Proceedings of the 12th International Coral Reef Symposium, Cairns, Australia, 9-13 July 2012
21B Enhancing coral reef resilience through management of water quality

Macrobioerosion in *Porites* corals from the northern South China Sea

Tianran Chen

South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China
Corresponding author: chentianran@scsio.ac.cn

Abstract. The potentially negative effects of bioerosion on tropical coral reefs are well documented, but few studies have quantified the direct impact of macroborers in subtropical coral waters. In this study, internal macrobioerosion of *Porites* corals was examined at Weizhou Island and Daya Bay, subtropical northern South China Sea. Twenty-six massive *Porites* corals were cut, and cross-sections were photographed. Image analysis was used to identify bioeroders and quantify the degree of bioerosion caused by each bioeroder group. The observed bioeroders included sponges, bivalves, barnacles, and sipunculid and polychaete worms. The most important borers were filter-feeding bivalves (*Lithophaga* spp.) and sponges ("porous" and "cavernous"), while worms and barnacles showed relatively low bioerosion activity. *Porites* corals near the coastal urban and aquacultural areas were heavily bioeroded. Total internal bioerosion decreased significantly with distance from coastal urban and aquacultural areas. Bioerosion of bivalves and sponges decreased the most significantly, associated with local patterns of eutrophication and nutrient availability. The bioerosion intensity of macrobioeroders, especially boring bivalves and sponges, can be interpreted as an indicator for chronic exposure to decreased water quality at coastal coral areas. High levels of bioerosion, especially boring bivalve infestation, significantly weaken the corals and increase their susceptibility to dislodgement and fragmentation by typhoons and destructive fishing activities, and are adverse to coral survival and reef development.

Key words: Bioerosion, *Porites* coral, eutrophication, northern South China Sea.

Introduction

In the northern South China Sea (NSCS), coral reefs and non-reef-building coral communities are distributed principally around the offshore islands and along the mainland coast of southern China. These coral areas play an important role in sustaining marine biodiversity and providing fishery and tourism resources for China (Huang 2005; Wilkinson 2008). Since the 1980s, however, significantly declining coral cover and changes in coral community composition were increasingly reported from almost all coral areas in the NSCS (reviewed by Huang 2005 and Wilkinson 2008). Poor water quality due to increased influx of sediments and nutrients associated with sewage, agricultural runoff and aquaculture development is considered as a major factor in coral community deterioration. But this viewpoint is largely unsupported by direct evidence.

One of the principle ways in which eutrophication threatens corals is by enhancing internal bioerosion, especially macrobioerosion (e.g. Sammarco and Risk 1990; Risk et al. 1995), which is recognized not only as a major factor influencing local calcium carbonate budgets and framework accumulation of coral reefs (e.g. Le Campion-Alsumard et al. 1993; Macdonald and Perry 2003), but also as an important contributor to the morphology of modern and ancient reefs (e.g. Peyrot-Clausade et al. 1992; Glynn 1997). Bioerosion is ubiquitous in coral areas of NSCS, but only little research has been undertaken. This paper quantitatively examines macroboring of *Porites* corals from two marginal coral environments, which are subjected to elevated levels of eutrophication, and assesses the intensity of internal bioerosion by macroboring organisms, aiming at improving the understanding of the impacts of nutrient pollution upon the preservation of framework-building corals and reef development.

Material and Methods

This study was carried out at Daya Bay and Weizhou Island (Fig. 1), where are important economic, tourism and aquacultural areas in the NSCS.

Daya Bayis a semi-enclosed bay, with an area of 600 km^2 and an average depth of 10 m. Average yearly sea surface temperature (SST)approaches 23 ºC, whilst the highest monthly SST (July-August) and lowest monthly SST (January-February) is 29ºC and 15ºC, respectively. Non-reefal coral communities are patchily distributed along the offshore islands and in some coastal areas (Chen et al. 2009). Based on regional ecological surveys, significant deterioration of coral communities was found in Daya Bay, i.e., coral cover declined dramatically from 76.6% in 1983 to only 15.3% in 2008 (Chen et al. 2009), probably attributed to anthropogenic impacts rather than climatic changes.

Weizhou Island is a volcanic island, with an area of 26 km^2. The monthly SSTs range from 17 ºC to 30ºC, with an average of 24.6ºC. Coral reefs are mainly found on the north and south west coasts, in a depth of 10m. From the 1980s, human impacts, such as water pollution and destructive fishing, have driven a sharp decline in coral cover, from ~60% to less than 20% (Huang et al. 2009).

Fish, shrimp and shellfish aquaculture are well developed in bays like Aotou and Dapeng at Daya Bay and Weizhou town at Weizhou Island (Fig 1), where waters were heavily polluted. Relatively high concentrations of nutrients (e.g. dissolved nitrogen, phosphorus and silicate) and phytoplankton biomasswere reported (Wei et al. 2005; Wang et al. 2006; Wang et al. 2008; Liu et al. 2008), and this may be a consequence of the oxidation of organic wastescoupled with poor water exchange in those bays.

A total of twenty-six live massive *Porites* corals were collected from Daya Bay and Weizhou Island (from 6 and 3 sampling stations, respectively; Fig.1, Table 1). Sampling stations at both sites differed in water quality, with sites 1, 2 and 3 at Daya Bay and sites 2 and 3 at Weizhou Island being more polluted and eutrophic, and site 4, 5 and 6 at Daya Bay and site 1 at Weizhou Island with relatively cleaner waters. Eutrophication levels were inferred from water turbidity and from distance to likely pollution sources. From each sampled coral head, three parallel, non-adjacent cross-sections were cut with a rock saw (Fig. 2). One face of each section was then digitally photographed for identification of macroboring species and analysis of infestation. Identification of borers (bivalves, sponges, barnacles, polychaetes and sipunculans) was based on the shape, size, and character of each borehole, as described by previous studies (Sammarco and Risk 1990; Klein et al. 1991). Surface areas of each section and all boreholes attributed to each taxon within digital images were measured using Scion Image (ver. 4.0.3) image analysis software. Data for polychaetes and sipunculans were analyzed as a single group, simply as “worms”, while sponge bioerosion was distinguished as “porous” (as mainly produced by *Cliona* spp.) and “cavernous” (as mainly produced by *Cliothosa* spp.). Bioerosion intensity was reported as the percentage of cross-sectional area removed by each type of boring organism, and total percent bioerosion of corals is the sum of the area removed by all types of boring organism divided the sum of cross-sectional area (Edinger et al. 2000; Holmes et al. 2000; Mallela and Perry 2007).

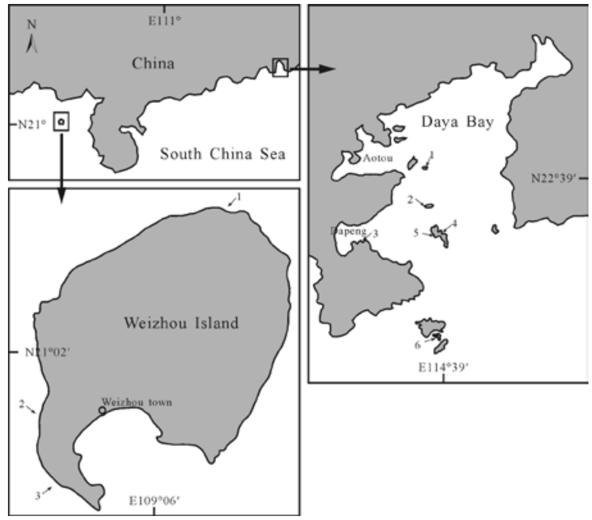

Figure 1: Map showing the location of Weizhou Island and Daya Bay and the positions of sampling sites (small arrows).Waters near Aotou and Dapeng at Daya Bay and Weizhou town at Weizhou Island were heavily polluted by domestic sewage and aquacultural feed and fecal wastes.

Results

The major taxa of boring organisms were bivalve mollusks (dominated by*Lithophaga* spp.), sponges (probably dominated by *Cliothosa* spp. and *Cliona* spp.), sipunculid and polychaete worms, and barnacles (Fig. 2). The percent of eroded coral surfaces (bioerosion intensity) is presented in Table 1, listing the corresponding taxonomic group and the study sites. The total average percent of erosion at Daya Bay and Weizhou Island were 12.71% and 6.66%, and ranged from 2.18% to 27.55% and 3.12% to 8.53%, respectively. Boring bivalves caused most of the destruction at both sites, but this was clearer at Weizhou. Erosion by boring sponges was in the same range as mollusk erosion and was also more prevalent at Daya Bay than at Weizhou. Borings caused by worms and barnacles were considerably less abundant than by the other taxa.

At both Daya Bay and Weizhou Island, bioerosion intensity (bivalves, sponges and total bioerosion) was clearly higher at sewage-polluted sites (site 1, 2 and 3 at Daya Bay; site 2 and 3 at Weizhou Island) than at the relatively unpolluted areas (site 4, 5 and 6 at Daya Bay; site 1 at Weizhou Island), and decreased with distance from coastal urban and aquacultural areas (e.g., Aotou, Dapeng and Weizhou town, Fig. 1). For example, the average bioerosion intensity of bivalves and sponges were 5.56% and 1.34% at Weizhou 3, and declined with distance from Weizhou town, falling to 1.82 % and 0.79% at Weizhou 1 (Table 1). This is consistent with the trend observed at the Great Barrier Reef (Sammaro and Risk1990; Risk et al. 1995; Cooper et al. 2008; Le Grand and Fabricius

2011), namely sponges and bivalves were dominant at inshore sites and decreased outward across the continental shelf.

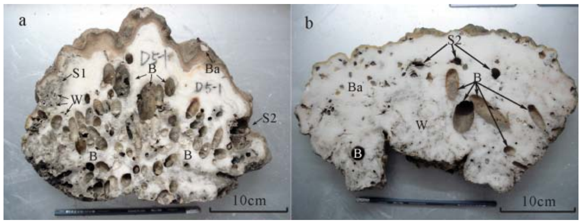

Figure 2: Traces of bioeroders on the cross-sections of two*Porites* corals collected from Daya Bay (a) and Weizhou Island (b) respectively. B: bivalve, Ba: barnacle, S1: sponge-porous, S2: sponge-cavernous, W: worms.

Discussion

While both sample areas are geographically far apart and geologically different, sample size was comparatively small, and a variety of environmental factors other than eutrophication influence bioerosion, observed patterns were similar at both areas. Higher levels of nutrient availability and plankton productivity appear to have contributed to the higher levels of internal bioerosion in *Porites*. Several authors found that levels of bioerosion in both live corals and coral rubble were significantly higher on reefs subjected to eutrophication than on unpolluted or offshore reefs (Rose and Risk 1985; Sammarco and Risk 1990; Risk et al. 1995; Holmes 1997; Holmes et al. 2000; Hutchings et al. 2005; Ward-Paige et al. 2005; Holmes et al. 2009).This probably applies predominantly to filter-feeders like bivalves and sponges, and various authors proposed that bioerosion levels were positively correlated with local patterns of primary productivity (Highsmith et al. 1983; Edinger et al. 2000; Holmes et al. 2000). During the past 30 years, Daya Bay and Weizhou Island have experienced rapid aquacultural and urban expansion which has adversely affected the water quality of nearshore waters. Domestic and restaurant sewage, waste feed and feces from cage culture are discharged into the surrounding waters, deteriorating water quality, increasing nutrient concentrations and turbidity. Nutrient-rich seawater favors bacterial and algal blooms, which can enhance larval survival and increase abundances of bioeroding organisms (e.g. Rose and Risk 1985; Tribollet and Golubic 2005; Cooper et al. 2008; Le Grand and Fabricius 2011).The bioerosion intensity of boring bivalves and sponges and total bioerosion were higher near polluted sites (Aotou and Dapeng at Daya Bay and Weizhou town at Weizhou Island) than at the relatively unpolluted areas (Fig.1; Table 1), which was consistent with the trend of local nutrient regimes. This study also implied that the bioerosion intensity of macrobioeroders, especially boring bivalves and sponges, can be interpreted as an indicator for chronic exposure to decreased water quality at coastal coral areas.

Porites corals in this work were heavily bioeroded by macroboring organisms. Skeletal excavation in our *Porites* corals is much greater than the results reported from other seas using similar methods, such as Carrie Bow Cay, Belize (Highsmith et al. 1983), Gulf of Eilat, Red Sea (Klein et al. 1991), Java Sea, Indonesia (Holmes et al. 2000), and the Great Barrier Reef (Sammarco and Risk 1990; Edinger and Risk 1997), probably attributed to the extreme eutrophic environment described in this study. Boring bivalves (*Lithophaga* spp.) proved to be the most abundant borers in the NSCS, in contrast to other studies which sponges constitute the major group of boring organisms on lots of tropical coral reefs (e.g. Risk and Sammarco 1982; Highsmith et al. 1983; Risk et al. 1995; Perry 1998; Holmes et al. 2000; Macdonald and Perry 2003). Endolithic *Lithophaga* bivalves seem to be the most effective bioeroders in this study and in other high latitude coral areas, such as the Solitary Islands, Australia (Smith 2011), Isla del Caño, Costa Rica (Scott and Risk 1988) and sites adjacent to Hong Kong (Clark and Morton 1999), and also on some tropical eastern Pacific reefs (Cantera et al. 2003; Londoño-Cruz et al. 2003), in where macrobioeroders, especially boring bivalves, were proved to be the key limiting factor for reef framework development. Boreholes by *Lithophaga* spp. are commonly larger than those of other bioeroders (Fig. 2). They can secrete acid to dissolve and significantly weaken the limestone substrate (Scott and Risk 1988). High levels of boring bivalve infestation as observed in this study, especially heavily bioerosion that occurs at the base of coral heads (Fig. 2), weakens the corals' attachments and increases their susceptibility to dislodgement and fragmentation imposed by catastrophic high energy events (e.g. typhoons) as well as destructive fishing practices (e.g. dynamite fishing and bottom trawling). During each underwater survey in the NSCS (Chen et al. 2009, and this work), the author always found some live and dead *Porites* corals with dense boreholes were dislodged from the substratum to the deeper sand seabed. In the NSCS, bioerosion is a major factor in local coral deterioration and is also a limiting factor for reef accretion and development. The present publication appeals to local governments to develop appropriate strategies to monitor and manage water quality and bioerosion and to maintain a functional environment for Chinese coral communities.

Acknowledgement

The author deeply thank the anonymous reviewer whose detailed comments and suggestions significantly improved the paper. This work was funded by the National Science Foundation of China (41106054, 40830852 and 41025007) and the "Strategic Priority Research Program" of the Chinese Academy of Sciences (XDA05080300).

References

Cantera KJR, Orozco C, Londoño-Cruz E, Toro-Farmer G (2003) Abundance and distribution patterns of infaunal associates and macroborers of the branched coral (*Pocilloporadamicornis*) in Gorgona Island (eastern tropical Pacific). Bull Mar Sci 72: 207-219

Chen TR, Yu KF, Shi Q, Li S, Price GJ, Wang R, Zhao MX, Chen TG, Zhao JX (2009) Twenty-five years of change in scleractinian coral communities of Daya Bay (northern South China Sea) and its response to the 2008 AD extreme cold climate event. Chin Sci Bull 54:2107-2117

Clark T, Morton B (1999) Relative roles of bioerosion and typhoon-induced disturbance on the dynamics of a high latitude scleractinian coral community. J Mar BiolAssoc U K 79:803-820

Cooper TF, Ridd PV, Ulstrup KE, Humphrey C, Slivkoff M, Fabricius KE (2008) Temporal dynamics in coral bioindicators for water quality on coastal coral reefs of the Great Barrier Reef. Mar Freshw Res 59: 703-716

Edinger EN, Limmon GV, Jompa J, Widjatmoko W, Heikoop JM, Risk MJ (2000) Normal coral growth rates on dying reefs: Are coral growth rates good indicators of reef health? Mar Poll Bull 40:404-425

Edinger EN, Risk MJ (1997) Sponge borehole size as a relative measure of bioerosion and paleoproductivity. Lethaia 29: 275-286

Glynn PW(1997) Bioerosion and coral reef growth: A dynamic balance. In: Birkeland C (eds) Life and death of coral reefs. Chapman&Hall, International Thomson, New York, pp 69-98

Highsmith RC, Lueptow RL, Schonberg SC (1983) Growth and bioerosion of three massive corals on the Belize barrier reef. Mar EcolProgSer 13:261-271

Holmes G, Ortiz JC, Schönberg CHL (2009) Bioerosion rates of the sponge *Clionaorientalis* Thiele, 1990: spatial variation over short distances. Facies 55: 203-211

Holmes KE (1997) Eutrophication and its effect on bioeroding sponge communities. Proc 8th Coral Reef Sym 2: 1411-1416

Holmes KE, Edinger EN, Hariyadi, Limmon GV, Risk MJ (2000) Bioerosion of live massive corals and branching coral rubble on Indonesian coral reefs. Mar Poll Bull 40:606-617

Huang H (2005) Status of coral reefs in northeast Asian countries: China. In: Japan Wildlife Research Center (eds)Status of coral reefs in East Asian Seas Region: 2004. Ministry of Environment, Tokyo, Japan, pp113-119

Huang H, Ma B, Lian J, Yang J, Dong Z, Fu Q, Liang W (2009) Status and conservation strategies of the coral reef in Weizhou Island, Guangxi. Tropical Geography 29: 307-312 (in Chinese)

Hutchings P, Peyrot-Clausade M, Osnorno A (2005) Influence of land runoff on rates and agents of bioerosion of coral substrates. Mar Poll Bull 51: 438-447

Klein R, Mokady O, Loya Y (1991) Bioerosion in ancient and contemporary corals of the genus *Porites*: patterns and paleoenvironmental implications. Mar Ecol Prog Ser 77:245-251

Le Campion-Alsumard T, Romano JC, Peyrot-Clausade M, Le Campion J, Paul R (1993) Influence of some coral reef communities on the calcium carbonate budget of Tiahura reef (Moorea, French-Polynesia). Mar Biol 115:685-693

Le Grand HM, Fabricius KE (2011) Relationship of internal macrobioeroder densities in living massive *Porites* to turbidity and chlorophyll on the Australian Great Barrier Reef. Coral Reefs 30: 97-107

Liu G, Shi H, Wei C, Li W (2008) Preliminary studies on phytoplankton and red tide organism composition in the coastal water of the Weizhou Island, Guangxi. Marine Science Bulletin 27: 43-48 (in Chinese)

Londoño-Cruz E, Cantera JR, Toro-Farmer G, Orozco C (2003) Internal bioerosion by macroborers in *Pocillopora* spp. in the tropical eastern Pacific. Mar EcolProgSer 265: 289-295

Macdonald IA, Perry CT (2003) Biological degradation of coral framework in a turbid lagoon environment, Discovery Bay, north Jamaica. Coral Reefs 22:523-535

Mallela J, Perry CT (2007) Calcium carbonate budgets for two coral reefs affected by different terrestrial runoff regimes, Rio Bueno, Jamaica. Coral Reefs 26:129-145

Perry CT (1998) Macroborers within coral framework at Discovery Bay, north Jamaica: species distribution and abundance, and effects on coral preservation. Coral Reefs 17:277-287

Peyrot-Clausade M, Hutchings P, Richard G (1992) Temporal variations of macroborers in massive *Porites lobata* on Moorea, French-Polynesia. Coral Reefs 11:161-166

Risk MJ, Sammarco PW (1982) Bioerosion of corals and the influence of damselfish territoriality – A preliminary study. Oecologia 52:376-380

Risk MJ, Sammarco PW, Edinger EN (1995) Bioerosion in *Acropora* across the continental shelf of the Great Barrier Reef. Coral Reefs 14:79-86

Rose CS, Risk MJ (1985) Increase in *Clionadelitrix* infestation of *Montastrea cavernosa* heads on an organically polluted portion of the Grand Cayman fringing reef. Mar Ecol 6:345-363

Sammarco PW, Risk MJ (1990) Large scale patterns in internal bioerosion of *Porites*: cross continental shelf trends on the Great Barrier Reef. Mar Ecol Prog Ser 59:145-156

Scott PJB, Risk MJ (1988) The effect of *Lithophaga* (Bivalvia, Mytilidae) boreholes on the strength of the coral *Poriteslobata*. Coral Reefs 7:145-151

Smith SDA (2011) Densities of the endolithic bivalve *Lithophaga lessepsiana* (Vaillant, 1865) in *Pocillopora damicornis*, Solitary Islands Marine Park, northern NSW, Australia .Molluscan Res 31:42-46

Tribollet A, Golubic S (2005) Cross-shelf differences in the pattern and pace of bioerosion of experimental carbonate substrates exposed for 3 years on the northern Great Barrier Reef, Australia. Coral Reefs 24:422-434

Wang YS, Lou ZP, Sun CC, Sun S (2008) Ecological environment changes in Daya Bay, China, from 1982 to 2004. Mar Poll Bull 56:1871-1879

Wang Z, Qi Y, Chen J, Xu N, Yang Y (2006) Phytoplankton abundance, community structure and nutrients in cultural areas of Daya Bay, South China Sea. J Mar Syst 62: 85-94

Ward-Paige CA, Risk MJ, Sherwood OA, Jaap WC (2005) Clionid sponge surveys on the Florida Reef Tract suggest land-based nutrient inputs. Mar Poll Bull 51: 570-579

Wei M, Li G, He B, Liang W (2005) Preliminary study of the relationship between plankton and environmental factors in the coral reef system around Weizhou Island. Transactions of Oceanology and Limnology 2:34-39 (in Chinese)

Wilkinson C (2008) Coral reefs of the world: 2008. Global Coral Reef Monitoring Network and Reef and Rainforest Research Centre, Townsville, Australia, pp 145-158

Study sites	Number of samples	% Erosion of coral surface				
		Bivalve	Sponge	Worms	Barnacle	Total
Daya 1	2	4.34±0.18	5.01±1.49	0.48±0.28	1.21±1.61	11.05±0.58
Daya 2	2	4.30±1.13	4.74±0.36	0.63±0.05	0.66±0.13	10.34±0.60
Daya 3	5	18.36±4.46	7.33±4.91	1.08±0.46	0.78±0.33	27.55±4.50
Daya 4	2	2.45±0.59	2.09±1.71	0.33±0.27	0.15±0.21	5.02±0.64
Daya 5	5	2.95±1.59	2.57±2.37	0.46±0.36	0.78±0.35	6.76±2.99
Daya 6	2	1.01±0.16	0.73±0.04	0.14±0.14	0.30±0.30	2.18±0.32
Weizhou 1	2	1.82±1.98	0.79±0.49	0.46±0.20	0.05±0.02	3.12±1.27
Weizhou 2	3	3.27±2.20	1.05±0.49	0.67±0.19	2.17±1.42	7.16±3.31
Weizhou 3	3	5.56±3.25	1.34±1.23	0.44±0.22	1.19±1.02	8.53±5.05

Table 1: Summary of percent of area removed by various groups of macroborers (mean±SD).