

Foraging behavior, substrate preference and influence of *Echinometra* sp. A on the carbonate budget of Nukubuco Reef, Fiji Islands

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Abstract—Bioerosion can be important to the configuration and destruction of coral reefs. Echinoids as grazers and burrowers can contribute significantly to coral reef destruction. The rock-boring sea urchin, *Echinometra* sp. A has colonized extensive areas of dead coral on the Nukubuco reef, Fiji. This study provides data on rates of bioerosion of the reef structure using gut analysis and how these rates vary among size classes of *Echinometra*. It also provides information on the distribution and behavior of different size classes of *Echinometra*. This is pertinent to Micronesia and the rest of the tropical Pacific because *Echinometra* is usually the most prevalent species on the coral reefs. Field sampling on size-specific behavior showed small and medium urchin dominance on the crests engaged chiefly in burrowing and feeding behavior while the flats demonstrated urchins from all representative size classes engaged in feeding, burrowing and scouring. This difference was a reflection of difference in environments. *Echinometra* sp. A showed a preference for coral rock due to the brittle framework it provides to make burrows and due to the availability of turf algae infested on the dead coral for food. In feeding on algae, it also removes a large portion of coral (CaCO₃) substrate. Bioerosion rate was lower on the Nukubuco flats 0.20×10^{-3} kg CaCO₃ /urchin/d, compared to the crests, 0.39×10^{-3} kg CaCO₃ /urchin/d. These rates compare closely with studies done on the turnover of gut contents by the two major burrowing echinoids on Enewetak Atoll (*Echinometra mathaei* and *Echinostrephus aciculatus*).

Introduction

Echinoids play an important role in the ecological and geological processes of the coral reefs as bioeroders, borers and grazers (Ogden 1977, Russo 1980, Sammarco 1982). Most abundant among the Echinometridae found on coral reefs are the species of the genus *Echinometra*, which is widely represented in the Indo west Pacific by *Echinometra mathaei*, both in tropical and sub-tropical zones (Clark 1976). *Echinometra* is a generalized herbivore, feeding on a variety of macrophytes, including seagrass, occasionally consuming benthic organisms such as sponges, corals and algae (McClanahan & Muthiga 2001). Calcium carbonate sediments are usually the largest fraction of the gut content of *Echinometra*, being between 65 and 95% (Black et al. 1984, Downing & El-Zahr 1987, McClanahan & Kurtis 1991). These measurements support the inference that grazing of benthic epi- and endolithic algae is the major source of food for *Echinometra* (Odum & Odum 1955).

Two basic feeding modes are adapted by both juvenile and adult *Echinometra* and these vary with species and environment: 1) catching algal drift, and 2) benthic grazing. The filtering mode is common in shallow waters along shorelines, but also occurs in areas with currents such as reef channels, or shallow tops of patch reefs or reef flats (McClanahan & Muthiga 2001).

In the Caribbean, Ogden (1977) based his estimates of the erosion caused by *Echinometra lucunter* from measurements of the proportion of calcium carbonate in the gut, together with an assumption that the gut turnover was approximately once per 24 h. Russo (1980) studied coral erosion by *E. mathaei* in Enewetak Atoll in the Marshall Islands, and based his estimate on an analysis of gut contents together with measurements of fecal pellet production of three "mean-sized" animals held in an aquarium. Shinn (in Hughes & Keij 1973) gave a rate of erosion of dead *Acropora* sp. by *E. mathaei* in the Arabian Gulf, but without details of methodology.

Birkeland & Randall (1981) found that corals successfully recruited to grooves left by grazing urchins at a higher rate than could be expected by chance. They concluded that corals were thus advantaged by a significant presence of grazing urchins, which increased the complexity of the reef topography. However, the role urchins play in enhancing or restricting coral recruitment is not clear. At very high densities grazing pressure probably kills most recruits, (Schuhmacher 1974, Sammarco 1980). Under conditions of low grazing pressure (low urchin density) algae and trapped sediment can cause high levels of mortality among coral and coral spat (Sammarco 1980). But where urchins exist at moderate densities and keep substrate from becoming dominated by algae, it has been suggested that coral settlement can be enhanced (Sammarco 1980, review in Birkeland 1989).

Foraging behavior, substrate preference and influence of genus *Echinometra* on the carbonate budget of reefs is known in other parts of the tropics but not in Fiji, where it may be different. This paper highlights research on *Echinometra* sp.

A in Fiji, which was initially thought to be *E. mathaei*. More specifically it explores size-specific behavior and urchin density relative to substratum cover to unveil patterns of activity and habitation by the urchins on different environments of Nukubuco reef. This provides an indirect reflection of the potential impact of urchin activity on Nukubuco reef. This study also explores a technique to measure coral erosion by *Echinometra* sp. A based on acid digestion of the gut content in animals removed from their feeding substrate.

Methods

DESCRIPTION OF STUDY SITE

Nukubuco reef is located on the south-east coast of Suva Harbor. It is part of the Viti Levu south-eastern reef chain and encloses Suva Peninsula and Laucala Bay. The annual sea surface temperatures in Laucala Bay vary from 24°C to 31°C, with an average annual variation of 6°C. Salinity values are normally 35 ppt but may drop to 10-15ppt after heavy rainfall (Zann et al. 1987). Both fish and coral species diversity are low. *Porites* spp. is the most common reef flat coral, but in some areas much of it is dead and extensively damaged by *Acanthaster planci* (see Zann et al. 1990) and *Echinometra* sp. A (mean densities ranging from 2-4 individuals/m⁻²) (see Appana & Vuki 2003). The urchin feeds on algae growing on the dead coral surface, but in doing so it rasps off a proportion of the coral substrate itself. The surface thus cleaned is once more open to colonization by algae, which encourages a return of the urchin for further grazing. The destruction of the gross morphology of *Porites* from its living subramose form to a deeply pitted and eroded mass of calcium carbonate rock appears to proceed rapidly.

Natural and anthropogenic disturbances affect Nukubuco reef. It is important to describe these disturbances because it is the interwoven effects of these that help to explain the low but consistent densities and impact of *Echinometra* sp. A. Nukubuco reef, which is a part of the coral reef system in Laucala Bay, has experienced recent bleaching events (South & Skelton 2000; Cumming et al. 2000) and *A. planci* outbreaks (Zann et al. 1990). The continuous influx of sewage from the Kinoya Sewage Treatment Plant (Naidu et al. 1991) magnifies opportunities for *A. planci* populations via enrichment of Laucala waters. Thus, the high fishing pressures, eutrophic waters and *A. planci* predation, provide conditions for *Echinometra* sp. A to flourish. Furthermore, high sediment loads from logging and highland farming (Hinrichsen 1998) could also contribute to coral decline.

SURVEYS

The survey was conducted from April to September, 2000 at a weekly interval. The Nukubuco reef (Figure 1) was demarcated into zones (reef crest and reef flat) and sites. Four sites were sampled at each zone; 8 sites were sampled in total (Figure 2). Each site was 1 x 104 m² plot of continuous reef, measuring 100m x 100m. The next site was chosen randomly. Within each site, twenty 1m x 1m grid-

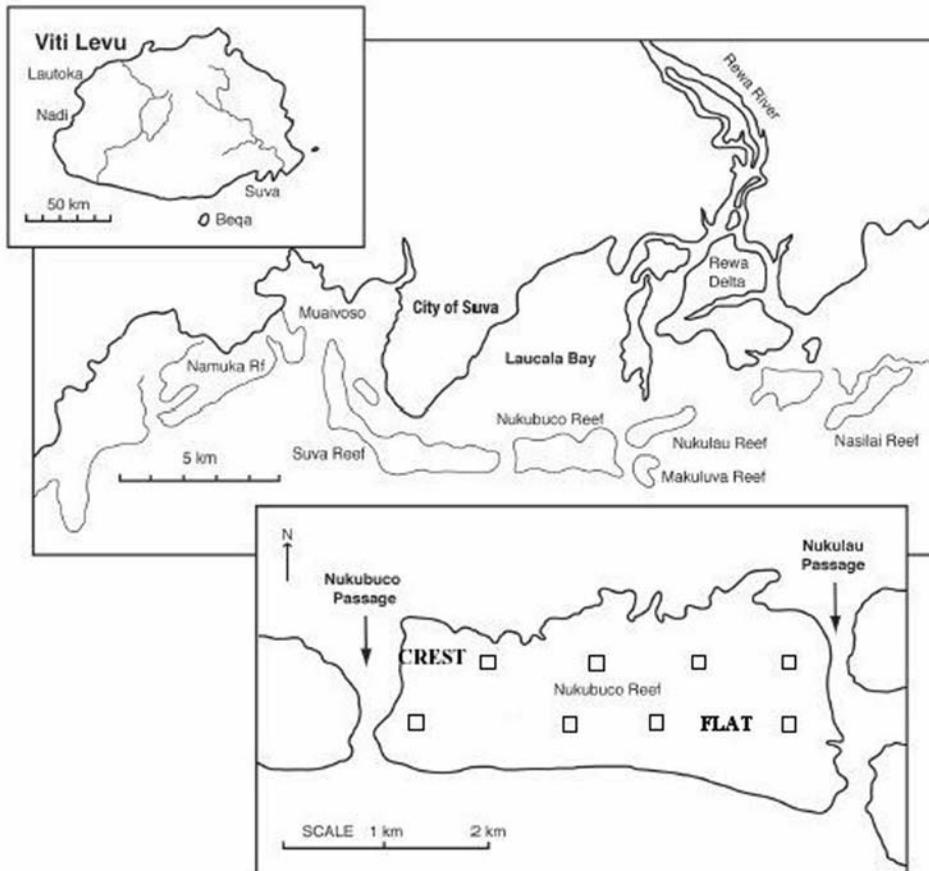


Figure 1. Map of Nukubuco reef.

ded quadrats were positioned haphazardly. Upon landing on a substrate, the quadrat was investigated for size-specific behavior of urchins, which was recorded via observations of feeding, burrowing and scouring for each urchin. When urchin spines were observed boring or resting tightly onto the walls of the burrow, it was classified as 'burrowing'; when the spines were seen propelling at the sight of sinking particles, it was termed 'feeding' and if they were seen to be stationary, 'scouring' was checked. Activity was coded as 1=feeding, 2=burrowing and 3=scouring. The sizes were categorized into 3 size classes: 1-39mm = small; 40-60mm = medium and 61-110mm = large.

The change in urchin density with substrate coverage was also investigated. The substratum type coverage beneath each urchin was noted. The gridded quadrat (each grid covered 4% of the total quadrat area) aided in calculating percent cover of the substratum. The dominant substratum types were live coral and coral rock. Other substratum types included sand, rubble, macroalgae, coralline

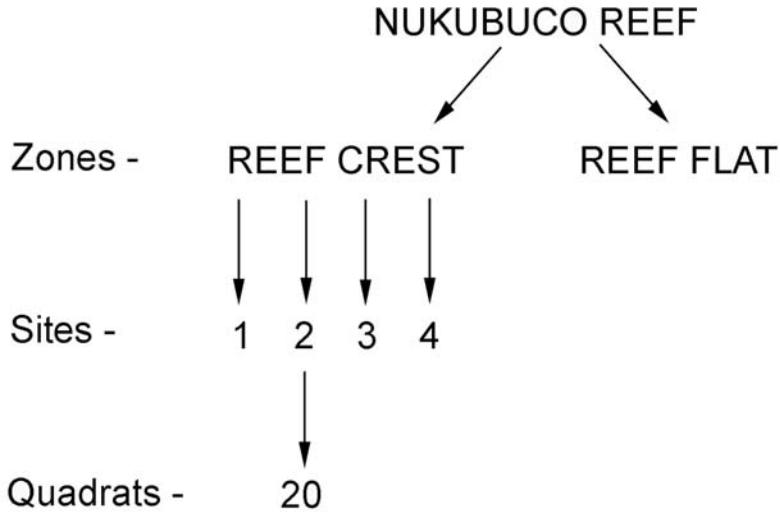


Figure 2. Nukubuco reef sectors.

algae, turf algae and rock. To facilitate analyses, percentage cover was estimated to the nearest 20%. Once a quadrat was haphazardly placed on a surface that had urchins, note was taken on how many squares occupied each type of substratum within the 1-m² quadrat.

GUT ANALYSES

Laboratory experiments on gut analyses of *Echinometra* sp. A allowed quantification of CaCO₃ erosion on Nukubuco reef, specific to zones i.e. reef crest and reef flat. Fifty urchins (25 from the reef-flat and 25 from the reef crest) were collected early in the morning to consider their full gut content as a measure of their daily consumption, the fact being that they feed during the night and that the gut is emptied during the day; Ogden 1977, Russo 1980, Bak 1990, 1994). Downing & El-Zahr (1987) have shown that gut-filling rates equal gut evacuation rates daily. Regression analyses [$y = \text{calcium carbonate (g)}$, $x = \text{test diameter (mm)}$] were performed to obtain the best function (linear, power or exponential) that fit the trends of the raw data on the gut content. The test diameter was measured using a Vernier caliper. Conventional gut-analysis protocols (Russo 1980, Bak 1990, 1994, Conand et al. 1997, Downing & El-Zahr 1987) were followed to assess the CaCO₃ content in the guts of urchins. Scatter plots demonstrated the correlation between test diameter of urchins and the respective CaCO₃ content in their gut.

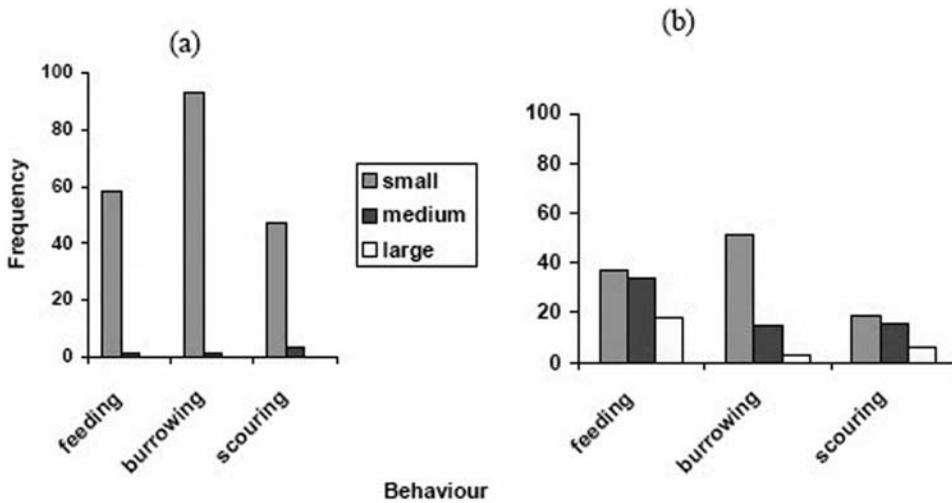


Figure 3. Behavioral activity of *Echinometra* sp. A size-classes at the (a) crest and (b) flat.

Results

SIZE-SPECIFIC BEHAVIOR

In the Nukubuco reef, *Echinometra* sp. A typically formed small, cryptic guilds on the dead branches of live coral colonies, in substratum crevices, under coral ledges or on dead coral skeleton. They formed immobile guilds near burrows or beside coral knolls, both dead and alive, during the day. The urchins on partly dead corals clustered around the white scars left from grazing activity, which were vividly visible. Urchins of all sizes were commonly seen nestled around massive and submassive *Porites* and smaller ones burrowed in crevices on *Porites* heads.

The reef crest displayed urchins actively burrowing followed by feeding then scouring (Figure 3a). Only small (1-39mm) and medium (40-60mm) urchins were observed at the crest. These urchins preferred a combination of burrowing and feeding. Small sized *Echinometra* sp. A dominated the crest, mostly observed very tightly welded to the crevices.

The reef flat showed all classes of activity by all size classes of *Echinometra* sp. A (Figure 3b). Similar to the crest, a higher percentage of urchins were burrowing on the reef flat compared with feeding. The higher burrowing response observed for the flat was specific to small sized urchins. The large (61-110mm) ones were rarely seen burrowing. The dominance of burrowing behavior may be explained by Forster's (1959) and Kelso's (1970) suggestion that ingestion of detrital algae washed into burrows is the main feeding strategy of *Echinometra*. It is possible that this feeding behavior may have been misinterpreted as a burrowing response as the urchins would tend to stay welded to their burrows, not changing their positions. Also *Echinometra* do not seem to home at all, and their positions in the habitat seem to be the result of chance (Khamala 1971). The

attraction for crevices would be selectively advantageous since it serves to hide them from predators, reduce light intensity and desiccation and provide protection against turbulent waves. Boring into rocks and other hard material by echinoids is well established (Reese 1966), and it is likely that the outer reef burrows and crevices in which *Echinometra* specimens are found are made by the urchins themselves.

All size categories of urchins existed on flats and demonstrated “all” behavioral responses (feeding, burrowing and scouring). The flats comprise a bigger area compared with the crests, and demonstrated a higher variability in substrata and topographic complexity. This increases options for micro-spatial preferences of *Echinometra* spp. (Russo 1980). Moreover, the flats provide ample opportunities for feeding; either using grazing or detrital mode and huge coral rock structures are available for burrowing and escaping predation. Since coral rock presents an ‘easy-to work-with’ substratum compared with live coral, burrowing activity should have been dominant on the flats than crests.

URCHIN DENSITY IN RELATION TO SUBSTRATUM COVERAGE

Large numbers of *Echinometra* sp. A were observed nestled under *Porites* boulders and tightly burrowed onto crevices of *Porites* heads on Nukubuco reef flats. The landward edge of the crest had high numbers of urchins colonizing the partly bleached *Porites cylindrica* microatolls. The reef flat had sturdier forms while the crest showed more digitate and plate forms of corals. Coral rock masses had high numbers of *Echinometra* sp. A which frequently appeared together with *Acanthaster planci*. Urchins were mostly evident on half-bleached or damaged corals and coral rock compared with live coral colonies.

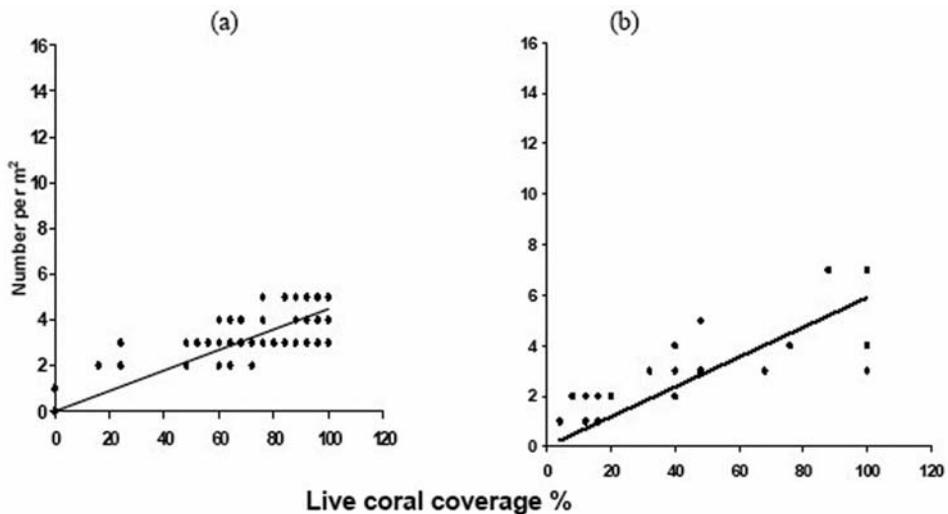


Figure 4. *Echinometra* sp. A density for varying live coral % coverage for 4 sites of the (a) reef crest and (b) reef flat. Data were $\log(x + 1)$ transformed to homogenize the variances.

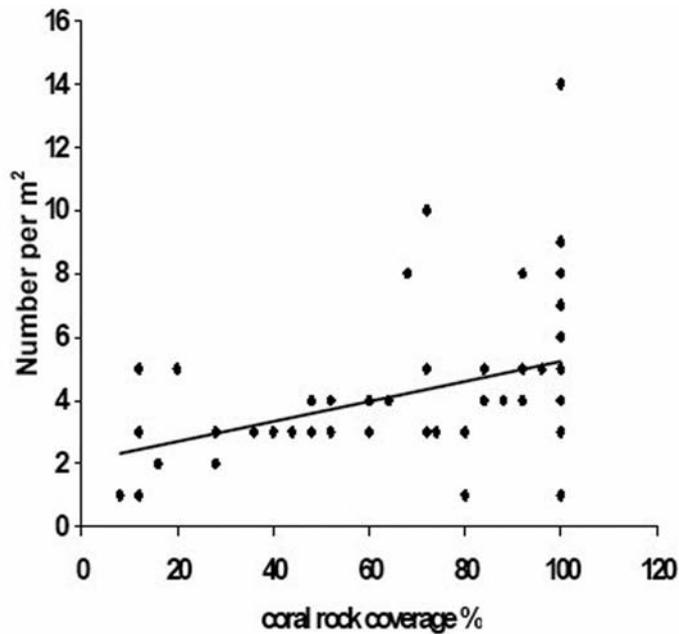


Figure 5. *Echinometra* sp. A density for varying coral rock % coverage for 4 sites of the reef flat. Data were $\log(x + 1)$ transformed to homogenize the variances.

The reef crest (Figure 4a) shows a strong association ($r = 0.767$) between live coral coverage and *Echinometra* sp. A density, whereby the coral coverage explained 58.3% ($r^2 = .583$) of the variation in number of urchins at the crest. The regression ANOVA showed a highly significant linear relationship ($F = 110.239$, $P < 0.01$) between the percent cover of live coral and density of urchins. Urchin density increased with increasing coverage of live coral. *Echinometra* sp. A were closely affiliated with live coral at the crest. Since mostly the small and medium sized urchins were observed at the crest, it could probably have been new recruits of a cohort as the oceanic waters disperse pelagic larvae. No coral rock was observed at the reef crest.

Although the flat had lower colonizations of *Echinometra* sp. A on live coral (Figure 4b), a strong correlation ($r = 0.793$) existed; live coral coverage explained 60.7% ($r^2 = .607$) of the variation in number of urchins at the flat. The regression ANOVA showed a significant linear relationship ($F = 30.403$, $P < 0.01$) between the two variables. Hence, live coral increase showed a relative decline compared with coral rock, in *Echinometra* sp. A densities at the flat.

The reef flat showed (Figure 5) a moderately good correlation ($r = 0.463$) whereby coral rock coverage explained 20.0% ($r^2 = .200$) of the variation in the number of urchins and the regression ANOVA showed a significant linear relationship ($F = 15.786$, $P < 0.01$) between the two variables. Large numbers of *Echinometra* sp. A (mean population density = 4 urchins/m²) were on coral rock at the reef flat.

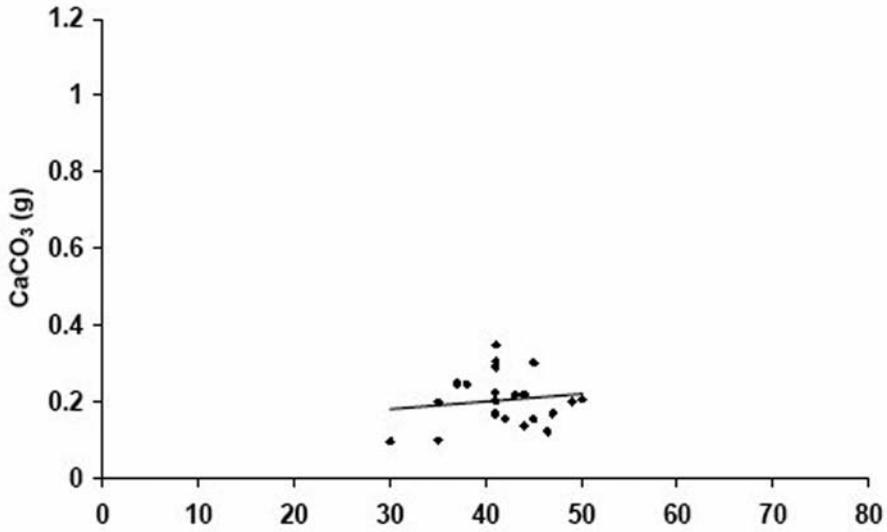


Figure 6. Size-specific CaCO_3 consumption rates for *Echinometra* sp. A on the reef crest of Nukubuco. Labels on the x-axis are the upper limit of each test diameter size (Total N = 25). $y = 0.0187x - 0.532$; $p < 0.01$; $r^2 = 0.419$

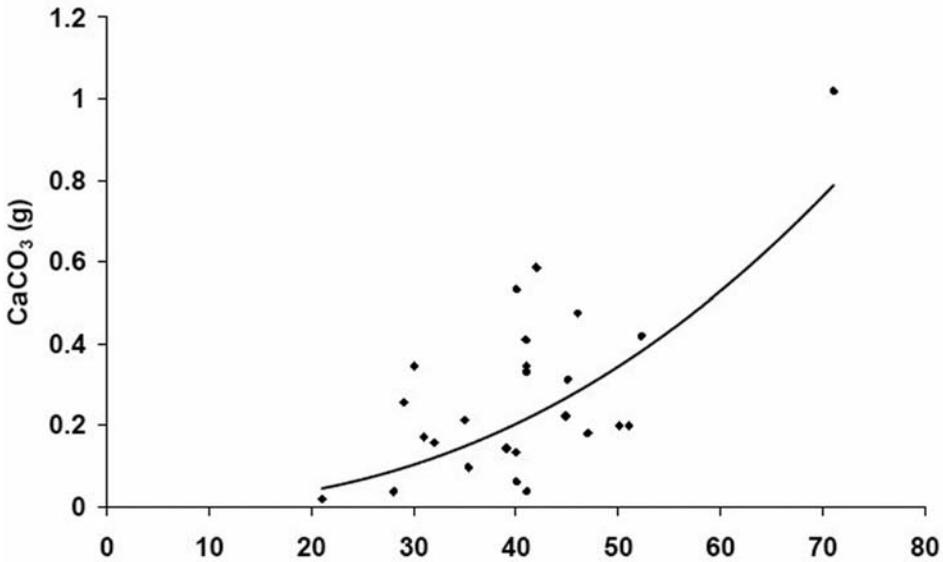


Figure 7. Size-specific CaCO_3 consumption rates for *Echinometra* sp. A on the reef flat of Nukubuco. (Total N = 25). $y = 0.0000726x^{2.142}$; $p = 0.006$; $r_2 = 0.253$

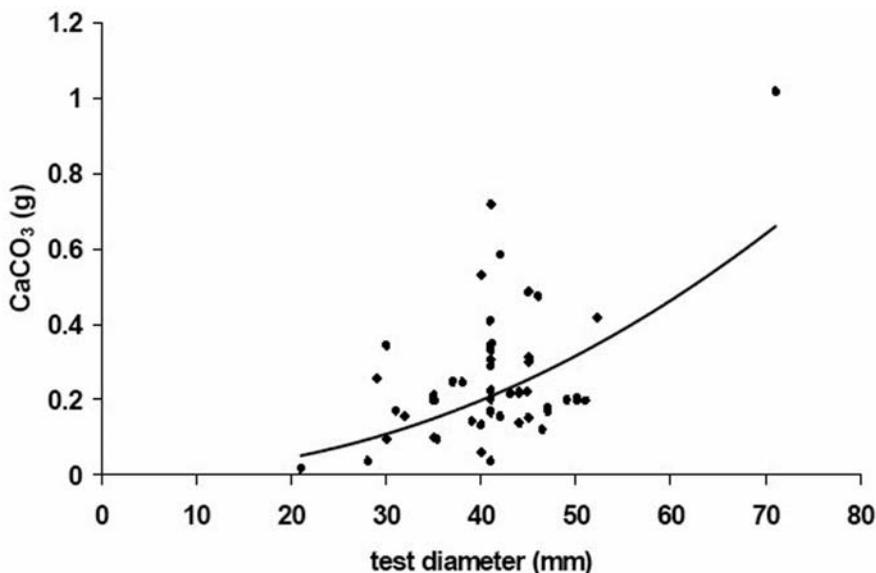


Figure 8. Size-specific CaCO_3 consumption rates for *Echinometra* sp. A on Nukubuco reef. (Total $N = 50$). $y = 0.0000838x^{2.107}$; $p < 0.01$; $r^2 = 0.28$.

GUT ANALYSIS

The gut analyses rates were reported using two different functions, power and linear on the different zones. This was only done as those functions demonstrated the best fit of data in those zones. Urchin sizes ranged from 30–50mm and reflected the sizes available at the crest (Figure 6) with small urchins being mostly cryptic (Zann et al. 1987, Zann et al. 1990). The crest data showed a linear correlation between CaCO_3 consumption and urchin test diameter of *Echinometra* sp. A. Using equation $y = 0.0187x - 0.532$, bioerosion rates on the reef crest (Figure 6) was reported to be 0.39×10^{-3} kg CaCO_3 /urchin/d for mean urchin size 41.9mm.

The flat on the other hand displayed urchins with sizes ranging between ≥ 20 mm and < 80 mm (Figure 7). The flat data fitted well as a power function ($F = 9.119$, $P = 0.006$) with high significance and $r^2 = 0.253$. Thus, the urchins on the flat were actively feeding proportional to increase in size and volume. The flat reported lower bioerosion rates, 0.20×10^{-3} kg CaCO_3 /urchin/d for mean urchin size 40.6mm using $y = 0.0000726x^{2.142}$. An analysis of the pooled data (Figure 8) also demonstrated power function as the best fit ($F = 20.752$, $P < 0.01$, $r^2 = 0.287$).

Discussion

Nukubuco reef is relatively unique as it withstands influence from the Kinoya Sewage Treatment Plant (Naidu et al. 1991) and high sediment inputs from Vatuwaqa, Samabula, Vunidawa and Rewa river run-offs (Hinrichsen 1998). This explains the influence that *Echinometra* sp. A may be having on this reef.

The high levels of terrigenous inputs of nutrients into the bay enhance phytoplankton production leading in turn to higher survivorship in planktotrophic echinoderm larvae (Birkeland 1989). Birkeland (1981) and Glynn (1988) have stated that an increase in algal abundance following *Acanthaster planci* outbreaks or other disturbances may elicit a numerical response from grazing urchins through facilitating higher recruitment. Thus *Echinometra* sp. A are believed to be a secondary effect of *A. planci* outbreaks (Keesing 1992). Furthermore, the increased sedimentation from river run-offs suffocates corals and leads to death (Birkeland 1989). Collectively, these effects provide a suitable substratum for *Echinometra* dominance on Nukubuco reef.

High numbers of *Echinometra* sp. A could also be explained by overfishing of predatory finfish such as triggerfish on the reef (Hay 1984, McClanahan & Muthiga 1988, 1989). Absence of parrotfishes and surgeonfishes on the reef supplement this inference. Urchins such as *Echinometra* and *Diadema* have often been dominant herbivores on unprotected (heavily fished) coral reefs while herbivorous fishes such as parrot and surgeonfishes dominate (little or unfished) protected reefs (Hay 1984, McClanahan & Shafir 1990).

Echinometra sp. A abundance on Nukubuco reef is associated with large numbers of submassive and massive *Porites* colonies and sparse colonies of *Montipora* and *Acropora*. McClanahan & Mutere (1994) suggested that coral cover, species richness and diversity are negatively associated with sea urchin abundance to the point where *Porites* compose >90% of the coral cover at the sites of sea urchin dominance. This study supported their findings where a strong association between *Echinometra* abundance and *Porites* assemblage was found on the Nukubuco reef. McClanahan & Mutere (1994) gave two general explanations: (1) sea urchins directly affect abundance, size and species composition of corals through their feeding and spine abrasion activities (Sammarco 1980, 1982, Carpenter 1981, McClanahan & Shafir 1990), and/or (2) environmental or human impacts simultaneously affect both sea urchins and hard corals.

McClanahan et al. (1996) stated that the effects of sea urchins on coral abundance and diversity could be more indirect and complicated. Field and computer simulation studies indicate that reefs dominated by sea urchins can maintain coral cover by reducing the abundance of algae that potentially compete with coral for light and space (Sammarco 1982, Hughes et al. 1987, Carpenter 1990, McClanahan 1995). On the other hand, sea urchin grazing, which is more intense than fish grazing (Birkeland 1989, McClanahan 1992), can damage corals and reduce their recruitment (Bak 1994, Sammarco 1980, McClanahan & Mutere 1994). Hence, the higher numbers of *Echinometra* sp. A on coral coverage imply the potential harm they can cause to the longevity of Nukubuco reef.

Foraging activity is related to body size (Hart & Chia 1990): medium-sized *Echinometra* are more inclined to feed than the small and large sized. In an experiment the small-sized urchins showed a low rate of feeding while large-sized initially demonstrated a low foraging rate, which increased throughout the experiment (Hart & Chia 1990). Growth in *Echinometra* is highly dependent on food

availability (Muthiga 1996). There are a number of factors that might be related to noted feeding difference among size classes. These include differing nutrient requirements, susceptibility to predation and intraspecific competition for space. Alternatively, this difference is probably due to different functions allocated for the crest and flat.

The gut analyses demonstrated a lower bioerosion rate on the flat 0.20×10^{-3} kg CaCO₃/urchin/d, compared to the crest, 0.39×10^{-3} kg CaCO₃/urchin/d. Russo (1980) estimated a daily mean erosion rate of 0.1 to 0.2×10^{-3} kg CaCO₃/urchin/day in his studies of *Echinometra mathaei* on Enewetak Atoll, and Ogden (1977) estimated 0.12×10^{-3} kg CaCO₃/urchin/day (mean dry weight CaCO₃ per gut was 0.12g, and a turnover of once per 24 h was assumed) with *E. lucunter*. The two estimates above compare very closely with this study, despite the different species and sampling in different locations.

This study highlights research on *Echinometra* sp. A in Fiji, which was initially thought to be *E. mathaei*. This study has demonstrated predominance of small and medium-sized urchins on the crest and flats of Nukubuco reef. These urchins showed high frequencies of feeding and burrowing activities, especially on the reef crest. With consistent events of bleaching and *Acanthaster planci* outbreaks, less live coral colonies exist on this reef. *Echinometra* showed proportional association with increasing coral rock substratum. Thus, *Echinometra* seem to play an important role in influencing coral reef carbonate budget and configurations.

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