

KECK GEOLOGY CONSORTIUM

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Dr Andrew P. de Wet, Editor
Keck Director
Franklin & Marshall College

Keck Geology Consortium
Franklin & Marshall College
PO Box 3003, Lancaster Pa, 17603

Dr Amy Rhodes,
Symposium Organizer
Smith College

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Dennis Hubbard and Karla Parsons-Hubbard (Oberlin College), Karl Wirth (Macalester College)
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Greg Wiles (The College of Wooster)
Students: Erica Erlanger, Alex Trutko, Adam Plourde

The Biogeochemistry and Environmental History of Bioluminescent Bays, Vieques, Puerto Rico

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Students: Erin Algeo, Jennifer Bourdeau, Justin Clark, Margaret Selzer, Ulyanna Sorokopoud, Sarah Tracy

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KARLA PARSONS-HUBBARD: Oberlin College
KARL WIRTH: Macalester College

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Research Advisor: Timothy C. Ku

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Keck Geology Consortium

Franklin & Marshall College PO Box 3003, Lancaster Pa, 17603 Keckgeology.org

TROPHIC CASCADES AND SEDIMENT PRODUCTION IN MARINE RESERVES

ALEX BURPEE: Washington & Lee University
Research Advisors: Lisa Greer and Robert Humston

INTRODUCTION

Caribbean reefs have been in decline for decades due to overfishing, pollution, disease, and climate change (Pandolfi et al., 2005). Historic overfishing caused a progressive shift in the grazer community from herbivorous fish like parrotfish to benthic *Diadema antillarum*. Widespread mortality of *Diadema* by an unidentified pathogen in 1983-1984 created a situation where grazer populations were not sufficient to keep macro-algal concentrations down, decreasing available space for coral recruitment (Jackson, 2001). The shift to macro-algal dominant reefs has been prevalent throughout the Caribbean, and the island of St. Croix has consequently been affected by up to a 439% increase in algal cover (Carpenter 1990). In order to study grazer-algae-coral dynamics on reefs with different levels of protection, Buck Island National Monument and an unprotected reef at Tague Bay (St. Croix, USVI) were chosen as study sites. The proximity of the two reefs, their similar orientation, exposure to currents, slope, and depth make for good comparative study areas.

Removal of species from the top or bottom of a food chain can cause complex changes in biological communities. For instance, removal of predators from coral reefs via fishing may increase grazer density, and decrease macro-algae abundance (Dulvey et al., 2004). Establishment of marine reserves and “no-take zones” typically lead to recovery of top predator populations, which consume more parrotfish and specifically consume more small parrotfish (Mumby et al., 2006). As a result, the density of large parrotfish on the protected reef increases as they reach maturity and become too large to be consumed by most predators. Large parrotfish consume comparatively more algae than small parrotfish, which should increase habitat available for coral recruit-

ment (Mumby et al., 2006). In communities dominated by *Diadema* a similar decrease of macro-algae can occur leading to an increase in juvenile corals (Edmunds et al., 2001).

Carbonate sediment budgets are determined by the abundance of calcifying organisms, the density of the organisms on the reef, and the sediment production rates by bioeroders (Hubbard et al., 1990). Marine protection may create conditions where protected reefs and unprotected reefs have different sediment budgets as a result of changing grazer dynamics.

This study aims to observe the ecological implications of trophic cascades in marine reserves by quantifying coral and algae ratios as well as fish populations. This study also focuses on the amount of sediment that is produced by both parrotfish and *Diadema* on the protected reef and the unprotected reef, and the difference in sediment production by the organisms as a result of trophic dynamics.

METHODS

Abundance of piscivorous predators, parrotfish, *Diadema antillarum*, corals, and algae were observed on the reefs at Tague Bay (TB) and Buck Island (BI) using SCUBA. At each reef, three locations were targeted for observation (see Hubbard et al, this volume), and 6 transects with the dimensions of 10 m wide x 3 m long x 2 m high were established at each location, with 2 transects at each of 3 different depths. Replicate ten-minute fish counts were taken at each transect. Following the count, all *Diadema* within a 10 m wide x 2 m long area were counted. To normalize *Diadema* count surface area to parrotfish count data, *Diadema* abundance was multiplied

by 1.5. Vertical bottom photographs were taken along 20-m transects near fish count sites to analyze reef cover. Five photographs were randomly chosen for analysis specific to each site, location, and depth. Percent cover of turf, live coral, macro-algae, and sand or rubble was quantified using Canvas and NIH ImageJ. Statistical significance was determined through t-test calculations on average abundances for coral cover, parrotfish, and *Diadema* by depth and site.

Sediment-production calculations rely on rates from the literature. An individual *Diadema* produces 2.8g of CaCO_3 sediment per day, while the parrotfish *Scarus croicensis* (and for the purposes of this study, *Scarus taeniopterus*) produces 8 grams of CaCO_3 sediment per day (Ogden, 1977). This rate was determined for mature parrotfish. In this study, we assumed that 2 juveniles produce sediment at a rate equivalent to one adult, and that 3 medium sized individuals produce sediment at a rate equal to 2 adults. Similar parrotfish species will typically produce 33% of their own wet body weight in sediment every day (Frydl and Stearn, 1978).

RESULTS

The total number of large predators (those able to consume at least small parrotfish) observed at BI was 60 (92.3% of the total predators counted in the study), while TB had only 5 (7.7%) (different at $P = 0.005$). The total number of individual parrotfish at BI was 2,286 versus 1,507 at TB. A total of 7 different species of parrotfish was observed at both study areas: queen (*Scarus vetula*), stoplight (*Sparisoma viride*), striped (*Scarus croicensis*), princess (*Sparisoma taeniopterus*), redband (*Sparisoma aurofrenatum*), redtail (*Sparisoma chrysopterus*), and redfin (*Sparisoma rubripinne*). Of all parrotfish counted (Table 1), 60.3% were found on BI and 39.7% on TB ($P = 0.012$). At 2 m, TB had 416 individuals (39.5%) and BI had 637 individuals (60.5%) ($P = 0.067$). At 4.5 m, TB had 413 individuals (32.3%) and BI had 864 (67.7%) ($P = 0.013$).

The total number of *Diadema antillarum* [normalized to surface area in brackets] was significantly

different between the two sites ($P = 0.022$). Buck Island contained 400 [600] individuals (11.4%) while Tague Bay contained 3,123 [4685] individuals (88.7%). The relationship between the total *Diadema* count and the total parrotfish count for each reef and by depth can be seen in Figures 1 and 2, respectively. The data for live coral, macro-algae, turf, and sand and rubble are shown in Figure 3. Buck Island and TB had similar overall coverage for live coral (BI = 7.8%, TB = 7.4%), with some variability of coral coverage by depth at each site.

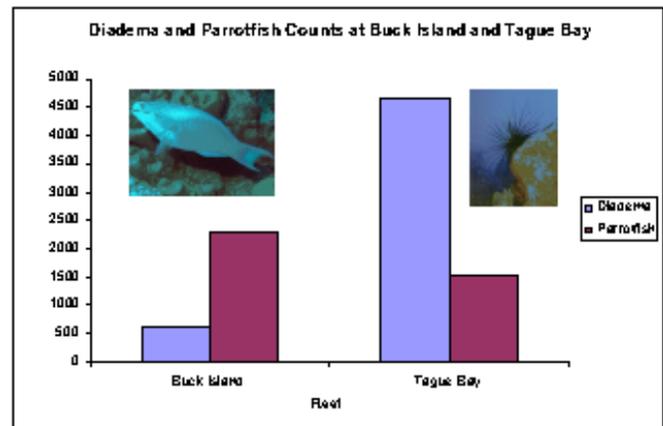


Figure 1. The distribution of *Diadema antillarum* and parrotfish at Buck Island and Tague Bay. Buck Island is a parrotfish dominant system and Tague Bay is a *Diadema antillarum* dominant system.

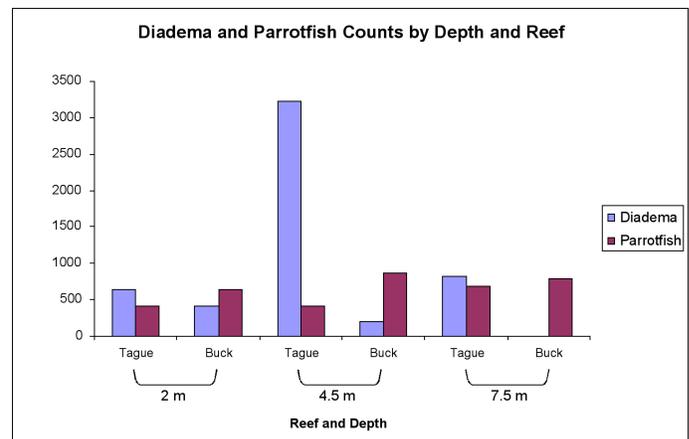


Figure 2. The distribution of *Diadema antillarum* and parrotfish by depth and by reef site. The 4.5 m depth may best represent the impacts of trophic cascades.

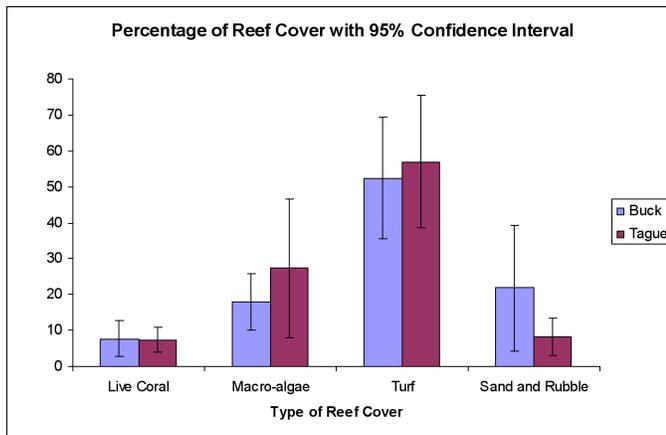


Figure 3. Reef cover by percentage for Buck Island and Tague Bay (95% confidence interval provided). The differences between individual components at either site are not statistically different.

DISCUSSION

Data from this study show how marine reserves affect trophic dynamics. The absence of fishing at BI has allowed recovery of the predator population; 92.3% of all predators counted were within the BI reserve. This is coincident with an increase in parrotfish; 60.3% of parrotfish counted were at BI. Although not statistically significant, macro-algae coverage was lower in the marine protected area (18.1%) compared to the unprotected reef (27.3%), supporting the assertion by Mumby et al, (2006) that increases in parrotfish numbers will decrease the macro-algae coverage. While this previous study described these dynamics in a grouper-dominated predator system, there are no grouper at BI yet the trophic effects still appear to be consistent.

Parrotfish compete with *Diadema antillarum* for food resources. Hay and Taylor (1985) demonstrated that, compared to control areas, a reef with its *Diadema* population removed experienced an increase in parrotfish activity on the order of 450% after 16 weeks. After a year, the *Diadema* population rebounded to 70% of the original density, and the parrotfish activity returned to the levels of pre-urchin removal. Marine protection may also affect coral recruitment via grazer dynamics and competition for food. After the *Diadema* die-off in the early 1980s, parrotfish had less competition for

food, but without *Diadema*, the parrotfish were not able to maintain grazing rates high enough to keep macro-algae from increasing (Hubbard et al., 1990), and this decreased open space for coral recruitment. With recovering populations of *Diadema* (Macia et al., 2007), competitive interactions among grazers may become an important issue for coral recruitment and sediment production.

A similar interaction between *Diadema* and parrotfish is demonstrated in this study. The inverse relationship between parrotfish and *Diadema* caused by trophic cascades is clearly shown in Figure 1. Where BI is a parrotfish-dominated system (60.3% of all parrotfish counted), TB is clearly urchin-dominated (88.7% of all *Diadema* counted). Urchin abundance is characteristic of reefs that have few predators and little competition for food (Hay, 1984), and the unprotected TB reef has been plagued by overfishing of predators and parrotfish for many years. As the *Diadema* population has recovered, urchins have thrived on an unprotected reef with a lack of competition and predation.

Trophic cascades are the driving force that determines species density and size of individuals. The contribution of CaCO_3 to the reef by each species is based on both the number and size of individuals present. Based on CaCO_3 production rates for *Diadema* and each species of parrotfish, their abundances and sizes on the two reefs (Figure 1), sediment production is clearly dominated by parrotfish abundance, regardless of urchin densities (Fig. 4; Table 1). Sediment production by *Diadema* herbivory is 7.8 times greater at TB than BI, while parrotfish herbivory is only 2.7 times greater at BI than TB. Yet, total sediment production is higher at BI. McClanahan (2008) found similar results in Kenya; herbivory by parrotfish can be up to 30 times more intense in marine reserve than on unprotected reefs, while *Diadema* herbivory is only 5 times higher in the unprotected areas. Calculations in this study (Figure 4) support the findings of McClanahan (2008) that sediment production associated with grazing should be higher on the protected reefs where parrotfish can thrive.

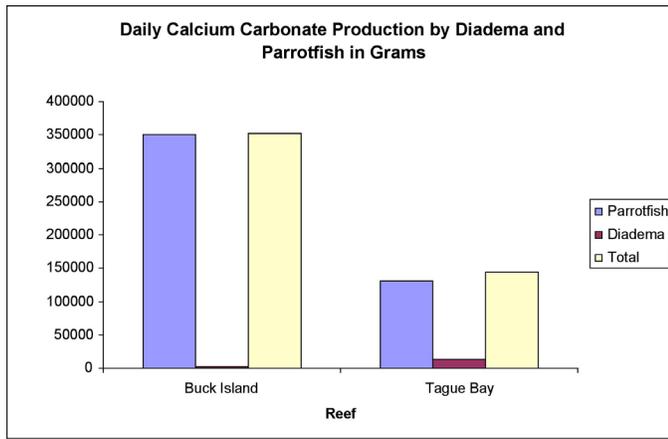


Figure 4. The difference in sediment production at Buck Island and Tague Bay. Parrotfish are the dominant sediment producers, and their abundance on a reef largely determines how much sediment will be produced, regardless of their relationship to *Diadema antillarum* abundance.

Production of CaCO₃ in Grams Per Day and Number of Individuals by Species and Size

Species	Sm BI	Sm TB	Med BI	Med TB	Lg BI	Lg TB	Total BI	Total TB
<i>Scarus</i>	916	760	1110	588	440	192	2466	1540
<i>croicensis</i>	(229)	(190)	(185)	(98)	(55)	(24)	(469)	(312)
<i>Scarus</i>	16	204	114	162	136	104	266	470
<i>taeniopterus</i>	(4)	(51)	(19)	(27)	(17)	(13)	(40)	(91)
<i>Scarus</i>	416	166	13435	5774	84794	17161	98645	23101
<i>vetula</i>	(35)	(14)	(121)	(52)	(252)	(51)	(408)	(117)
<i>Sparisoma</i>	1835	1099	19190	15771	190639	52639	211664	69509
<i>viride</i>	(187)	(112)	(174)	(143)	(402)	(111)	(763)	(366)
<i>Sparisoma</i>	0	42	350	2301	9874	11261	10225	13603
<i>rubripinne</i>	(0)	(7)	(7)	(46)	(57)	(65)	(64)	(118)
<i>Sparisoma</i>	0	23	0	399	1180	472	1180	894
<i>chrysopterus</i>	(0)	(2)	(0)	(5)	(5)	(2)	(5)	(9)
<i>Sparisoma</i>	383	421	3052	4015	22663	17369	26098	21806
<i>aurofrenatum</i>	(110)	(121)	(133)	(175)	(247)	(210)	(517)	(504)
<i>Diadema antillarum</i>	N/A	N/A	N/A	N/A	N/A	N/A	(600)	(4685)
Total							352241	144182

Table 1. Sediment production by parrotfish species and *Diadema antillarum* on Buck Island and Tague Bay (in g indiv-1 day-1). Abundances of small, medium, and large parrotfish by species and site are in parentheses.

CONCLUSIONS

This study tested the trophic cascade effects described by Mumby et al. (2007) to investigate the potential effects of marine protection on grazer densities and carbonate sediment production. Data from this study show that the management of BI has influenced the recovery of predator and parrotfish populations from overfishing, supporting the idea that trophic cascade dynamics associated with a marine reserve significantly alter the grazer community, in turn impacting carbonate sediment production. On St. Croix, these effects seem to be most prominent at the mid-depth range which may be a result of parrotfish congregating at that depth to

avoid high wave energy at the shallow depth. Parrotfish are clearly the dominant sediment producers, regardless of whether they dominate the grazer population or not.

At the sites studied, marine protected status does not seem to positively impact coral cover, indicating that other management techniques may be necessary if increased coral recruitment and higher live coral cover are the main goals for protection. Will the addition of grouper or more *Diadema* to the BI ecosystem help coral recruitment? Are other variables like climate change or nutrient influx making it more difficult for corals to rebound? Is parrotfish grazing damaging juvenile corals? More research must be performed to investigate why coral recruitment and coral cover are not higher in the BI marine reserve than in the unprotected TB.

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