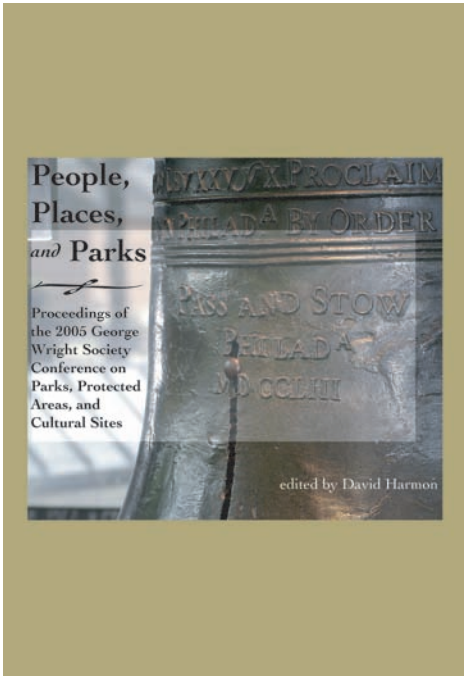

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Is Coral Recruitment Limited by Sedimentation at War in the Pacific National Historical Park?

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Introduction

Coral reefs are important economic, cultural, and ecological resources. However, on Guam poor land management, anthropogenic fire regimes, and soil chemistry contribute to soil erosion and subsequent sedimentation of nearshore reefs. Following even modest rain events, sediment plumes are visible at river inputs along Guam's entire coast. Although significant interspecific differences exist (Rogers 1990; McClanahan and Obura 1997), heavy sedimentation rates (greater or equal to 95% coverage of substrate) have been shown to inhibit coral settlement completely, while more moderate rates (between 50–90%) severely inhibit settlement (Hodgson 1990). Sediments can kill adult coral colonies by burial, decreasing light penetration, disrupting polyp gas exchange, and inhibiting nutrient acquisition (Rogers 1990; Richmond 1993). Some adult species can be effectively smothered at relatively low sedimentation rates, while others are able to secrete mucous to remove these sediments and are thus more tolerant of elevated sediment inputs (Rogers 1990; Richmond 1993). Even if sedimentation is not visibly affecting adult coral colonies, sedimentation rates may be high enough to inhibit all or some juvenile recruitment (Gilmour 1999; Fabricus and Wolanski 2000).

Elevated sedimentation can cover potential recruitment habitat, intensifying competition for space on the benthos. Additionally, increased sediment loads seem to disrupt the attachment and metamorphosis process (Hodgson 1990; Gilmour 1999), a critical process for planulae to successfully recruit to the benthos. Since juvenile corals are more susceptible to environmental disturbances, they may be a good indicator of reef health. Reefs that appear "healthy" may not be receiving sufficient recruits to replace adults, and over time the coral community will deteriorate. This phenomenon has been observed already on some Guam reefs (Richmond 1993; Richmond 1994; Wolanski et al. 2003), raising concern among resource managers about the future, long-term health, and stability of marine resources on Guam.

Soil erosion on Guam is occurring at significant levels (National Resource Conservation Service 1996; Wolanski et al. 2003; Minton et al., this volume) and may be acting as a barrier to coral recruitment, particularly at some locations along the reef at War in the Pacific National Historical Park. Understanding the relationship between sediment load and recruitment is vital to mitigating disturbance and understanding one of the mechanisms that regulate benthic populations and mediate species coexistence on the reef (Underwood and Fairweather 1989).

The objectives of this study were to: (1) assess spatial and temporal patterns of coral

recruitment at War in the Pacific National Historical Park; (2) examine the relationship between the sediment deposition and coral recruitment rates; and (3) provide baseline data on coral recruit taxonomy. With this information, natural resource managers would be able to identify areas experiencing sedimentation-related recruitment limitation and better develop best management practices for erosion mitigation in the adjacent watershed.

Study design

A pilot study was conducted from March through August 2004 to assess the feasibility of settling corals onto experimental plates and to determine the level of taxonomic resolution for recruit identification. Information from this study was also used to aid in site selection for the project. Data and logistical insight derived from two three-month deployments of recruitment plates indicated that working at a single depth, using paired sites would diminish possible confounding variables (i.e., coral cover, species richness, wave action, temperature, and salinity). Additionally, data from a year-long sedimentation baseline study (Minton et al., this volume) provided sufficient data to allow us to select paired sites approximately 150 m apart that experienced elevated and moderately elevated sediment loads. The close proximity of these paired sites reduced the likelihood of confounding variables affecting the project's results. All selected sites were at 20 m depth on the fore reef slope.

Methods

At each of the eight study sites, three recruitment plate units (Figure 1) were attached directly to the benthos using "all thread" posts. Each unit consisted of four plates arranged in two stacks of two plates separated by a 10-mm gap using rubber washers. The plates were drilled through the center and held together using stainless steel bolts, washers, and wing nuts. Stacks were braced using three Plexiglas strips, which could be attached to the posts and secured with a short section of tubing and a hose clamp. To ensure uniform orientation and elevation with respect to the benthos, a small spacer was placed underneath the plate unit and held the plates approximately 5 cm off the bottom.

Plates were immersed in running seawater in a covered bucket for at least two weeks prior to deployment to cultivate algal and microbial communities, which are thought to be requisite for coral recruitment (Heyward and Negri 1999). Plates were deployed for three-month periods, collected and transported to a wet lab. All plates were handled by the edges and transported so that their settlement surfaces were not damaged. At the wet lab, high-resolution digital photographs (5 megapixel) were taken while organisms were immersed and fresh to record community composition for possible future analysis. Plates were then disassembled, labeled, and bleached. Algal material was carefully removed while searching for recruits under a dissecting microscope. All recruits were identified to the lowest possible taxonomic level, generally family. High-resolution digital photographs of each recruit were obtained using a dissecting scope and a MaxView Plus adapter set.

Temperature data loggers (Onset HoboTemp) were deployed at each site. Two CTD units (Star-Oddi DST CTD data logger) were rotated among sites every three weeks to obtain salinity, tidal, and temperature data. Daily weather and rainfall data were obtained from the National Weather Service at Tiyan, Guam.

Figure 1. Recruitment sampling apparatus, "plate unit." Photo by Ian Lundgren.

Results

At present, only one of four replicates has been retrieved and analyzed, so these data are preliminary in nature. Additional replicates are being conducted with an expected project completion date in the fall of 2005. We have included data from the pilot study to facilitate analysis; however, interpretation of these results must be done with care because of differences in the study design between the pilot study and replicate 1 of this study.

To date, a total of 30 plate units have been deployed, collected, and examined (120 individual plates and 240 plate surfaces). Only four coral recruits were observed during the pilot study, with an additional three recruits observed in replicate 1 of this study. All of the observed recruits were in the family Pocilloporidae. These recruits occurred at sites with both moderate and heavy sediment loads (Table 1), ranging from as low as 5.15 g to 298.84 g. With these limited data, no relationship between gross sediment loads and recruitment is evident (binomial regression; $Z=1.54$, $p=0.123$).

Using data from both the pilot study and from replicate 1 of this study, pocilloporid recruits trend toward settling on the upper surfaces of the top plate (Table 2), but this result was not significant (c^2 Goodness of Fit; $X^2=5.15$; $df=3$, $p=0.161$). Data is limited, however, but if this trend continues over the course of this project, we expect to find a settlement preference among coral recruits for this upper surface.

Discussion

Considerable research on the effect of sediment on corals reefs has been conducted over the past twenty-five years. Much of this literature suggests that corals are negatively affected by increased sediment loads, but efforts to determine a specific threshold level at which sediments become lethal to corals (e.g., Pastorak and Bilyard 1985; Rogers 1990) have not been overly successful (Hopley et al. 1990). Healthy coral reefs can be found in regions of elevat-

Site	Study	Total Sediment (g)	Sediment/day (g/day)	# of Recruits
D60	Pilot	5.15	0.05	2
N60	Pilot	91.76	1.02	1
D60	Pilot	18.00	0.20	1
D60	Rep. 1	9.24	0.10	1
K60	Rep. 1	5.48	0.07	1
O60	Rep. 1	298.84	3.05	1

Table 1. Recruitment under varying sediment stress.

Plate Surface		# of Recruits
Top Plate	Upper	4
	Lower	2
Bottom Plate	Upper	1
	Lower	0

Table 2. Recruit orientation.

ed sediment, suggesting that some species are able to locally adapt to chronic sediment inputs (Ayling and Ayling 1998). This appears to be particular apparent in the Indo-Pacific region, where coral reefs can routinely persist in regions with sediment loads greater than any published threshold (Hopley et al. 1990). Whether these adaptations extend to early life history stages is unclear. Reefs currently surviving in areas of high sediments may be experiencing recruitment failure or sub-lethal stress that may impair their ability to survive a future, acute impact (Wolanski et al. 2003).

Only seven recruits have been observed on 120 plates in this study. By comparison, Neudecker (1981) observed 112 recruits on 282 plates when researching coral recruitment on Guam, using similar methods. While elevated sediment levels may account for this low observed recruitment rate, an alternative explanation is that two weeks of plate conditioning prior to deployment was not sufficiently long enough to ensure that appropriate requisite algal and microbial communities were present. Alternatively, overall recruitment levels may have decreased over the past two decades in response to increased disturbance.

Our results show no significant relationship between coral recruitment and sedimentation. Coral recruits were found across a range of gross sediments loads, from 5.15 g to as high as 298.85 g. Explanations for this are not readily available at these early stages of this work, but it is possible that high sedimentation events are infrequent, and that the sediment flushing time is adequate so that sediments are not inhibiting coral recruitment, or are inhibiting recruitment for only short isolated periods of time. Alternatively, reefs on Guam routinely receive high sediment loads (Randall and Birkeland 1978; Wolanski et al. 2003; Minton et

al., this volume), and species may be adapted to these ambient conditions. However, Te (1992) showed that high sediment levels could induce polyp bail-out in a pocilloporid species on Guam, suggesting that recruits of some Guam species may not be able to tolerate elevated sediments. A final alternative is that sediment levels observed in this project were sufficiently high as to have a uniform negative effect across all sites. We hope additional replicates will yield answers to this question.

The orientation of recruits observed during both the pilot study and replicate 1 of this study are showing a trend toward settling on the upper surfaces of plates. Most studies to date show that vertical edges and the undersurfaces of plates are favored by coral recruits, but in studies conducted over a range of depths recruits often shift their settlement to the upper surfaces of plates at increasing depth (Birkeland et al. 1982; Rogers et al.1984; Harrison and Wallace 1990; Carlon 2001). Depth-related changes in recruit orientation are most likely associated with light intensity, which can vary with suspended sediment loads. Recruits require a minimum threshold of light intensity, which might not be met on the more-obscured orientations at increased depths. Decreases in light may also reduce competition with algae for space.

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