0.36 m) between the total amount of live coral present on Tague forereef and Buck Island south forereef. The average percent of the substrate covered by live coral is the same on Buck Island National Monument and Tague forereef (Table 3).

The coral species present at each reef are different but on the whole, the reefs of St. Croix and Buck Island south forereef contain relatively small, non-framework building corals.

Discussion

Because of the close interaction between humans and the natural environment, it is important to understand how ecosystems react and respond to major disturbances such as hurricanes so that we can try to adjust and plan accordingly.

In a paper detailing the effects of hurricanes in the Caribbean, Lugo (2000) discusses the impacts on terrestrial vegetation. The pattern witnessed by Lugo (2000) closely resembles that of the Intermediate Disturbance Theory proposed by Connell (1978). At first, in terrestrial environments, there is massive mortality of vegetation over a short time period (Lugo 2000; Done, 1999). This mass mortality is followed by a delayed pattern of tree mortality (Lugo 2000). The final step is a high turnover of terrestrial species.

The reefs of St. Croix post-Hurricane Hugo are a good example of Lugo (2000) and Connell (1978)'s models. At first, Bythell et al. (1993a) recorded a loss of 40-46% of the pre-hurricane live coral cover on Buck Island south forereef. Hubbard et al. (1991) also reported near total destruction of the south facing reefs on Buck Island. Next, Bythell et al. (2000) found that the coral abundance on the reefs of St. Croix remained in the immediate post-hurricane condition for two to three years before returning to approximate pre-hurricane levels by June 1991 (Bythell et al. 1993a).

Lugo's last observation is clearly demonstrated, as there were only two locations at which the dominant coral species did not change in the eighteen years between the two studies on Tague forereef, and species richness increased in all but one transect. Bythell et al. (2000) found that the recruitment of coral species on the south side of BIRNM was strong following Hurricane Hugo. The massive sediment transfer, reported by Hubbard et al. (1991) on the reefs of St. Croix could allow for settlement 'colonization gaps' in which new recruits with better regeneration strategies could settle and flourish. Bythell et al. (2000) found that the area most severely impacted by hurricane disturbance demonstrated the greatest increase in species richness of all the sites studied due to high recruitment of uncommon species into the newly cleared niches. These high recruitment rates are essential to sustaining the ability of the reefs to re-establish complex communities in the wake of hurricane damage (Bythell at al. 2000).

An apparent shift has occurred from high relief, framework building corals to smaller, low relief, non-framework building corals, soft corals and macroalgae (Aronson and Precht 1997; Done 1999; Aronson and Precht 2006). Population modeling suggests that an increase in the frequency and/or the intensity of disturbances should tend to skew size frequency distributions towards smaller size classes of organisms (Done 1999). These population models could help explain why there was a large increase in dominance of small, low relief coral populations on the reefs of St. Croix.

Reef building by larger corals is very important for reefs to cope with global sea level change (Grigg 1998; Kleypas et al. 2001). Globally, there are many documented cases where reefs have failed to keep up with Holocene sea-level rise and subsequently contain no live corals (Kleypas et al. 2001). The rate of reef growth in these cases was too slow to keep the corals and their algal symbionts in the photic zone. The production of calcium carbonate by larger, high relief, branching corals also provides topographical complexity, including nooks and crannies that support the vast number of reef species.

BIRNM has been nationally protected for 46 years, but no significant difference was found between the percent live coral cover on Buck Island south forereef and Tague forereef (Table 4). In a study conducted concurrently with this study, and at the same locations on Tague forereef and Buck Island south forereef, Burpee (2007, pers. comm.) found that the ban on fishing established on BIRNM has been successful in protecting the herbivorous and predatory fish populations. Overall, he found that the parrotfish on Buck Island south forereef are larger and in higher abundance than those on Tague forereef. Common sense and many scientific studies lead to the conclusion that the increase in size and number of grazers would produce a decrease in macroalgal cover and provide suitable settlement substrata for new corals (Mumby et al. 2006; see also Aronson and Precht 2006 for a review of related studies). As Table 4 shows, however, there was no significant difference between the live coral cover on Tague forereef and Buck Island south forereef.

These results reveal that local conservation efforts of MPAs are only a first step in the conservation of coral reefs (Reaser et al. 2000; Hughes et al. 2002). There are many Caribbean-wide factors, such as diseases and climate change, affecting coral reefs that cannot be prevented by eliminating fishing pressures in an MPA (Aronson and Precht 2006). MPAs can, however, be greatly aided by better management of surrounding ecosystems and more effective, stronger international efforts to reduce global warming (Reaser et al. 2000; Hughes et al. 2002; Aronson and Precht 2006).

The extent of damage from tropical storm and the subsequent recovery of reefs are highly variable between reef sites (Bythell et al. 1993a), and we are just beginning to understand influences on coral reef community structure (Bythell et al. 1993a). The data collected in 1989 (Hubbard 2007, pers. comm.) and 2007 should help contribute to future analyses of the effects of tropical storms on the reefs of St. Croix. More frequent and regular surveys should be performed on St. Croix and Buck Island reefs to evaluate exactly how the communities adapt to large-scale disturbances.

Conclusions

Coral reef communities are dynamic and are constantly driven to change due to many biological and ecological processes, including environmental disturbances (Aronson and Precht 1997). Overall the live coral species richness has increased on Tague forereef, St. Croix, in the eighteen years since Hurricane Hugo. There were no noticeable differences in live coral cover between the protected reef on Buck Island Reef National Monument and that on the main island of St. Croix. This research shows that annual surveys of MPAs will be crucial for determining the role they can play in maintaining and/or protecting enough live coral to help re-populate reefs in the wake of ecosystem change. Without efforts to tackle global environmental issues, MPAs will not fix the problem of worldwide coral decline (Aronson and Precht, 2006).

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