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Origin of big garnets in amphibolites during high-grade metamorphism, Adirondacks, NY
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Students: Denny Alden, Erica Emerson, Kathryn Stack

Carbonate Depositional Systems of St. Croix, US Virgin Islands
Dennis Hubbard and Karla Parsons-Hubbard (Oberlin College), Karl Wirth (Macalester College)
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Sedimentary Environments and Paleoecology of Proterozoic and Cambrian "Avalonian" Strata in the United States
Mark McMenamin (Mount Holyoke College) and Jack Beuthin (U of Pittsburgh, Johnstown)
Students: Evan Anderson, Anna Lavarreda, Ken O'Donnell, Walter Persons, Jessica Williams

Development and Analysis of Millennial-Scale Tree Ring Records from
Glacier Bay National Park and Preserve, Alaska (Glacier Bay)
Greg Wiles (The College of Wooster)
Students: Erica Erlanger, Alex Trutko, Adam Plourde

The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico
Tim Ku (Wesleyan University) Suzanne O'Connell (Wesleyan University), Anna Martini (Amherst College)
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Keck Geology Consortium: Projects 2007-2008
Short Contributions – St Croix

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POST-HURRICANE DYNAMICS OF CORAL REEFS IN ST. CROIX, USVI

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INTRODUCTION

Change in composition, distribution and complexity are natural occurrences, which are vital to maintaining species diversity within coral reef communities (Bythell et al., 2000). The Intermediate Disturbance Hypothesis predicts that complex communities are aided by moderate disturbances over time (Connell, 1978; Bythell et al., 2000). Hurricanes can be positive—when of intermediate frequency—for coral reef communities, making room for new coral recruits that could not have settled due to high levels of competition for space (Bythell et al., 2000).

On September 17, 1989, Hurricane Hugo raged over St. Croix for more than 12 hours (Hubbard et al., 1991). The nearshore reefs on St. Croix endured large waves (6-7 m) on Tague Reef, which caused extensive reef damage and increased sediment transport (Hubbard et al., 1991). Since they are usually protected by their proximity to the mainland during near-miss hurricanes, the south-facing reefs of Buck Island Reef National Monument sustained the most extensive damage of any reefs on St. Croix (Hubbard et al., 1991). However, the north-facing Tague Bay forereef also sustained heavy, but patchy damage.

Hurricane Hugo was only one of a number of factors that have led to lower coral cover on these reefs since the late 1970s, when monitoring started at Buck Island. This paper compares coral cover on a reef protected from human activity since 1961 (Buck Island) to that of an unprotected reef on nearby St. Croix (Fig. 1). Historical patterns of recovery hopefully provide insight into the effectiveness of marine protected areas under the present range of human impacts.

METHODS

Tague Bay Reef protects the northeast shore of the mainland of St. Croix, and has an east-west trend that does not follow the shape of the coastline (Fig. 1). Because of this linear orientation, the lagoon separating the island and the reef varies in width (Burke et al., 1989). The reef crest is at a general depth of about 0.5 m (Burke et al., 1989), and the reef face plunges to a depth of about 10 m (Carter et al., 1989). Buck Island National Monument is located 2.5 km off the northeast coast of St. Croix. The southern forereef of Buck Island reaches depths of 10-15 m (Bythell et al., 1989).

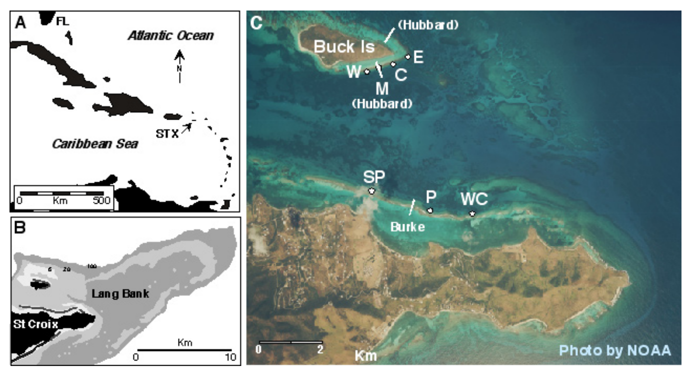

Figure 1. A) Location map showing the location of St. Croix in the Caribbean Sea. B) Map of eastern St. Croix showing the general bathymetry of the shelf. C) NOAA air photo showing the location of the survey sites.

The research performed in this study provides follow-up data for comparison with surveys conducted in 1989 and 1990 by Karla and Dennis Hubbard. For consistency, this study used the same chain transect technique (Bythell et al., 2000) that was used to measure the after-effects of Hurricane Hugo. My data was collected at the same locations on Tague Bay forereef, and at an additional three sites on

Buck Island (Fig. 1). At each location, 10- or 20-m horizontal chain transects were measured at depths of 3, 6, and 9 m. Types of substrate included: live coral, dead coral, rubble, pavement, or sand. This paper compares coral diversity and the total live coral of each species between 1989 and 2007. The total percent substrate cover was compared between Buck Island South Forereef and Tague Forereef to assess the differences between a reef protected by a National Park and one that is not.

RESULTS

Coral Diversity

At the 9 m and 6 m depth, the diversity of corals was relatively low in 1989 as compared to 2007 (Table 1). On the three 1989 St. Croix transects, only four coral species were found at 9 and 6 meters. Within the 18-year interim, 8 new species colonized at 9 m and 9 new species colonized at 6 m. At 3 m, the number of species only increase by one, and many were different than those initially preesent. *A. palmata* was present in 1989 but had all died off by 2007.

CORAL SPECIES	3 M Depth		6 M Depth		9 M Depth	
	1989	2007	1989	2007	1989	2007
Siderastrea radians	0	.065(1.4%)	0	.76(15.7%)	.05(0.9%)	.35(9.9%)
Siderastrea siderea	0	0	0	0	0	0
Acropora cervicornis	0	0	0	0	0	0
Acropora palmata	.4 (17.8%)	0	0	0	0	0
Montastraea annularis	0	.125 (2.6%)	0	.19 (3.9%)	5.00 (86.5%)	.54 (15.2%)
Montastraea cavernosa	0	0	0	0	0	.175 (4.9%)
Porites porites	.26 (11.6%)	.19 (4.0%)	5.06 (71.2%)	1.105 (22.9%)	.70 (12.1%)	1.385 (39.1%)
Porites asteroides	.47 (20.9%)	3.675 (76.8%)	1.15 (16.2%)	.745 (15.4%)	0	.16 (4.5%)
Agaricia sp.	.32 (14.2%)	.19 (4.0%)	.58 (8.2%)	1.085 (22.5%)	0	.345 (9.7%)
Diploria labyrinthiformis	0	0	0	.225 (4.7%)	0	.10 (2.9%)
Diploria clivosa	0	.04 (0.8%)	0	.14 (2.9%)	0	.115 (3.2%)
Diploria strigosa	.28 (12.4%)	.42 (8.8%)	0	.185 (3.8%)	0	.055 (1.6%)
Millepora sp.	.50 (22.2%)	.085 (1.8%)	.32(4.5%)	.285 (5.9%)	.03 (0.5%)	.185 (5.2%)
Stephanocoenia intersepta	0	0	0	.04 (0.8%)	0	0
Dichocoenia stokesi	0	0	0	.02 (0.4%)	0	0
Mussa angulosa	0	0	0	.035 (0.7%)	0	.03 (0.9%)
Madracis sp.	0	0	0	0	0	.105 (3.0%)
Meandrina meandrites	0	0	0	0	0	0
Favia fragum	.02 (0.9%)	0	0	0	0	0
Eusmilia fastigiata	0	0	0	.015 (0.3%)	0	0
Total (m)	2.25	4.79	7.11	4.83	5.78	3.545

Table 1. Coral cover on the Tague Bay forereef in 1989 and 2007. Values are averages for all three survey sites. The first number reports percent cover by each species at that depth. The second value (in parentheses) reports the percent of live cover for that species.

Live Coral Cover

Although there was a general trend towards increasing diversity in all but one Tague Bay transect between 1989 and 2007, coral abundance increased only slightly (from 10.5% to 12.3%: Table 2). The 9 m and 6 m transects for Whaler Cut and Platform showed a decrease in overall live coral cover. The 6m transect at the Whaler Cut showed the greatest change in coral cover—a 16.8% decrease in live coral cover between 1989 and 2007. All of the depths at Solar Panel transect showed an increase—an average of 8.2%—in live coral. The 3 m Whaler Cut and Platform transects likewise showed an increase in live coral cover, but the change was not as great as in the Solar Panel transects. In 2007, there was no significant difference between the live coral cover on Buck Island forereef and Tague Bay forereef (Table 3). Over all there was slightly more live coral measured on Buck Island (12.3%) than on Tague Bay reef (10.5%). There was also more irregular substrate, or the natural contours of the reef, measured on Buck Island, perhaps reflecting higher coral cover at some time in the distant past. It is unlikely that any of the differences in coral cover (by depth or overall) are statistically significant.

Depth	Year	Location			Total
		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%	
Total	1989				10.5%
	2007				12.3%

Table 2: Percent live coral by location and depth.

	Average total live coral measured (m)		Average total substrate measured (m)	
Depth	Buck Island	Tague Reef	Buck Island	Tague Reef
3 m	2.15 (15.7%)	1.60 (14.2%)	13.7	11.3
6 m	1.71 (10.9%)	1.64 (12.9%)	15.7	12.7
9 m	1.67 (10.4%)	1.21 (9.8%)	16.0	12.3

Table 3: Live coral and total substrate measured on the Buck Island Forereef and Tague Bay Forereef in 2007. Values in (parentheses) are the coral percents computed as live coral/total substrate.

DISCUSSION

Because of the close interaction between humans and the natural environment, it is important to understand how ecosystems react and respond to natural phenomena so that we can try to adjust and plan accordingly. Hurricanes can change landforms and vegetation, influence the quality of human life, and wreak havoc on economies over vast areas in relatively short time periods (Lugo 2000). Overall, the 6 m and the 9 m depths on Tague Forereef showed a much higher diversity of coral species in 2007 than in 1989 (Table 1). Hurricane Hugo appears to have cleared the reef of sediment, thus increasing the types of niches available for colonization. This initially allowed for decreased competition for space and led to higher diversity (Bythell et al. 2000). The shallowest (3 m) transects showed little difference in live coral species diversity between 1989 and 2007. Minor and tropical storms may produce waves that scour the shallower depths on a more frequent basis than at deeper locations. Thus, the coral polyps already established on the upper parts of the reef are well accustomed to wave action and diversity levels have stabilized.

Lugo (2000) discusses a pattern similar to that witnessed on St. Croix for impacts from hurricanes on terrestrial vegetation in the Caribbean. At first, massive mortality over a short period of time occurs (Lugo 2000; Done, 1999), then a delayed pattern of tree mortality for months to years, and finally, a high turnover of species and many opportunities for species change (Lugo 2000). While no mass mortality was observed on St. Croix, Bythell et al. (1993) recorded a loss of 2% of the live coral cover. Coral breakage, abrasion from sediment and debris and near-total removal of the upright soft bottom community also occurred (Hubbard et al., 1991). The community composition on the reefs of Buck Island remained in the post-hurricane condition for two to three years before returning towards, but not reaching, the pre-hurricane condition (Bythell et al. 2000). This pattern appears to follow for the Tague Bay forereef as well. Diversity increased at all depths (Table 1). The massive sediment transfer in depths shallower than 10 m reported by Hubbard et al. (1991) allows for settlement 'colonization gaps' in which new recruits with differences in regeneration strategies could settle and flourish (Lugo 2000). The increase in diversity is consistent with the Intermediate Disturbance Hypothesis. As Bythell et al. (2000) found on Buck Island, in disturbed habitats, species richness increased to above the pre-Hugo levels due to high recruitment rates 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 that comprise a heterogenous mix of species in the wake of hurricane damage (Bythell at al. 2000).

Many researchers have observed an apparent shift from frame-building corals to smaller non-framework building soft corals and macroalgae (Gardner et al., 2003; Done, 1999; Aaronson and Precht 1997). Population modeling suggests that an increase in frequency and/or the intensity of disturbances will tend to skew size-frequency distributions toward smaller size classes (Done, 1999). These population models could help explain why there was an increase in dominance of *P. porites* populations at the 9 m Whaler Cut and Platform transects. In the future, sea-level rise, an expected outcome of the polar ice caps melting during global warming, could have an impact on the smaller corals. As environmental temperatures increase, a large number of reefs will spend more time in earlier successional stages than would be expected if increases in frequency and intensity of extreme events were not to occur (Done 1999). As sea levels rise, it may be hard for reefs with only smaller corals to keep at the required depth.

No significant difference was found between the percent live coral cover on Buck Island South forereef and that on Tague forereef. The percent live coral cover was higher at 3 m and 9 m depths on Buck Island but lower than on Tague Forereef at the 6 m depth (Table 3). The recruitment on the south side of Buck Island was strong following Hurricane Hugo (Bythell et al. 2000). The recruitment and diversity increased on both reefs, and there was still no large difference between live coral cover on Buck Island and Tague Forereef. On an island that is relatively devoid of tourists, there are many other coral reef damaging factors which National Reserves cannot prevent. Marine Protected areas can, however, be greatly aided by better management of surrounding ecosystems and more effective, stronger international effort to reduce global warming. The data collected in the study provide an essential baseline for further research into the impacts of future disturbances on Buck Island South Forereef.

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