Chemical and mechanical bioerosion of boring sponges from Mexican Pacific coral reefs

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SUMMARY

Species richness (S) and frequency of invasion (IF) by boring sponges on living colonies of *Pocillopora* spp. from National Park Isla Isabel (México, East Pacific Ocean) are presented. Twelve species belonging to the genera *Aka*, *Cliona*, *Pione*, *Thoosa* and *Spheciospongia* were found, and 56% of coral colonies were invaded by boring sponges, with *Cliona vermifera* Hancock 1867 being the most abundant species (30%). Carbonate dissolution rate and sediment production were quantified for *C. vermifera* and *Cliona flavifodina* Rützler 1974. Both species exhibited similar rates of calcium carbonate ($CaCO_3$) dissolution (1.2±0.4 and 0.5±0.2 kg $CaCO_3$ m^{-2} $year^{-1}$, respectively, mean ± s.e.m.), and sediment production (3.3±0.6 and 4.6±0.5 kg $CaCO_3$ m^{-2} $year^{-1}$), resulting in mean bioerosion rates of 4.5±0.9 and 5.1±0.5 kg $CaCO_3$ m^{-2} $year^{-1}$, respectively. These bioerosion rates are close to previous records of coral calcification per unit of area, suggesting that sponge bioerosion alone can promote disequilibrium in the reef accretion/destruction ratio in localities that are heavily invaded by boring sponges. The proportion of dissolved material by *C. vermifera* and *C. flavifodina* (27 and 10.2%, respectively) confirms that chemical bioerosion plays an important role in sponge bioerosion and in the $CaCO_3$ cycle in coral reefs.

Key words: coral reef, boring sponge, bioerosion rate, carbonate dissolution, sediment production, Mexican Pacific Ocean.

INTRODUCTION

The growth and maintenance of coral reefs is the result of an equilibrium between the deposition and the erosion of carbonate (Hutchings, 1986). A significant part of the erosion process is of a biological nature and is termed bioerosion (Neumann, 1966). In coral reefs, bioerosion is driven by a high diversity of organisms but, usually, the dominant groups around the world are boring sponges (MacGeachy and Stearn, 1976; Hudson, 1977). The activity of these sponges and other bioeroders can weaken the reef by causing dislodgment of the framework, especially during wear and tear caused by waves (Stearn and Scoffin, 1977; Macdonald and Perry, 2003) and in some Caribbean coral reefs they are thought to be responsible for reef destruction (Rose and Risk, 1985; Ward-Paige et al., 2005).

As the sponge penetrates the coral, the substrate is gradually destroyed as a result of the sponge hollowing out an extensive system of cavities and tunnels (López Victoria et al., 2006; Calcinai et al., 2007). These excavations are produced by the expulsion of small lenticular calcareous chips (15–100 μm in diameter) through the aquiferous system of the sponge (mechanical boring) (Rützler and Rieger, 1973). Boring sponges can remove large amounts of calcareous material from the reef framework by chip production (up to 22 kg $CaCO_3$ m^{-2} $year^{-1}$), generating up to 40% of the sediment deposited on some reef ecosystems (Neumann, 1966; Rützler and Rieger, 1973; Fütterer, 1974; Rützler, 1975).

In addition, boring sponges are able to dissolve part of the carbonate during the bioerosion process (chemical boring) (Rützler and Rieger, 1973; Pomponi, 1977). Traditionally, it was considered that the amount of chemically dissolved material was minimal compared with the material removed mechanically (Rützler and Rieger, 1973; Rützler, 1975; Acker and Risk, 1985). However, it was recently shown that *Pione cf. vastifica* (Hancock 1849) dissolves three masses of reef $CaCO_3$ framework per each part of carbonate removed mechanically, suggesting that chip production represents only a small fraction of the sponges bioerosion capacity (Zundelevich et al., 2007).

The coral communities of the Eastern Pacific coast are distributed between 30 deg. N and 5 deg. S (Glynn and Ault, 2000), and the Mexican Pacific coast comprises 46% of their total distributional range. The present study was carried out in the National Park Isla Isabel (México), which harbors a typical coral community from the Eastern Pacific, formed mainly by corals of the genus *Pocillopora* (Reyes-Bonilla, 1993).

We addressed the hypothesis that boring sponges may have a major role in the incorporation of dissolved $CaCO_3$ to the water column.

This work had four goals: (1) to study the species richness (S) and the frequency of invasion (IF) by boring sponges on living colonies of *Pocillopora verrucosa* (Ellis and Solander 1786) at Isla Isabel; (2) to quantify the carbonate dissolution rate of *Cliona vermifera* Hancock 1867 and *Cliona flavifodina* Rützler 1974, two of the most abundant and amply distributed boring sponges from the east Pacific Ocean (Carballo et al., 2004; Carballo et al., 2008). This is especially important to ensure the validity and generality of previous results for *Pione cf. vastifica* (Zundelevich et al., 2007), which would allow us to establish a confident prediction about the real importance of boring sponges in coral reef environments; (3) to quantify the sediment production of *C. vermifera* and *C. flavifodina*; and (4) to quantify the bioerosion rate of these species.

MATERIALS AND METHODS
Study site
The Mexican Pacific coast harbors only a few important reef structures due to coastal upwelling and high river discharge (Reyes-Bonilla, 1993). Isla Isabel (21 deg. 50′35″N–105 deg. 53′04″W) is an oceanic island located 32 km off the coast (Fig. 1) that harbors a diverse coral community (14 species), dominated by corals of the genus *Pocillopora*, a common Eastern Pacific species (Reyes-Bonilla, 1993). Since the island is protected by natural reserve there is no significant human impact.

Quantification of the diversity and abundance of boring sponges
The species richness and abundance as frequency of invasion (IF) of boring sponges was quantified by examining living colonies of *P. verrucosa* (Carballo et al., 2008).

Sampling was carried out by scuba diving, collecting 25 fragments of the basal portion of live corals approximately 90 cm^3 along 10 transects 25 m long perpendicular to the shoreline (Carballo et al., 2008). The samples were examined in the laboratory for the presence of boring sponges. Each sample was broken into small pieces. When a sponge was found, a sample of its tissue was digested with sodium hypochlorite, and its spicular characteristics were examined under an optical microscope. The identification was done to the highest taxonomic level using the available literature (Carballo et al., 2004; Carballo and Cruz-Barraza, 2005; Bautista-Guerrero et al., 2006). The IF for each species (mean ± s.e.m.) was recorded as the proportion (%) of fragments where boring sponges were found.

Quantification of the carbonate dissolution rate
The variation in the alkalinity of the seawater has been accepted as a reliable and rapid methodology to quantify small changes in the dissolved carbonate concentration in the water (Smith and Kinsey, 1978). It was initially utilized to calculate bioerosion rates by litophagid molluscs (Lazar and Loya, 1991) and calcification in corals (Chisholm and Gattuso, 1991). Recently, this technique has been successfully tested to calculate the sponge bioerosion rate of *Pione cf. vastifica* (Zundelevich et al., 2007).

Five fragments of dead corals invaded by the boring sponge *C. vermifera* and five fragments invaded by *C. flavifodina* were

Fig. 1. Map of the National Park Isla Isabel showing the study site (arrow).

selected and transported to the laboratory. Boring sponges were allowed to recover for 24 h. Before the beginning of the experiment, each coral fragment was externally cleaned with a soft brush to remove particles that could confound the measurements of sediment production. It was then placed in a plastic container with 2.5 l of filtered, aerated seawater. Another five coral fragments without sponges were cleaned and used as controls (Zundelevich et al., 2007).

The experiment started once all fragments of both species were laid in plastic containers, under aeration and at room temperature. To record the initial total alkalinity (A_T) in the water, a 100 ml aliquot of seawater was taken from each plastic container and 25 ml of 0.01 mol l^{-1} hydrochloric acid was added. The aliquot was then homogenized and its pH was measured when it reached room temperature. A_T was determined from the following equation (modified from Rosales-Hoz, 1980):

$$A_T = \{[1000\,(VN)\,/\,X] - [1000\,(X + V)\,/\,X]\,[\text{antilog pH} / f_{H^+}]\}/1000, \quad (1)$$

where A_T is expressed in equiv. l^{-1}, V is the clorhidric acid volume used in each measurement (25 ml), N is the normality of the hydrocloric acid (0.01), X is the aliquot volume of each plastic container (ml) and f_{H^+} (0.758) is the activity coefficient.

The procedure to calculate A_T was carried out after 24 h, when the experiment concluded. The mass of CaCO$_3$ dissolved by the sponges, M (kg), was calculated from the change in total alkallinity [ΔA_T (equiv. l^{-1})] during the experiment (A_T at the end of the experiment minus A_T at the beginning, 24 h earlier) using the following equation adapted from Zundelevich et al. (Zundelevich et al., 2007):

$$M = [0.5(\text{mol equiv. l}^{-1})\,\Delta A_T 100 V_{SW}\rho_{SW}]\,/\,1000, \quad (2)$$

where 100 is the molecular mass of CaCO$_3$, V_{sw} is the volume (l) of the water in the plastic container and ρ_{sw} is the density of the seawater (1.026 kg l^{-1}).

Quantification of the sediment production
Since the size of the chips produced by boring sponges range from 15 to 100 μm (Rützler and Rieger, 1973), the water in each plastic container was passed through a sieve (150 μm mesh) to eliminate bigger particles before sieving it with a pre-weighed and dried 0.45 μm glass fiber filter. All particles within the size range of the chips produced by the sponge were retained in the filters. The particles were then gently washed with distilled water before being dried, heated to 500°C for 2 h and weighed again. The mass of the particles was determined from the difference between the final and initial masses of the filters.

Later, all particles of each filter were washed and homogenized in 1 ml of distilled water. The mean proportion of sponge chips and non-sponge chips (%) was then counted from multiple samples in a hematocytometer cell-counting slide using an optical microscope.

Sediment production (mean ± s.e.m.) was estimated as the mass of the sponge chips (kg) subtracted from the total mass of the particles retained in the filter.

Quantification of the bioerosion rate
When the experiment was finished, the fragments of dead coral were fixed with a 4% solution of formalin. To determine the amount of sponge in the fragments, these were cut into 0.5 cm sections, and both sides of the sections were photographed on a 1 cm^2 grid. The photographs were digitalized and analyzed on a computer to
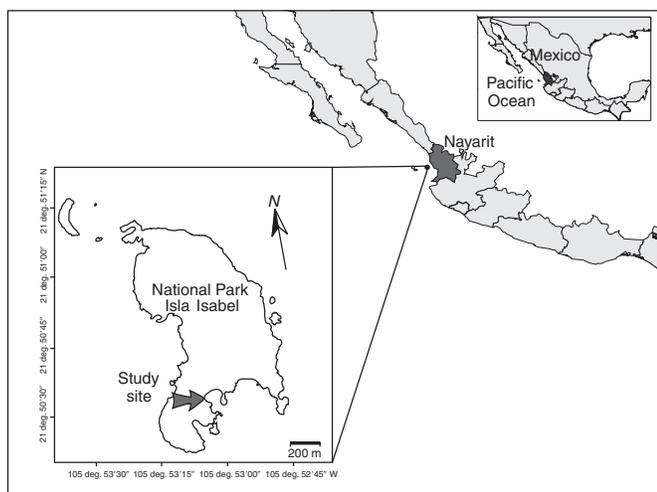
calculate the area of sponge in each section, using the grids as a reference, thus obtaining the total amount of sponge per m^2.

Since the carbonate dissolution and the production of sponge chips were quantified during a 24 h period, the bioerosion rates (mean ± s.e.m.) were extrapolated to kg $CaCO_3 m^{-2} year^{-1}$.

Data analysis
Significant differences in dissolution rate, sediment production and bioerosion rate between species were detected by analysis of variance (ANOVA) (Cochran's C-test).

RESULTS
Species richness and abundance of boring sponges
12 species belonging to four genera (*Aka*, *Cliona*, *Pione* and *Spheciospongia*) were identified, and 56% of the samples examined were invaded by boring sponges. *C. vermifera* was the most abundant species (30±2.2%, mean ± s.e.m.), followed by *Thoosa mismalolli* (Carballo et al., 2004) (18.8±1.6%). The rest of the species, including *C. flavifodina* (0.7±0.3%), had low abundance (Fig. 2).

Sponge bioerosion rate
The dissolution rate oscillated from 0.6 to 2.4 kg $CaCO_3 m^{-2} year^{-1}$ (1.2±0.4, mean ± s.e.m.) for *C. vermifera*, and from 0.1 to 1.1 kg $CaCO_3 m^{-2} year^{-1}$ (0.5±0.2, mean ± s.e.m.) for *C. flavifodina*, respectively, while the production of chips varied from 2.1 to 4.7 kg $CaCO_3 m^{-2} year^{-1}$ (3.3±0.6, mean ± s.e.m.) and from 3.8 to 5.6 kg $CaCO_3 m^{-2} year^{-1}$ (4.6±0.5, mean ± s.e.m.), respectively (Fig. 3). However, there were no significant differences between the species for both factors (ANOVA). Thus, the total bioerosion rate (sum of chemical and mechanical phases) was similar for both sponges. It ranked from 2.9 to 7.1 kg $CaCO_3 m^{-2} year^{-1}$ (4.5±0.9, mean ± s.e.m.) for *C. vermifera* and from 3.9 to 6.3 kg $CaCO_3 m^{-2} year^{-1}$ (5.1±0.5, mean ±s.e.m.) for *C. flavifodina* (Fig. 3).

DISCUSSION
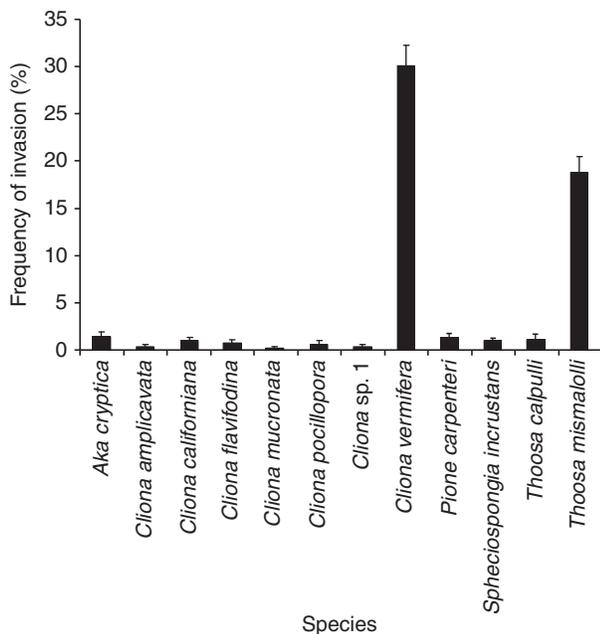#### Species richness and abundance of boring sponges
Studies that quantify the species richness and abundance of boring sponges in coral reef ecosystems are relatively scarce (Highsmith et al., 1983; Holmes, 2000; MacDonald and Perry, 2003; López-Victoria and Zea, 2005; Venkataraman and Wafar, 2005), especially in the Eastern Pacific Ocean (Carballo et al., 2008). Thus, the present study increases knowledge about the diversity and abundance of coral boring sponges in this important region.

The results showed that coral reefs from Isla Isabel harbor a more diverse boring sponge community (12 species) compared with those from southern México (seven species) (Carballo et al., 2008) but are similar to what was found in coral reefs affected by anthropogenic (eutrophication) and natural disturbances (bleaching) (MacGeachy, 1977; Hutchings and Peyrot-Clausade, 1988; Holmes, 2000; Venkataraman and Wafar, 2005).

In addition, a large proportion of the living colonies from Isla Isabel were invaded by boring sponges (56%). This percentage is higher than has been recorded from southern reefs (35%) (Carballo et al., 2008) and is similar to what has been found in eutrophic reefs or in reefs impacted by natural processes, such as El Niño (Sheppard et al., 2002; Venkataraman and Wafar, 2005).

Corals from Isla Isabel are not currently affected by anthropogenic impacts but it seems that they were affected by an El Niño event in the past, which considerably increased the availability of substrate by sponge colonization (information provided by the Isla Isabel National Park authority). The availability of dead coral substrata is a key factor in the development of the assemblages of boring sponges (Lopez-Victoria and Zea, 2005). The most abundant boring sponge was *C. vermifera* (30% of the fragments analyzed), the main coral-boring sponge from the Mexican Pacific ocean (Carballo et al., 2008).

Bioerosion rates
This study provides the bioerosion rate of two coral boring sponges from the Eastern Pacific, and confirms the high capacity of these sponges to dissolve carbonate during the erosion process.

C. flavifodina and *C. vermifera* dissolved 0.5 and 1.2 kg $CaCO_3 m^{-2} year^{-1}$, respectively, which represents almost one-tenth and one-third of carbonate dissolved per part removed mechanically. *P. cf. vastifica* dissolved 0.3 kg $CaCO_3 m^{-2} year^{-1}$, which represents
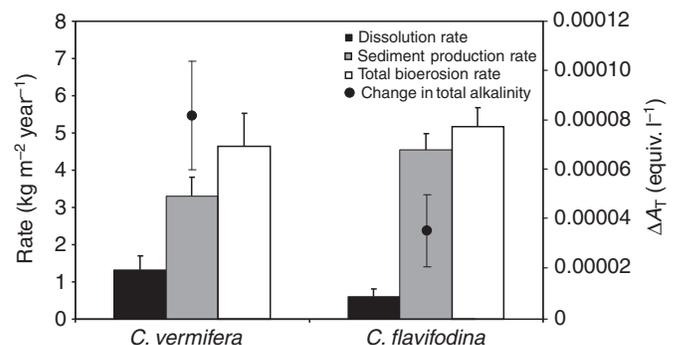

Fig. 2. Frequency of invasion (%, mean ± s.e.m.) for each species of coral boring sponges.

Fig. 3. Dissolution rate (kg $m^{-2} year^{-1}$; mean ± s.e.m., black bars), sediment production (gray bars) and total bioerosion rate (open bars) of the coral boring sponges *Cliona vermifera* and *Cliona flavifodina*. The mean change in total alkalinity (ΔA_T, in equiv. l^{-1}) are shown as closed circles in the y_2-axis.

Table 1. Bioerosion rates (kg $CaCO_3\,m^{-2}\,year^{-1}$) and proportion of dissolved $CaCO_3$ (DP) produced by different boring sponges in coral reefs of several localities

Species	Bioerosion rate (kg $CaCO_3\,m^{-2}\,year^{-1}$)	DP (%)	Locality	Source
Cliona caribbaea	8.0	2	Grand Cayman Island	(Acker and Risk, 1985)
Cliona peponaca	2.5–3.3	–	Curaçao	(Bak, 1976)
Cliona lampa	22.0–23.0	–	Harrington Sound, Bermuda	(Neumann, 1966)
Cliona vermifera	4.6	28.7	Bahía Tiburón, México	Present study
Cliona flavifodina	5.2	11.8	Bahía Tiburón, México	Present study
Cliona aprica	7.0	–	Carrie Bow Cay, Belize	(Rützler, 1975)
C. lampa	6.6–14.2	2–3	Bermuda	(Rützler, 1975)
C. lampa	–	2–3	Bermuda	(Rützler and Rieger, 1973)
Cliona orientalis	3.4–10.3	–	Great Barrier Reef	(Schönberg, 2002)
Pione cf. vastifica	0.84	75	Red Sea	(Zundelevich et al., 2007)

three parts of $CaCO_3$ per part of carbonate removed in the form of sediment (Zundelevich et al., 2007).

Since previous studies did not calculate the dissolution rate during the bioerosion process, comparisons with different sponges cannot be made. The dissolved fraction, 27.0% in *C. vermifera*, 10.2% in *C. flavifodina* and 75% in *P. cf. vastifica*, is greater than the 2–3% reported in early studies (see Table 1), which confirms the importance of the chemical phase in the bioerosion process.

Some studies suggested that the chemical phase is relevant to the size of the sediments produced by the sponges (Rützler and Rieger, 1973; Zundelevich et al., 2007). The results of this study suggest that boring sponges could exert an important role as $CaCO_3$ recyclers, even benefiting corals in healthy communities by accelerating the reincorporation of carbonate in the water column.

However, there was no difference in sediment production between the two sponges, 3.3 kg $CaCO_3\,m^{-2}\,year^{-1}$ for *C. vermifera* and 4.6 kg $CaCO_3\,m^{-2}\,year^{-1}$ for *C. flavifodina*. By contrast, *P. cf. vastifica* produced a lower amount of sediment; 0.08 kg $CaCO_3\,m^{-2}\,year^{-1}$ (Zundelevich et al., 2007). The dissolved carbonate together with the sediment production accounted for a bioerosion rate of 5.1 kg $CaCO_3\,m^{-2}\,year^{-1}$ for *C. flavifodina* and 4.5 kg $CaCO_3\,m^{-2}\,year^{-1}$ for *C. vermifera*, which are in the range reported for sponges of the genus *Cliona* (Acker and Risk, 1985) (Table 1). For example, while the bioerosion rate of *Cliona peponaca* did not exceed 3.3 kg $CaCO_3\,m^{-2}\,year^{-1}$ (Bak, 1976), *Cliona caribbaea* reached 8 kg $CaCO_3\,m^{-2}\,year^{-1}$ (Acker and Risk, 1985) and *Cliona orientalis* ranked from 3.4 to 10.0 kg $CaCO_3\,m^{-2}\,year^{-1}$ (Schönberg, 2002). Higher bioerosion rates, such as 23 kg $CaCO_3\,m^{-2}\,year^{-1}$, have been recorded in fragments of *Cliona lampa* transplanted on experimental substrata (Neumann, 1966). However, as discussed by Rützler (Rützler, 1975), the initial phase of substrata colonization in boring sponges may be conducive to higher bioerosion rates, as could have happened in Neumann's experiment (Neumann, 1966).

Other source of variation may be the density of the substrata (Neumann, 1966; Calcinai et al., 2007). In an experimental study of the sponge *C. orientalis*, Schönberg recorded bioerosion rates from 3.4 to 10.3 kg $CaCO_3\,m^{-2}\,year^{-1}$ in different species of corals, and 17.6 kg $CaCO_3\,m^{-2}\,year^{-1}$ in the denser shell of individuals of *Tridacna squamosa* (Schönberg, 2002).

The calcification rates in coral communities have been estimated to be between 1.1 and 4.0 kg $CaCO_3\,m^{-2}\,year^{-1}$ (Kinsey, 1985; Silverman et al., 2007). The bioerosion rates recorded in the present study confirm that coral destruction is similar to the corals' rate of construction capability per unit area. These results also suggest that in localities heavily invaded by boring sponges, bioerosion alone could reach a critical level, resulting in the disequilibrium of the ratio of reef accretion/destruction.

Given the frequency of invasion of *Cliona vermifera* in live colonies of Pocilloporid corals (30%), an important participation of this species in the bioerosion of coral reefs from the Mexican Pacific coast is expected.

REFERENCES

Acker, K. L. and Risk, M. J. (1985). Substrate destruction and sediment production by the boring sponge *Cliona caribbaea* on Grand Cayman Island. *J. Sediment. Res. A* **55**, 705-711.

Bak, R. P. M. (1976). The growth of coral colonies and the importance of crustose coralline algae and burrowing sponges in relation with carbonate accumulation. *Neth. J. Sea. Res.* **10**, 285-337.

Bautista-Guerrero, E., Carballo, J. L., Cruz-Barraza, J. A. and Nava, H. H. (2006). New coral reef boring sponges (Hadromerida: Clionaidae) from the Mexican Pacific Ocean. *J. Mar. Biol. Assoc. UK* **86**, 963-970.

Calcinai, B., Azzini, F., Bavestrello, G., Gaggero, L. and Cerrano, C. (2007). Excavating rates and boring pattern of *Cliona albimarginata* (Porifera: Clionaidae) in different substrata. In *Porifera Research: Biodiversity, Innovation and Sustainability* (ed. M. R. Custódio, G. Lôbo-Hajdu, E. Hajdu and G. Muricy), pp. 203-210. Rio de Janeiro: Série Livros 28, Museu Nacional.

Carballo, J. L. and Cruz-Barraza, J. A. (2005). *Cliona microstrongylata*, a new species of boring sponge from the Sea of Cortés (Pacific Ocean, México). *Cah. Biol. Mar.* **46**, 379-387.

Carballo, J. L., Cruz-Barraza, J. A. and Gómez, P. (2004). Taxonomy and description of clionaid sponges (Hadromerida, Clionaidae) from the Pacific Ocean of Mexico. *Zool. J. Linn. Soc.* **141**, 353-397.

Carballo, J. L., Bautista-Guerrero, E. and Leyte-Morales, G. E. (2008). Boring sponges and the modeling of coral reefs in the East Pacific Ocean. *Mar. Ecol. Prog. Ser.* **356**, 113-122.

Chisholm, J. R. M. and Gattuso, J. P. (1991). Validation of the alkalinity anomaly technique for investigating calcification and photosynthesis in coral reef communities. *Limnol. Oceanogr.* **36**, 1232-1239.

Fütterer, D. K. (1974). Significance of the boring sponge *Cliona* for the origin of fine grained material of carbonate sediments. *J. Sediment. Res. A* **44**, 79-84.

Glynn, P. W. and Ault, J. S. (2000). A biogeographic analysis and review of the far eastern Pacific coral reef region. *Coral Reefs* **19**, 1-23.

Highsmith, R. C., Lueptow, R. L. and Schonberg, S. C. (1983). Growth and bioerosion of three massive corals on the Belize barrier reef. *Mar. Ecol. Prog. Ser.* **13**, 261-271.

Holmes, K. E. (2000). Effects of eutrophication on bioeroding sponge communities with the description of new West Indian sponges, *Cliona* spp. (Porifera: Hadromerida: Clionidae). *Invertebr. Biol.* **119**, 125-138.

Hudson, J. H. (1977). Long-term bioerosion rates on a Florida reef: a new method. *Proc. Int. Coral Reef Symp.* **2**, 491-497.

Hutchings, P. A. (1986). Biological destruction of coral reefs. *Coral Reefs* **4**, 239-252.

Hutchings, P. A. and Peyrot-Clausade, M. (1988). Macro-infaunal boring communities of *Porites* a biogeographical comparison. *Proc. Int. Coral Reef Symp.* **3**, 263-267.

Kinsey, D. W. (1985). Metabolism, calcificaion and carbon production. System level studies. *Proc. Int. Coral Reef Congr.* **4**, 505-526.

Lazar, B. and Loya, Y. (1991). Bioerosion of coral reefs-a chemical approach. *Limnol. Oceanogr.* **36**, 377-383.

López-Victoria, M. and Zea, S. (2005). Current trends of space occupation by encrusting excavating sponges on Colombian coral reefs. *Mar. Ecol.* **26**, 33-41.

López-Victoria, M., Zea, S. and Weil, E. (2006). Competition for space between encrusting excavating Caribbean sponges and other coral reef organisms. *Mar. Ecol. Prog. Ser.* **312**, 113-121.

Macdonald, I. A. and Perry, C. T. (2003). Biological degradation of coral framework in a turbid lagoon environment, Discovery Bay, Jamaica. *Coral Reefs* **22**, 523-535.

MacGeachy, J. K. (1977). Factors controlling sponge boring in Barbados reef corals. *Proc. Int. Coral Reef Symp.* **2**, 477-483.

MacGeachy, J. K. and Stearn, C. W. (1976). Boring by macroorganisms in the coral *Montastrea annularis* on Barbados Reefs. *Int. Rev. Gesamten. Hydrobiol.* **61**, 715-745.

Neumann, A. C. (1966). Observations on coastal erosion in Bermuda and measurements of the boring rate of the sponge *Cliona lampa. Limnol. Oceanogr.* **11**, 92-108.

Pomponi, S. A. (1977). Etching cells of boring sponges: an ultrastructural analysis. *Proc. Int. Coral Reef Symp.* **2**, 485-490.

Reyes-Bonilla, H. (1993). Biogeografía y ecología de los corales hermatípicos (Anthozoa:Scleractinia) del Pacífico de México. In *Biodiversidad Marina y Costera de México* (ed. S. I. Salazar-Vallejo and N. E. González), pp. 207-222. Chetumal: CONABIO/CIQRO.

Rosales-Hoz, M. T. L. (1980). Manual de Laboratorio de Oceanografía. México: Universidad Nacional Autónoma de México.

Rose, C. S. and Risk, M. J. (1985). Increase in *Cliona delitrix* infestation of *Montastrea cavernosa* heads on an organically polluted portion of the Grand Cayman fringing reef. *Mar. Ecol.* **6**, 345-363.

Rützler, K. (1975). The role of burrowing sponges in bioerosion. *Oecologia* **19**, 203-216.

Rützler, K. and Rieger, G. (1973). Sponge burrowing: Fine structure of *Cliona lampa* penetrating calcareous substrata. *Mar. Biol.* **21**, 144-162.

Schönberg, C. H. L. (2002). Substrate effects on the bioeroding demosponge *Cliona orientalis*. 1. Bioerosion rates. *Mar. Ecol.* **23**, 313-326.

Sheppard, C. R. C., Spalding, M., Bradshaw, C. and Wilson, S. (2002). Erosion vs. recovery of coral reefs after 1998 El Niño: Chagos reefs, Indian Ocean. *Ambio.* **31**, 40-48.

Silverman, J., Lazar, B. and Erez, J. (2007). Effect of aragonite saturation, temperature, and nutrients on the community calcification rate of a coral reef. *J. Geophys. Res.* **112**, 1-14.

Smith, S. V. and Kinsey, D. W. (1978). Calcification and organic carbonic metabolism as indicated by carbon dioxide. In *Coral Reefs: Research Methods* (ed D. R. Stoddart and R. E. Johannes), pp. 469-484. Paris: UNESCO.

Stearn, C. W. and Scoffin, T. P. (1977). Carbonate budget of a fringing reef, Barbados. *Proc. Int. Coral Reef Symp.* **2**, 471-476.

Venkataraman, K. and Wafar, M. V. M. (2005). Coastal and marine biodiversity of India. *Indian J. Mar. Sci* **34**, 57-75.

Ward-Paige, C. A., Risk, M. J., Sherwood, O. A. and Jaap, W. C. (2005). Clionid sponge surveys on the Florida reef tract suggest land-based nutrient inputs. *Mar. Pollut. Bull.* **51**, 570-579.

Zundelevich, A., Lazar, B. and Ilan, M. (2007). Chemical versus mechanical bioerosion of coral reefs by boring sponges-lessons from *Pione* cf. *vastifica. J. Exp. Biol.* **210**, 91-96.