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Active sediment rejection efficiency of five scleractinian coral species in Singapore

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Abstract. Sediment rejection efficiency of five scleractinian corals was studied in situ at the western fringing reef of Pulau Hantu, Singapore. Colonies of five coral species were exposed to two sediment treatments: low (100 g cm^{-2}) and high (200 g cm^{-2}). Clearance was calculated from photographs taken after initial sediment deposition (100% cover on a 50-mm diameter circle of relatively flat colony surface) and again after 3 h. Results indicated that sediment rejection efficiency of corals varied significantly among species and between sediment treatments. Overall, *Podabacia crustacea* showed relatively high clearance efficiency at both low and high sediment levels, while *Dipsastraea lizardensis* exhibited the lowest clearance efficiency among all five species. All species cleared less effectively under the greater sediment load. These findings contribute to efforts to understand the responses of scleractinian corals to Singapore's heavily sedimented coastal waters.

Key words. sediment deposition, sediment clearance, urban coral reefs, hard corals

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INTRODUCTION

Adverse impacts from sediment pollution due to coastal modifications continue to be one of the largest threats to coral reefs worldwide (Erftemejier et al., 2012). High sediment input can result in increased water turbidity, affecting the productivity of photosynthetic endosymbionts supporting the coral host (Roth, 2014). Further, sediments can directly smother coral surfaces, requiring energy to remove (Gilmour, 2002) and potentially leading to either partial or full tissue mortality (Riegl, 1995). Sediments also affect recruitment as they cover substrates that may otherwise be suitable for coral planulae settlement (Babcock & Davies, 1991; Bauman et al., 2015).

Sediment clearance off coral surfaces can be a passive and/or active process (Stafford-Smith, 1993). Passive rejection is reliant on coral morphology; for example, sediments tend to fall off branching colonies more readily than laminar ones. Active rejection mechanisms include localised tissue expansion, tentacular action, ciliary beating, mucus secretion and extrusion of mesenteries (Stafford-Smith & Ormond, 1992). However, active sediment rejection is energetically expensive, which can compromise energy budgets for other important biological functions (Gilmour, 2002). There exists substantial inter- and intraspecific variation for sediment rejection efficiency (reviewed in Erftemeijer et al., 2012), but the influence of sediment load on active rejection efficiency across different species is not so well studied (Rogers, 1990; Stafford-Smith & Ormond, 1992; Weber et al., 2006). In addition, current knowledge regarding sediment rejection efficiency in corals is generally derived from controlled tank experiments, which may not necessarily represent conditions in the natural reef environment.

In Singapore's highly urbanised reefs, sedimentation levels can reach up to 37 mg cm^{-2} d^{-1} (Browne et al., 2015), well above Rogers' (1990) threshold for "high" (i.e., > 10 mg cm^{-2} d^{-1}). Decades of coastal development has caused ~60% loss of Singapore's coral reefs (Hilton & Manning, 1995), with remaining coral communities generally restricted to shallow depths (≤ 6 m) as a consequence of sediment-related turbidity and associated light attenuation (Chou, 1996; Guest et al., 2016; Heery et al., 2018). This combination of turbidity and downwelling sediments is thought to have altered the composition of coral assemblages in Singapore (Low & Chou, 1994; Chow et al., 2019) as well as affected coral morphology (Todd et al., 2001, 2004). However, to date, there has been little experimental work conducted to test sediment rejection among corals in Singapore, with only one aquarium study reported (Lui et al., 2012), although some work has been conducted on physiological responses to sediment stress (Browne et al., 2014, 2015; Junjie et al., 2014; Poquita-Du et al., 2019).

In this study, the sediment rejection efficiencies of five commonly found coral species in Singapore were examined in situ. We asked two questions: (1) Do the tested species vary in their sediment rejection efficiency? (2) Does sediment rejection efficiency depend on sediment load?

MATERIAL & METHODS

The study was performed in situ at the western fringing reef of Pulau Hantu, Singapore, using SCUBA apparatus. Five taxa that were found to be common at the study site (~4 m depth), *Astreopora myriophthalma*, *Diploastrea heliopora*, *Dipsastraea lizardensis*, *Pachyseris speciosa* and *Podabacia crustacea*, were chosen as the test species. Ten colonies of each species (10 colonies × 5 species) were tagged with a stake hammered into the substratum nearby. The sediment exposure experiment was conducted on separate days from 1000 hours to 1600 hours due to the large number of colonies tested. On each day, colonies were selected randomly from the total pool of 50 colonies (number reducing each day until all colonies were tested) to minimise potential bias from among-day differences in ambient conditions.

To avoid confounding effects from associated microbiome and organic matter in natural sediments, a mixture of different silicon carbide grit sizes (SiC) was used to recreate the sediment profile of Pulau Hantu following the procedures described in Lui et al. (2012). Each colony was exposed to two sediment treatments: low (100 mg cm^{-2}) and high (200 mg cm^{-2}), with each load introduced to a different side of the colony using a specially fabricated sediment depositor with an internal base diameter of 50 mm (Fig. 1a). To account for microenvironmental variations in water movement in the vicinity of each colony, a control was installed for each of the treatments using a cement-filled Teflon-coated tin covered with a 50-mm diameter rubber sheet that had small hemispherical protrusions (Fig. 1b) to mimic coral polyps. Thus, every colony that was used in the study had two controls: the control for low was installed near the side of the colony where the low treatment was implemented, and the high control was installed near the side of the colony where high treatment was implemented. For both the treatments and controls, photographs were immediately taken after each load was deposited and again after three hours. The photographs were subsequently analysed using ImageJ v1.43 to estimate percentage area of sediment clearance.

Two-way analysis of variance (ANOVA) was used to test for differences in percentage area of sediment cleared among species and between low and high sediment load. Assumptions of normality and homoscedasticity were checked prior to the analysis. Post-hoc multiple comparisons were performed on all parameters that yielded significant results for ANOVA using Holm's test.

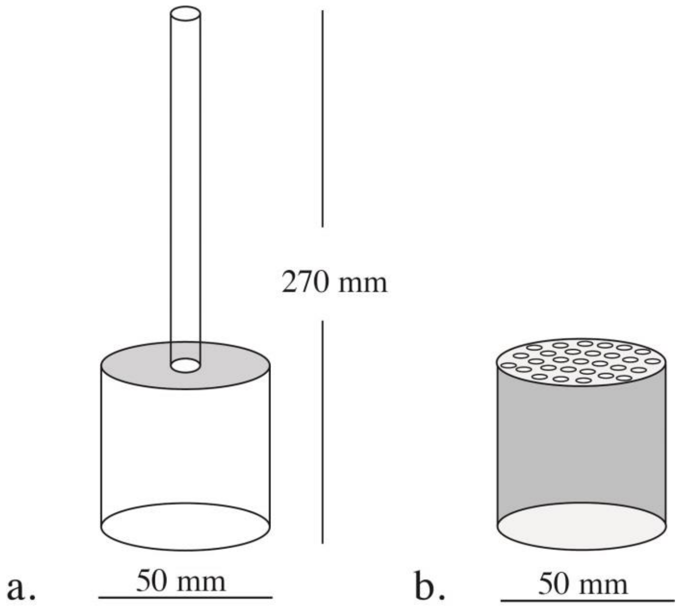

Fig. 1. Equipment used to test for sediment rejection of corals in Singapore. a, the apparatus to deposit the sediment (introduced via the top of the narrow tube); b, the control setup to take into account water movement near each colony.

RESULTS & DISCUSSION

Sediment pollution is a major issue for Singapore's coral reefs (Todd et al., 2010), yet little is known about how local species cope with sediments settled on coral tissues. In this study, sediment rejection efficiencies of five coral species exposed to low and high sediment loads were examined in their natural habitat. None of the species cleared all the sediments deposited on their surfaces within three hours, regardless of sediment treatment (Fig. 2). The percentage area of sediment cleared from the controls was found to be only less than one percent of the total sediment deposited (Fig. 3). Further, the results for *Diploastrea heliopora* align very closely with the findings of Lui et al. (2012), who used a similar approach, but in an aquarium setting. Thus, it is probable that the sediment clearance observed in the current study was primarily due to the corals using active clearing mechanisms.

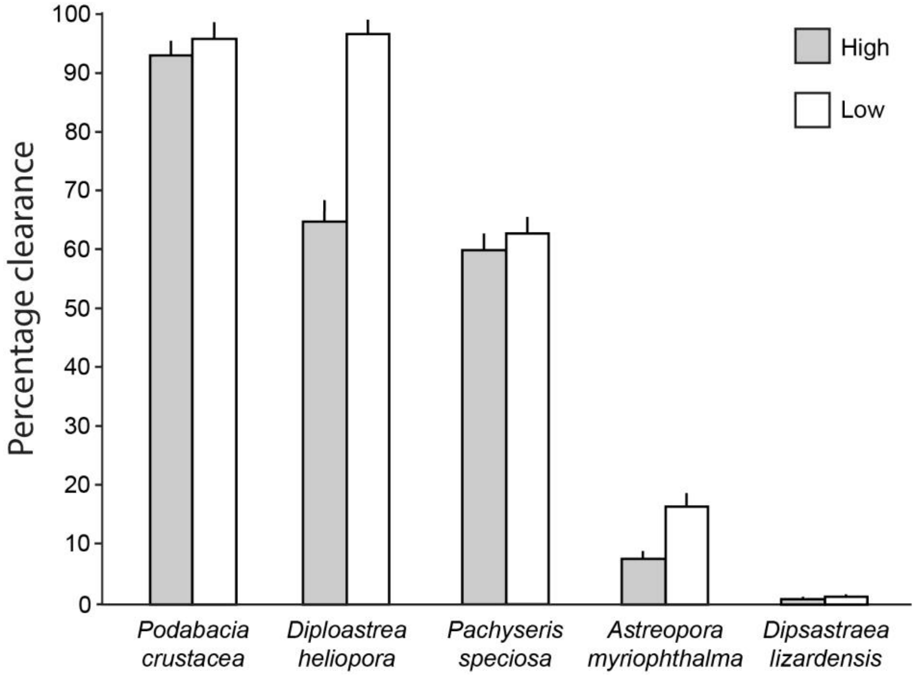

Fig. 2. Percentage (mean ± s.d.) clearance of the five coral species exposed to high and low sediment treatment. Overall, the percentage clearance in all colonies varied significantly among species (df = 4, F = 8532.82, p < 0.0001) and sediment treatment (df = 1, F = 422.30, p < 0.0001) (Table 1). Pair-wise comparisons showed significant differences in sediment rejection efficiencies among all coral species (except between *Diploastrea heliopora* and *Podabacia crustacea* for the low sediment treatment) and between low and high sediment treatments for each species.

Table 1. Results from two-way ANOVA test for percentage clearance of all colonies from different species exposed to two sediment treatment. Significant results are in bold.

Response	**Variable**	**df**	**MS**	**F**	***p***
Sediment clearance	Species	4	281.461	8532.82	**< 0.0001**
	Sediment treatment	1	13.930	422.30	**< 0.0001**
	Species × sediment treatment	4	2.729	82.73	**< 0.0001**
	Residuals	90	0.033	-	-

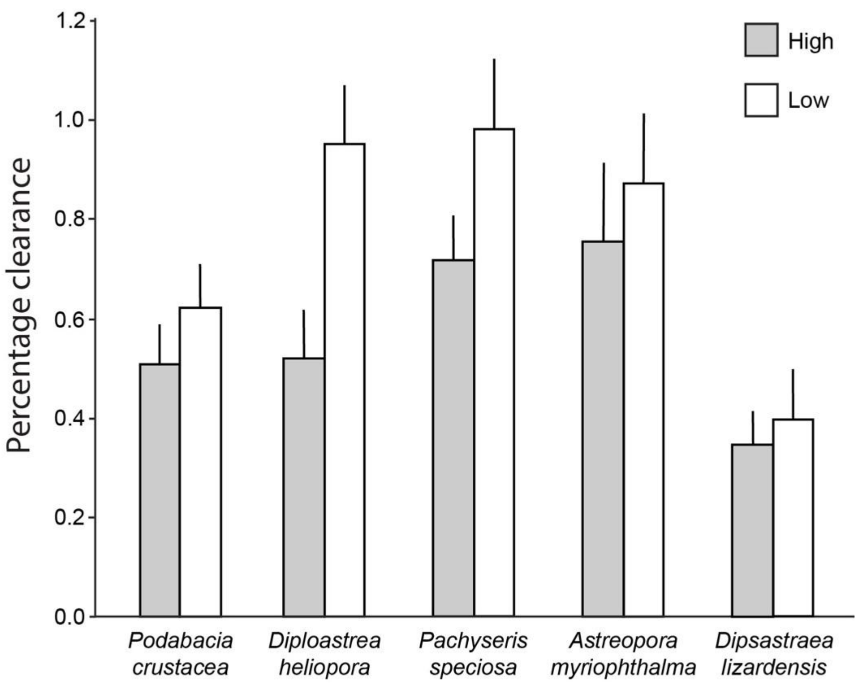

Fig. 3. Percentage (mean ± s.d.) clearance of controls for high and low sediment treatment for each species.

Among the five coral species, *Diploastrea heliopora* showed the highest average percentage clearance (97%) under low sediment treatment, followed by *Podabacia crustacea* (96%), *Pachyseris speciosa* (62%), *Astreopora myriophthalma* (16%) and lastly, *Dipsastraea lizardensis* (1%) (Fig. 2). Compared to *Podabacia crustacea* and *Pachyseris speciosa*, *Diploastrea heliopora* showed a substantial reduction of its rejection efficiency under the high sediment treatment. This is likely due to excessive demands on energy associated with sediment removal, as its primary mechanism of sediment rejection is through mucus secretion, which is energetically expensive and can take up more than three times a coral's daily energy budget (Stafford-Smith, 1993; Riegl & Branch, 1995).

Podabacia crustacea exhibited relatively high levels of sediment rejecting efficiency, regardless of the intensity of the load. This species is polystomatous (i.e., multiple mouths) and possesses large tentacles that can facilitate effective sediment clearance (Hoeksema & Waheed, 2012). In addition, both the abovementioned traits are advantageous for heterotrophic feeding (Hoeksema & Koh, 2009), particularly when photosynthetic production is limited due to light reduction associated with sediment stress.

The species *Dipsastraea lizardensis* was the least efficient at rejecting sediments among all the species examined. Similar to *Astreopora myriophthalma*, the colony morphology of *Dipsastraea lizardensis* is massive with larger and more concave interior surfaces of corallites that likely caused the sediments to be trapped. In contrast, both the plating corals *Pachyseris speciosa* and *Podabacia crustacea* exhibited relatively high sediment rejection efficiency compared to the massive coral species.

In conclusion, this study shows that three commonly found corals in Singapore (*Diploastrea heliopora*, *Podabacia crustacea* and *Pachyseris speciosa*) have substantial active sediment rejection capacity, but that two others (*Astreopora myriophthalma* and *Dipsastraea lizardensis*) are much less effective at actively removing sediment from colony surfaces. While exhibiting active rejection mechanisms is beneficial, it is also energetically costly. Thus, coral species that exhibit both active and passive (through their colony morphology) mechanisms are likely to have an advantage in the sedimented waters of Singapore.

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