Sea urchin bioerosion on coral reefs: place in the carbonate budget and relevant variables.

Bak, R.P.M.

Published in:
Coral reefs

Citation for published version (APA):
Sea urchin bioerosion on coral reefs: 
place in the carbonate budget and relevant variables

R. P. M. Bak
Netherlands Institute for Sea Research (NIOZ) P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands

Accepted 13 May 1993

Abstract. Two aspects of erosion by sea urchins (Echinoidea) 
in coral reef habitats are: the direct passage of reef 
framework material through the gut and the indirect 
effects through the weakening of the reef structure. Urchin 
bioerosion can equal or exceed reef carbonate production. 
The impact of urchins on reefs depends on three variables: 
species type, test size and population density. Large 
differences in bioerosion by urchins of the same test size 
occurs between different species. Size differences between 
species in a sea urchin community, as well as size differences 
within a species along a reef, can be significant. Bioerosion 
per urchin increases enormously with size. Changes in 
population density, through time and space, result in 
significant changes in bioerosion. It is demonstrated how 
the interaction of these variables determines in-situ sea 
urchin bioerosion.

Introduction

In the interplay between constructive and destructive 
forces in reef-building, bioerosion plays a major rôle: In 
fact the outcome of this interaction may decide the fate of 
the reef structure (Stearn et al. 1977; Scoffin et al. 1980; 
Lessios 1988; Bak et al. 1984; Glynn et al. 1979; Bak 1990). 
A variety of organisms are involved in bioerorative processes 
and a group frequently listed is the sea urchins (Echinoidea). 
A large group of sea urchins, the irregular echinoids, are 
not engaged in bioerosion. They live on soft bottoms and 
feed as sediment ingestors. The regular echinoids are the 
dominating urchins in coral reefs. They can erode hard 
substratum indirectly through weakening their structural 
environment, causing parts to become dislodged in storms, 
and directly through their feeding behaviour. Regular 
urchins employ four sources of food: attached/driftling 
plants, encrusting/excavating organisms, sessile organisms, 
and detritus. The last three categories of food especially 
are accessed using a strong, agile and somewhat protractile 
chewing apparatus, which is responsible for the scraping 
erosion caused by grazing on hard substrata. 

In contemporary reefs, a limited number of species 
are capable of grazing/abrad ing the carbonate reef substrata 
and are commonly reported to be of importance in bio-
erosion. In the Atlantic, important species are: Diadema 
antillarum Philippi, and Echinometra lucunter (Linnaeus) 
(1974; Ogden 1976; Scoffin et al. 1980; Carpenter 
1988). In the Indo-Pacific Euclidaris thouarsii (Valenciennes), 
Diadema savignyi Michelin, D. setosum (Leske), Echinolithrix 
calamaris (Pallas), E. diadema (Linnaeus), Echinometra 
mathaei (de Blainville), and Echinostrephus molaris (de 
Blainville) have been mentioned as important bioeroders 
(Glynn and Wellington 1983; McClanahan and Muthiga 
1988; Bak 1990). At least two of these species, Diadema 
antillarum and Euclidaris thouarsii, feed on the non-living 
component of the reef framework as well as on living coral 
surfaces (Bak and van Eys 1975; Carpenter 1981; Glynn 
and Wellington 1983).

Bioerosion by urchins has many aspects. One significant 
aspect of urchin bioerosion, though not treated here, has 
major biological and geological effects. This includes all 
abrasive activities, including spine abrasion, which results 
in the forming of cavities and burrows. In the same category 
are all effects resulting from urchin abrasive activity, such 
as the dislodgement of large massive coral colonies after 
storms have weakened the bases of coral colonies. 
Echinoid bioerosion in this report is limited to the erosion 
caused by the feeding activities of the organisms. This 
short study incorporates the literature, supplemented with 
unpublished data collected by the author, to address the 
questions: how important is sea urchin bioerosion in the 
context of reef construction/destruction, and, what are the 
important variables in sea urchin bioerosion?

How important is sea urchin bioerosion?

How important is urchin bioerosion compared with the 
total bioerosion? Unfortunately, the activities of the dif-
fiercely different groups of bioeroders have rarely been assessed on one reef, but where they have been studied, echinoids played a major role. Table 1 shows total bioerosion from the activities of three groups of organisms, parrot fish (Scaridae), excavating sponges (mainly Clionidae), and sea urchins (Diadema antillarum), on two Caribbean fringing reefs. Sea urchins played a major role on each reef since more than 75% of the total bioerosion was attributed to their feeding behaviour.

Table 1. Echinoid erosion as percentage of total bioerosion (g·m⁻²·d⁻¹)

<table>
<thead>
<tr>
<th>Echinoid (%)</th>
<th>Total (g)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbados</td>
<td>79.4</td>
<td>18.7</td>
</tr>
<tr>
<td>Curacao</td>
<td>87.8</td>
<td>9.0</td>
</tr>
</tbody>
</table>

Table 2. Gross production estimates of reefs versus estimated rates of echinoid bioerosion

<table>
<thead>
<tr>
<th>Gross prod (kg·m⁻²·y⁻¹)</th>
<th>Echinoid bioerosion (kg·m⁻²·y⁻¹)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–10*</td>
<td>Chave et al. 1972</td>
<td></td>
</tr>
<tr>
<td>1–2</td>
<td>Smith and Harrison 1977</td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>Land 1979</td>
<td></td>
</tr>
<tr>
<td>15**</td>
<td>Stearn et al. 1977</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Scoffin et al. 1980</td>
<td></td>
</tr>
<tr>
<td>3.4–8.0</td>
<td>Glynn and Wellington 1983</td>
<td></td>
</tr>
<tr>
<td>3.0</td>
<td>Bak et al. 1984</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Bak 1990</td>
<td></td>
</tr>
<tr>
<td>0–5.78 (1.21***</td>
<td>Hubbard et al. 1990</td>
<td>Ogden 1977</td>
</tr>
</tbody>
</table>

* 100% cover, ** excluding sandy area, *** average

Table 3. Echinoid erosion as percentage of gross production (g·m⁻²·d⁻¹)

<table>
<thead>
<tr>
<th>Echinoid (%)</th>
<th>Gross prod.</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barbados</td>
<td>47</td>
<td>24.7–31.2</td>
</tr>
<tr>
<td>Curacao</td>
<td>96</td>
<td>8.2</td>
</tr>
<tr>
<td>Galapagos</td>
<td>5–100</td>
<td>9.3–21.9</td>
</tr>
<tr>
<td>Moorea</td>
<td>216</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 4. Erosion rates (g·m⁻²·d⁻¹) for groups of excavating and scraping animals in reef environments

<table>
<thead>
<tr>
<th>Locality</th>
<th>Polychaetes</th>
<th>Sponges</th>
<th>Echinoids</th>
<th>Scarids</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caribbean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>St. Croix</td>
<td></td>
<td></td>
<td>23.3</td>
<td>1.3</td>
<td>Ogden 1977</td>
</tr>
<tr>
<td>Panama</td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
<td>Scoffin et al. 1980</td>
</tr>
<tr>
<td>Barbados</td>
<td>3.8</td>
<td>14.8</td>
<td></td>
<td>1.4–19.2</td>
<td>Bruggeman personal communication</td>
</tr>
<tr>
<td>Curacao</td>
<td>0.5</td>
<td>7.9</td>
<td></td>
<td></td>
<td>Bak et al. 1984</td>
</tr>
<tr>
<td>Bonaire</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moorea</td>
<td>0.9–13.2</td>
<td>12.5</td>
<td></td>
<td></td>
<td>Bak 1990</td>
</tr>
<tr>
<td>GBR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hutchings and Bamber 1985</td>
</tr>
</tbody>
</table>

The importance of echinoid bioerosion is evident by comparing it with a gross carbonate production. Estimates of gross production on reefs generally vary with three variables: coral cover, coral species and growth rate (the last two being interrelated). Values of gross production range from zero (no cover, Hubbard et al. 1990) to 10–15 kg·m⁻²·y⁻¹ (100% cover, Chave et al. 1972; Stearn et al. 1977), but generally are 1–4 kg·m⁻²·y⁻¹ (Table 2). Records of sea urchin bioerosion are in the same range and it appears that urchin bioerosion can sometimes equal or exceed reef carbonate production.

A much more accurate picture is obtained if we compare echinoid bioerosion with gross production on the same reef. This comparison has been made in widely separate localities: the Caribbean, the central and the eastern Pacific. In all cases echinoid erosion was an extremely important factor in the carbonate budget (Table 3). A substantial part of the gross production can be eroded. In some cases the balance between reef construction and destruction was negative because the rate of reef framework destruction was higher than that of framework formation. When sea urchin erosion rates are compared with such figures for other groups of bioeroding organisms (Table 4), urchin erosion is considerable. This is the case even though other organisms, e.g. parrot fishes in the shallow reef of Bonaire (Bruggeman personal communication), can make very substantial contributions.

What are the important factors in echinoid bioerosion?

Urchin communities on reefs vary in species composition, in size frequency distributions, and in densities. The importance of a factor such as density seems obvious, as well as the possible consequence of the taxonomic composition of an echinoid community. Even so, there are very few data on the quantitative impacts of different densities of different urchin species in the same reef habitat. Similarly, the significance of sea urchin size frequency distribution in reef bioerosion processes has only rarely been described (e.g. Scoffin et al. 1980). Interaction of these three variables in the same reef habitat in quantitative terms has never been quantified. I studied bioerosion of a mixed community of echinoids, consisting of Diadema savigniy, Echinohthrix diadema and Echinometra mathaei, in a reef at Tiahura on the island of Moorea, French Polynesia. The depth of the study site was 1.5 to 2.5 m, (see Galzin and Pointer 1985);
for details on measuring urchin densities, population size frequencies and bioerosion see Bak (1990).

First, there are important differences in species. Quantitative differences in bioerosion between two species of urchins, *E. Mathaei* and *D. savignyi*, in the same size class are shown in Fig. 1. *E. mathaei* individuals eroded more material than *D. savignyi* of the same size in all but the largest *E. mathaei* size class (test diameter 35–39 mm, Fig. 1a). When larger individual *D. savignyi* erosion rates are compared with the larger individuals of *E. diadema* there is also a small difference (Fig. 1b) but it is difficult to say if these are universal characteristics of the species, since no other data sets are available.

The next variable to assess is size. Two aspects are important, differences in size between species and differences in size between populations of the same species. The data from Moorea (Fig. 2a) clearly show the difference in size between the small species *E. mathaei* and the large *D. savignyi*. In addition, mean size and size frequency of populations can vary significantly within a species. The test size in three populations of *D. antillarum* was measured occurring at shallow depths (< 10 m) along the south coast of Curacao (Bak and van Eys unpublished) and the data show that there are considerable differences in size frequency between the populations (Fig. 2b). Most obvious is the difference between the large animals of the Awa population and the smaller ones of the Carmabi buoys, but the difference between all three populations was significant (Kolmogorov-Smirnov two sample test on the three density functions, all comparisons P < 0.0001). Such variation in size is possibly related to factors such as food availability (Levitan 1988).

These large differences in size frequency of populations have significant consequences for sea urchin bioerosion. Figure 1 indicates, apart from the differences between the species, the increase in bioerosive potential with increasing size in each urchin. Within each species larger animals are much more effective as bioeroders. Data on the mean bioerosion rates of *Echinometra* species support this relationship (Table 5). In populations with a test size of about 30–40 mm mean erosion rates are 5 to 10 times higher as in populations with mean tests half that size.
Table 5. Mean test size (mm) and mean erosion rates in Echinometra (g urchin⁻¹ d⁻¹) at a range of localities

<table>
<thead>
<tr>
<th>Size</th>
<th>Erosion</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hawai</td>
<td>19.5</td>
<td>0.11</td>
</tr>
<tr>
<td>Moorea</td>
<td>19.3</td>
<td>0.14</td>
</tr>
<tr>
<td>Arabian Gulf</td>
<td>37.1</td>
<td>0.9–1.4</td>
</tr>
<tr>
<td>Kenya</td>
<td>40.8</td>
<td>0.7</td>
</tr>
<tr>
<td>E. lucunter</td>
<td>30.0</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Finally, the density of urchin populations is also an important variable. There are large differences in spatial densities within species at all scales. The smallest scale at which density differences can be demonstrated, a few metres, has no significance for bioerosion. Urchins operate on a larger scale in the process of bioerosion. There are also variations in density with depth, over tens of metres and along coasts, on scales of hundreds of metres or kilometres (Table 3 Birkeland 1989). Urchin density ranges from less than one to more than ten per square metre. Variations in time also occur. In 1974 we measured densities in shallow D. antillarum populations of 12.5 and 11.3 urchins m⁻² at two sites on the south coast of Curacao (Bak and van Eys unpublished). In 1983 these densities were 2.9 and 4.2 urchins m⁻², respectively (Bak et al. 1984). Events such as sea urchin mass mortalities result in significant decreases in density and as a result, bioerosion and foraging processes are significantly altered (de Ruyter van Steveninck and Bak 1986; Carpenter 1985).

The major question is how these variables, taxonomic identity, test size and population density, interact. Interaction is demonstrated by the results of the Moorea study (Fig. 3). When urchins are in the same size class, Echinometra (per urchin) has more impact as a bioeroder than Diadema (Fig. 1a). This is a species specific characteristic. The impact of Echinometra was enhanced because its density was nearly twice that of Diadema, 7.4 versus 4.8 urchins m⁻². Nevertheless, because the Diadema were much larger in size, the Diadema population has a much larger impact as a bioeroder than the Echinometra population (Fig. 3). The third important urchin at the site, Echinothrix, had a very large test size. However, density was relatively low and consequently total bioerosion caused by the population was low. The effect of high density and large test size was shown by the Diadema population. It was by far the most important urchin in terms of bioerosion (Fig. 3).

In conclusion, sea urchin bioerosion appears to be a major factor determining the fate of the reef structure and is a significant component in the carbonate budget. In conclusion, it has been shown that a simple model where bioerosion B:

\[ B = (n_1 \times s_{p1})(n_2 \times s_{p2}) \ldots (n_i \times s_{pi}) \]

in which \( n_i \) is urchin density in each size class \( i \) and \( s_{pi} \) is species specific bioerosion in size class \( i \), can be used to quantify the impact of urchin bioerosion. The impact of the three variables was demonstrated through analysis of urchin bioerosion on coral reefs of Moorea, French Polynesia.

Acknowledgements. I thank Dr. M. Peyrot-Clausade and Prof. B. Salvat for supporting my research in French Polynesia. Birthe Gade was kind to read the ms. This paper was originally presented at the Seventh International Coral Reef Symposium, Guam.

References


Chave KE, Smith SV, Roy KJ (1972) Carbonate production by coral reefs Mar Geol 12:123–140


Smith SV, Harrison JT (1977) Calcium carbonate production of the mare incognitum, the upper windward reef slope, at Enewetak Atoll. Science 197:556–559