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Distribution and Abundance of Sea Urchins in Singapore Reefs and Their Potential Ecological Impacts on Macroalgae and Coral Communities

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Abstract – The sea urchin *Diadema setosum* is often encountered in the coral reefs in the Southern Islands of Singapore. While sea urchins have been known to play a role in regulating algal communities and influencing coral recruitment in other parts of the world, their role in Singapore reefs has not been determined. This study was conducted to determine the distribution and abundance of sea urchins in Singapore reefs, to examine algal cover, algal biomass, algal species and live coral cover, and to determine any interactions between urchin density and algal communities that may impact coral cover. Several reefs in Singapore were surveyed using belt transects measuring 20 m by 2 m, laid down on the reef crest. Abundance of urchins, algal species, biomass, and live coral cover were determined by the use of quadrats within each belt transect. This study revealed an increasing abundance of the sea urchin *Diadema setosum* in reefs progressing southwards away from mainland Singapore with low density of urchins occurring in Sisters' Island, St John's Island, Pulau Tekukor, and Kusu Island, and the highest density observed at Raffles Lighthouse. A significant negative linear relationship between algal cover and live coral cover ($P < 0.05$) was established. The results of this study indicate that sea urchins may not be an important component of the herbivore guild in Singapore.

Key words – sea urchin, *Diadema setosum*, Singapore coral reefs, herbivory, macroalgae

1. Introduction

Sea urchins of the genus *Diadema* are among the most widespread, abundant and ecologically important echinoderms in shallow tropical seas, occurring primarily in shallow reef habitats. Their occurrence and feeding habits play a very important role in the dynamics and structure of the algal and coral ecosystems (Villalobos et al. 2008).

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The herbivorous activity of *Diadema antillarum* has been reported to affect the diversity, abundance, and productivity of algal communities (Ruiz-Ramos et al. 2011). *D. antillarum* also influences coral recruitment by consuming algae and opening new reef substrates, making them available for coral larval settlement. One of the best pieces of evidence pointing to the importance of urchins as a moderator of the reef ecosystem came from a study of reefs at Discovery Bay in Jamaica. In the 1950s, the reefs at Discovery Bay were characterized by small amounts of macroalgae, and scleractinian corals covered as much as 90% of the substratum (Edmunds and Carpenter 2001). However, the mass mortality of sea urchins in 1984 led to an enormous bloom of algae, with algal cover increasing from 4% to 92%, and a consequent reduction of coral cover from an average of 52% to 3%, between 1977 and 1993 (Knowlton 2001).

Urchins are also known to be major bioeroders on reefs, influencing benthic community structure. The spines of *D. antillarum* function as a refuge for their own juveniles (Miller et al. 2007), as well as for juvenile stages of other species, such as lobsters and grunts. At high densities, however, *D. antillarum* are known to inhibit coral recruitment (Sammarco 1980), as well as prey on living coral tissue of mature colonies (Ruiz-Ramos et al. 2011).

While many studies have been conducted on sea urchins and their importance in influencing reef dynamics in other parts of the world, only two studies were carried out in Singapore, to document the distribution and abundance of the sea urchin *Diadema setosum* in Singapore. A study in 1996 reported increasing *D. setosum* populations along a south-southwest axis, moving away from mainland Singapore, with the highest population densities observed at Raffles

Lighthouse and lowest in St John's Islands. It was postulated that the gradient of sea urchin occurrence was inversely related to a gradient of sedimentation rates associated with land reclamation in Singapore (Grignard et al. 1996). Another study in 1988 reported the occurrence of *D. setosum* at all reefs surveyed (Pulau Hantu, Pulau Semakau, Pulau Jong, Raffles Lighthouse, Terumbu Pandan, Beting Bemban Bersar), with particularly high densities occurring at Pulau Hantu, Terumbu Pandan and Beting Bemban Bersar (Lim and Chou 1988). However, no localised studies have been conducted to date to investigate the importance of sea urchins as a moderator of algal communities in Singapore, and consequently their effect on coral cover.

This study was aimed at determining a) the distribution and abundance of the sea urchin *Diadema setosum;* b) algal cover, algal biomass, algal species and live coral cover in Singapore coral reefs; and c) identifying possible interactions between urchin density and algal communities, and how these interactions might impact coral cover.

2. Materials and Methods

Sample sites

The study was conducted at selected sites at the Southern Islands of Singapore (Fig. 1). A total of 23 sites were surveyed from January 2011 to April 2011. These were fringing reefs

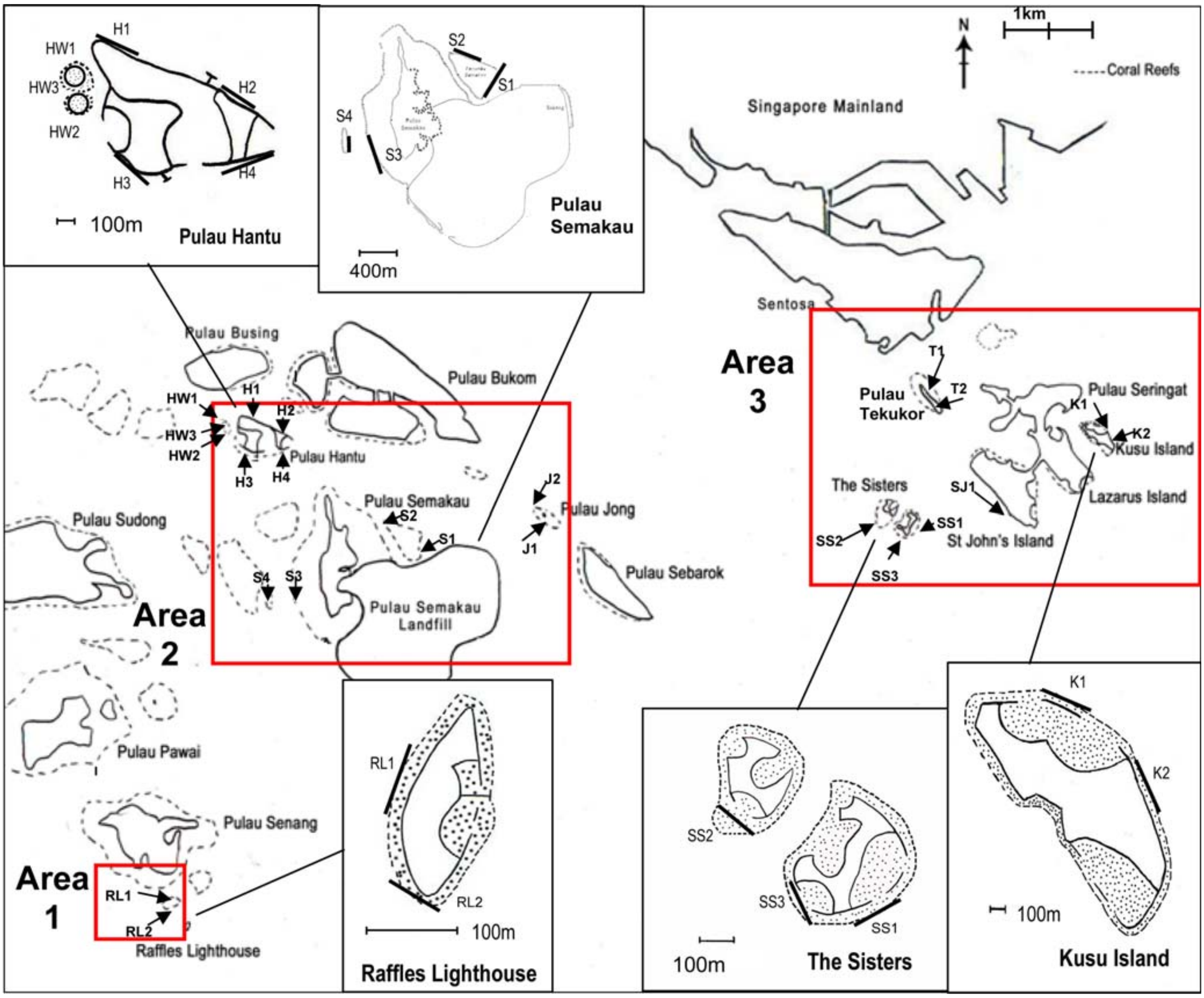

Fig. 1. Map of the Southern Islands of Singapore showing the location of sample sites. (HW1-3: Hantu West Patch reef 1-3; H1-4:Pulau Hantu 1-4 S1-4: Pulau Semakau 1-4; J1,2; Pulau Jong 1,2; RL 1,2: Raffles Lighthouse 1,2; SS1-3: The Sister's Islands 1-3; K1,2: Kusu Island 1,2; T1,2; Pulau Tekukor 1,2; SJ1: St John's Island 1)

around the island of Raffles Lighthouse, denoted as Area 1; fringing reefs at the islands of Pulau Semakau, Pulau Hantu, Pulau Jong and patch reefs at Pulau Hantu West, denoted as Area 2; and reefs surrounding Sisters' Islands, Kusu Island, Pulau Tekukor and St John's Island, denoted as Area 3. The three areas were demarcated according to their proximity within a particular area.

Sampling Method

At each sample site, populations of urchins were sampled within belt transects (English et al. 1994) measuring 20 m × 2 m. Three replicate transects were surveyed at each site. Transects were laid parallel along the reef crest at a depth of between 2.8 - 3.5 m (at the reef crest and reef flat), where urchins were generally more abundant. The density of the urchins was then expressed as mean number of ind/100 m^2.

Within each replicate transect, 20 quadrats (50 cm × 50 cm) were sampled to estimate algal and live coral cover. Five random quadrats were placed at every 5 m interval along the belt transect, and cover was determined as total area covered (in m^2/100 m^2 of reef). Only macroalgal growth of more than 1 cm in height was taken into consideration.

Additionally, algae was collected from four quadrats per transect for biomass estimation (English et al. 1994). All algae occurring within the quadrats were collected for biomass estimation, and quadrat samples were taken at every 10 m interval within each belt transect. The algae were oven dried at 60°C over 24 hours until a constant weight was achieved. Biomass of algae was then expressed as dry mass of algae (g/m^2 of reef). Algal species were also determined using taxonomic keys (Littler and Littler 2003).

Statistical analyses

Data collected were tested for normality and homogeneity of variances prior to statistical analysis. Multiple regression analysis was carried out to determine if the following factors: algal cover, algal biomass and urchin density affected coral cover, and to determine which factor most significantly affected coral cover. Linear regression analysis was then carried out to determine the strength of the relationship between urchin density and algal cover. Correlation analysis was also performed between algal cover and algal biomass to determine if they were related. All statistical analyses were carried out using MINITAB© software and analysed accordingly (MINITAB 16).

3. Results

Between sample sites, Raffles Lighthouse (Area 1, Fig. 2) was observed to have high urchin density with a corresponding low algal cover, low algal biomass and high live coral cover at both of the sample sites. At Pulau Hantu West, Pulau Hantu, Pulau Jong and Pulau Semakau (Area 2, Fig. 3), where the

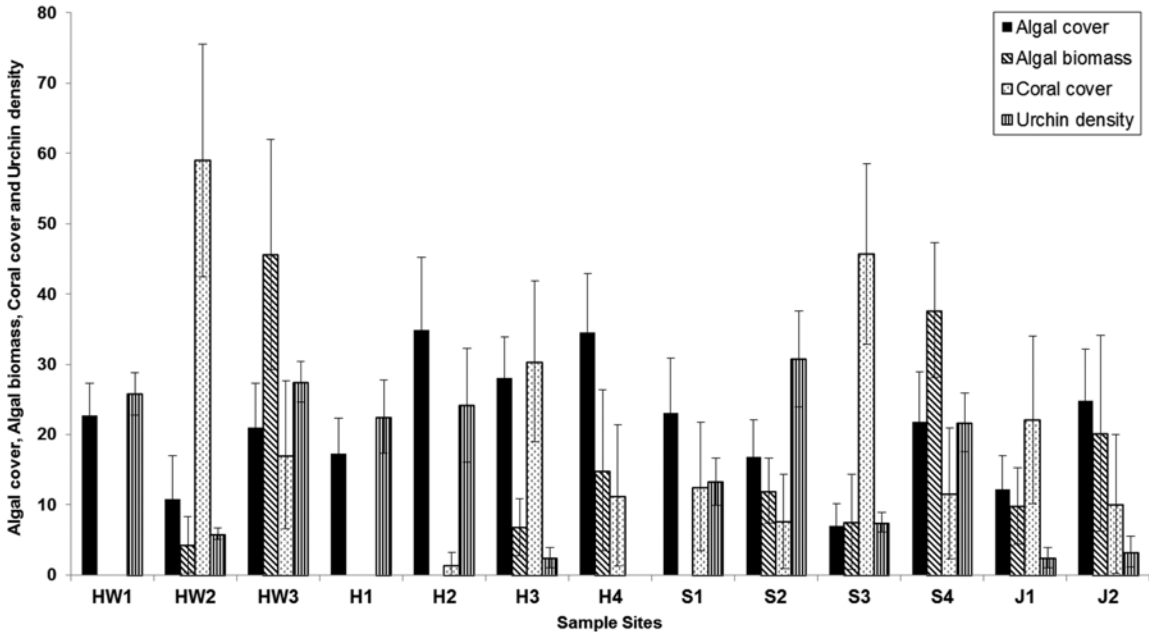

Fig. 2. Graph showing mean coral cover (m^2/100 m^2 reef), algal cover (m^2/100 m^2 reef), algal biomass (g/m^2 reef) and urchin density (individuals/100 m^2 reef) at sample sites in Area 1. Values are mean ± S.E. (RL 1, 2: Raffles Lighthouse 1, 2)

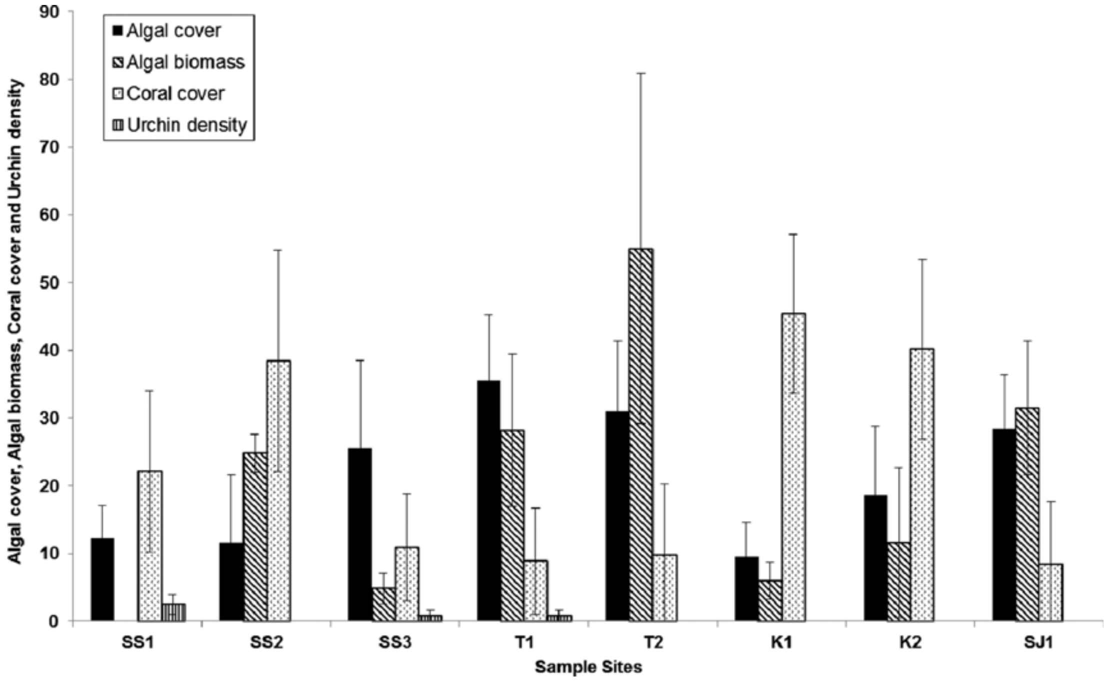

Fig. 3. Graph showing mean coral cover (m^2/100 m^2 reef), algal cover (m^2/100 m^2 reef), algal biomass (g/m^2 reef) and urchin density (individuals/100m^2 reef) at sample sites in Area 2. Values are mean ± S.E. Algal biomass data is absent for HW1, H1, H2 and S1. Coral cover data is absent for HW1 and H1. (HW1-3: Hantu West Patch reef 1-3; H1-4: Pulau Hantu 1-4; S1-4: Pulau Semakau 2-4; J1,2: Pulau Jong 1, 2)

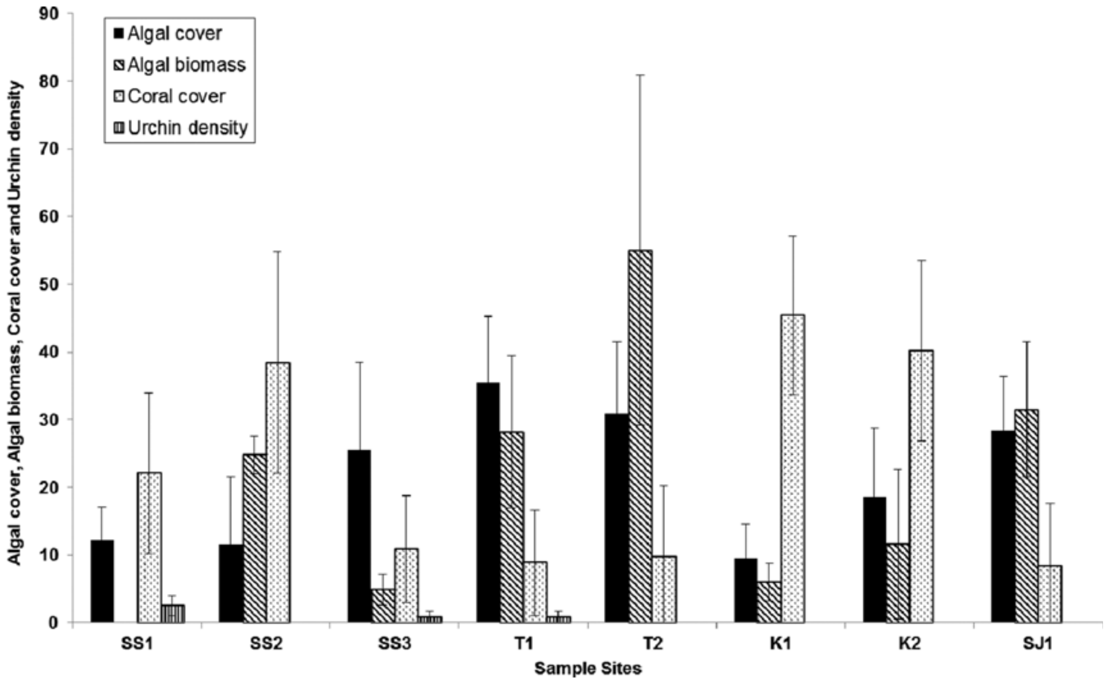

Fig. 4. Graph showing mean coral cover (m^2/100 m^2 reef), algal cover (m^2/100 m^2 reef), algal biomass (g/m^2 reef) and urchin density (individuals/100 m^2 reef) at sample sites in Area 3. Values are mean ± S.E. Algal biomass data is absent for SS1. (SS1-3: The Sisters' Islands 1-3; K1,2: Kusu Island 1,2; T1,2: Pulau Tekukor 1,2; SJ1: St John's Island 1)

urchin density ranged between 0-30 ind/100 m^2 reef, there was no distinctive trend observed between urchin density, algal cover, algal biomass and live coral cover. Sample sites at Sisters' Islands, Pulau Tekukor, St John's Island and Kusu

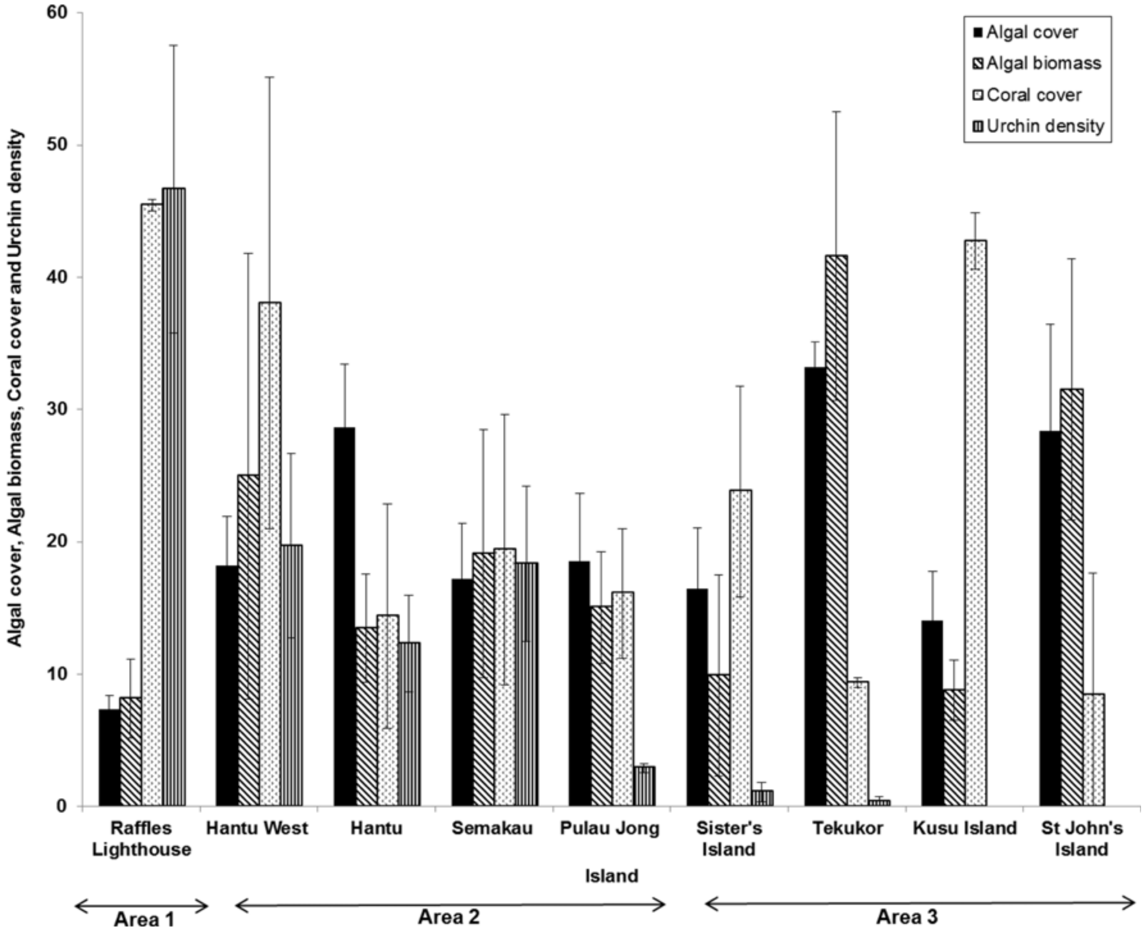

Fig. 5. Graph showing pooled mean coral cover (m^2/100 m^2 reef), algal cover (m^2/100 m^2 reef), algal biomass (g/m^2 reef) and urchin density (individuals/100 m^2 reef) for each island sampled. Values are mean ± S.E

Island (Area 3, Fig. 4) were more varied. Reefs in this area were observed to have low urchin densities, and some sample sites exhibited high algal cover, high algal biomass and low live coral cover, while other sites exhibited low algal cover, low algal biomass and high live coral cover.

The highest urchin density was observed at Raffles Lighthouse (Area 1, Figs. 5 and 6) with more than 40 ind/100 m^2 reef, followed by the sites at Pulau Hantu West patch reef, Pulau Hantu, Pulau Semakau and Pulau Jong(Area 2, Figs. 5 and 6) with 3-20 ind/100 m^2 reef. The sites at Sisters' Island, Pulau Tekukor, Kusu island and St John Island (Area 3, Figs. 5 and 6) were observed to have low urchin populations (< 3 ind/100 m^2 reef). The sizes of urchins were not measured in this study, and hence, any relationships between urchin size, grazing behaviour and algal abundance were not determined.

Macroalgal species

A total of eight genera of macroalgae were identified at the 18 sample sites based on collected algal samples. The families Bryopsidaceae, Dictyotaeceae, Soliieriaceae, Sargassaceae, Hypneaceae and Caulerpaceae were represented (Table 1). *Hypnea* spp. was the most dominant species (in terms of highest algal cover) at Area 1 (Raffles Lighthouse), while the dominant species in Area 2 (Hantu West patch reef, Pulau Hantu and Pulau Semakau) were mainly *Eucheuma* spp. and *Sargassum* spp. The dominant species at Pulau Jong was *Bryopsis* spp. At Area 3, the dominant species was *Bryopsis* spp. with the exception of Pulau Tekukor where *Lobophora* spp. was the most abundant. *Sargassum* spp. and *Eucheuma* spp. were also the most common species occurring in most sites.

Statistical analyses

Regression analysis yielded the following relationship between coral cover (live coral cover), algal cover, algal biomass and urchin density:

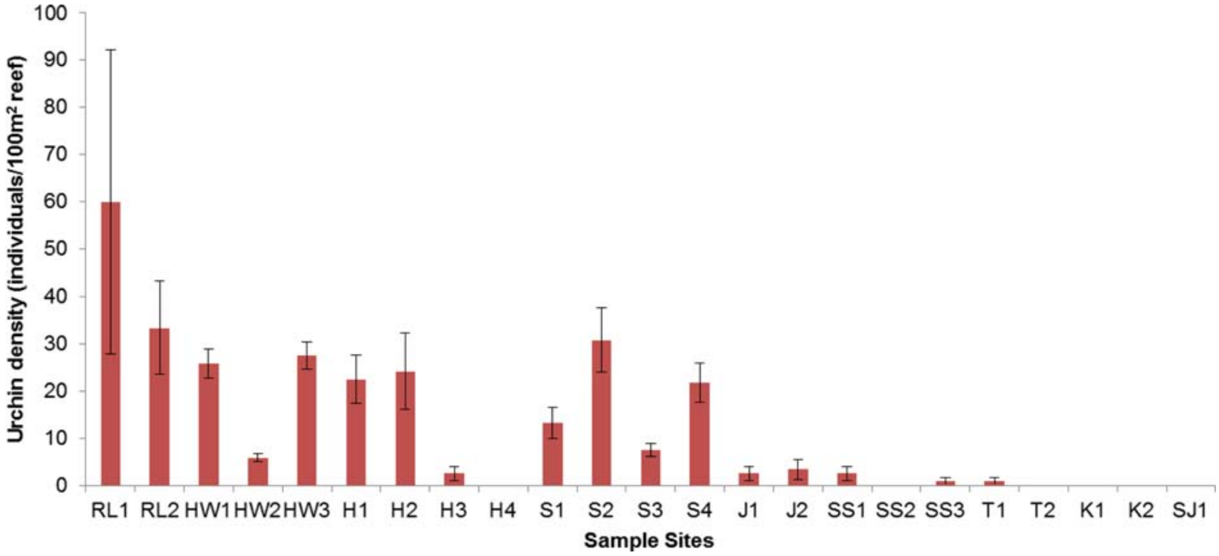

Fig. 6. Graph illustrating urchin density (individuals/100 m^2 reef) at all sample sites. Values are mean ± S.E. (RL 1, 2: Raffles Lighthouse 1, 2; HW1-3: Hantu West Patch reef 1-3; H1-4: Pulau Hantu 1-4; S1-4: Pulau Semakau 2-4; J1,2: Pulau Jong; SS1-3: The Sisters' Islands 1-3; K1,2: Kusu Island 1,2; T1,2: Pulau Tekukor 1,2; SJ1:St John's Island 1)

Table 1. Macroalgae sampled (Genera) from the Southern Islands of Singapore. (RL1,2: Raffles lighthouse HW2,3: Hantu West Patch reef 2,3; H3,4:Pulau Hantu 3,4 S1-4: Pulau Semakau 2-4; J1,2; Pulau Jong 1,2; RL 1,2; SS2,3: The Sister's Islands 2,3; K1,2: Kusu Island 1,2; T1,2; Pulau Tekukor 1,2; SJ1: St John's Island 1). Bry: *Bryopsis* spp.; Lob: *Lobophora* spp.; *Pad: Padina* spp.; Sar*: Sargassum* spp.; Tur*: Turbinaria* spp.; Hyp*: Hypnea* spp.; Cau: *Caulerpa* spp.) '-' represents absence; '+' represents presence while '++' represents dominant species (in terms of highest algal cover)

Sample Site	Bryopsidaceae	Dictyotaceae		Solieriaceae	Sargassaceae		Hypneaceae	Caulerpaceae
	Bry	Lob	Pad	Euc	Sar	Tur	Hyp	Cau
RL1	-	-	+	+	+	-	++	-
RL2	-	-	+	+	+	+	++	-
HW2	-	-	-	++	+	-	+	-
HW3	+	-	-	+	++	-	+	-
H3	-	-	-	++	+	-	+	-
H4	+	-	-	+	++	-	-	-
S2	-	-	-	++	+	-	-	-
S3	-	-	+	++	+	-	-	-
S4	+	-	+	+	++	-	+	-
J1	++	+	-	+	+	-	-	-
J2	++	-	-	+	+	-	+	-
SS2	++	-	-	-	-	-	-	-
SS3	++	-	-	-	+	-	-	-
SJ1	++	-	-	+	+	-	+	-
K1	++	-	-	+	+	-	+	-
K2	++	-	-	+	+	-	-	-
T1	-	++	-	-	-	-	+	+
T2	-	++	-	+	-	-	+	-

$$LCC = 56.2 - 1.09\ AC - 0.429\ AB - 0.109\ UD$$

where LCC = Live coral cover (m^2/100 m^2 reef);

AC = Algal cover (m^2/100 m^2 reef);

AB = Algal biomass (g/m^2 reef) and

UD = Urchin density (ind/100 m^2 reef)

Results from regression analysis of independent variables indicated that the variable that most significantly affected coral cover was algal cover ($P < 0.05$, Table 2).

Table 2. Results of multiple regression using coral cover as response and algal cover, algal biomass and urchin density as the predictors at the sample sites

Predictors	T	P
Constant	7.65	0.000
Algal cover	-2.75	0.016
Algal biomass	-1.68	0.115
Urchin density	0.62	0.547
S = 10.5778	R-Sq = 69.3%	R-sq(adjusted) 62.7%
Analysis of variance df = 3,14	F = 10.54	P = 0.001

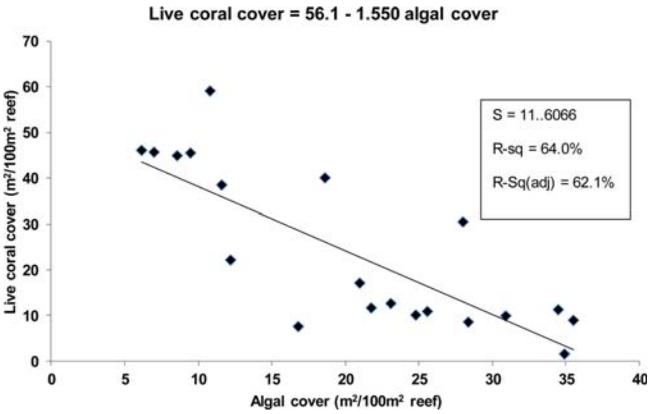

Fig. 7. Graph showing fitted line plot of live coral cover versus algal cover across sample sites

In terms of algal cover and algal biomass across various sample sites, correlation analysis revealed some positive correlations ($r = 0.633$, P value < 0.05), with a few exceptions. At sample site HW3, the algal biomass was more than twice the algal cover (Fig. 3). In comparison, at sample sites H3, SS3, K1 and K2, algal cover was twice that of algal biomass.

A scatter plot between coral cover and algal cover (Fig. 7) showed a significant negative liner relationship between algal cover and live coral cover.

A subsequent linear regression between algal cover and urchin density carried out to determine if urchin density played a role in regulating algal cover indicated no significant relationship at all sample sites ($P > 0.05$).

4. Discussion

This study has established patterns of distribution and population densities of the sea urchin *Diadema setosum* on the reefs of the Southern Islands of Singapore. Sea urchin distribution was highly variable with the highest densities recorded at Raffles Lighthouse (Area 1), moderate densities at Pulau Hantu, Pulau Hantu West, Pulau Semakau, Pulau Jong (Area 2), and the lowest densities occurring at the Sisters' Island, Pulau Tekukor, Kusu Island and St John's Island (Area 3). This pattern of distribution and relative abundance of sea urchins indicating an increase southwards away from mainland Singapore are in agreement with the study conducted in 1996 (Grignard et al. 1996). A higher abundance of the sea urchins *D. setosum* was recorded at Area 1, compared to the reefs at Area 3, closer to mainland Singapore. These results also support the theory that sedimentation and pollution may have considerable effects on reef organisms, as the southern-most reefs (Raffles Lighthouse) located further away from mainland Singapore, have been reported to have less sedimentation (Lim and Chou 1988). In the 1988 study, Raffles Lighthouse was also reported to have the highest number of species of echinoderms, while reefs closer to mainland Singapore such as Terumbu Pandan had low echinoderm species richness.

This study also showed some correlation between algal cover and algal biomass ($r = 0.633$, $P < 0.05$) with a few exceptions. Higher algal biomass to algal cover ratios observed at HW3 could be attributed to the dominant *Sargassum* spp. (in terms of highest algal cover), having larger fronds. In contrast, the dominant species at sites H3, SS3, K1 and K2, where algal cover was twice that of algal biomass, were represented by *Bryopsis* spp. and *Eucheuma* spp. These macroalge have smaller fronds and hence recorded smaller overall dry weights.

Examining the relationship between algal species and urchin density, it was observed that sample sites with dominant species comprising *Sargassum* spp., *Hypnea* spp. and *Eucheuma* spp. yielded a greater abundance of *D. setosum* urchins. In contrast, reefs with dominant species comprising *Bryopsis* spp. and *Lobophora* spp. had low abundance of *D. setosum* urchins. Results from other studies have indicated that *D. setosum* has a feeding preference for *Padina* spp. over *Eucheuma* spp. and either avoided or had a low preference for *Sargassum* spp. and *Turbinaria* spp. (Shanula and Ndibalema 1986, Solandt and Campbell 2001). Hence the abundance of *Sargassum* spp. observed may be due to the lack of grazing by *D. setosum*. This can be attributed to the tough and leathery morphology of *Sargassum* spp. (Paul and Hay 1986) and the presence of tannins and phenols in *Sargassum* spp. (Solandt and Campbell 2001) that repel echinoid herbivory. On the other hand, while *Eucheuma* spp. was eaten by *D. setosum*, this macroalgae was not as highly preferred as *Padina* spp., explaining the abundance of *Eucheuma* spp. in many sample sites in this study. *Hypnea* spp. are also known to be a secondary food source for sea urchins (Teran et al. 2008) but were less preferred compared to *Padina* spp., explaining its abundance in Area 1 in this study. *Lobophora* spp. (Solandt and Campbell 2001) and *Bryopsis* spp. (Sprung and Delbeek 1997) were reported to be rarely eaten by urchins and hence were dominant in reefs where urchin density was low.

While there was evidence that macroalgal cover and grazing are negatively related in the Caribbean (Williams and Polunin 2000; Newman et al. 2006), and reduced macroalgal cover was associated with elevated densities of juvenile corals (Edmunds and Carpenters 2001), this relationship was not evident in Singapore reefs.

When making comparisons between live coral cover, algal cover and urchin density between areas, it was observed that Area 1, where the highest urchin density occurred, (> 40 ind/ 100 m^2 reef, Figs. 5 and 6) had the lowest algal cover and the highest live coral cover. At Area 2 where urchin density was observed to be between 3-20 ind/100 m^2 reef, there seemed to be a state of equilibrium between algal cover (15-30 m^2 / 100 m^2 reef) and live coral cover (15-40 m^2 / 100 m^2 reef , Figs. 5 and 6). At Area 3 where the lowest urchin density occurred, there was no clear relationship between algal cover and live coral cover. In reefs where no urchins were sampled (Kusu island and St John's Island), algal cover was highly variable. A high algal cover and low live coral cover was observed in St John's Island, while a low algal cover and high live coral cover occurred at Kusu Island. Similarly, at Pulau Tekukor where only one urchin was sampled, high algal cover with a low live coral cover was recorded. Hence no clear relationship could be determined in reefs where urchin densities were very low.

No significant relationship could be ascertained between algal cover and urchin density in the reefs of Singapore ($p > 0.05$). This may indicate that urchins do not constitute an important herbivore guild for algal communities in Singapore, or that their densities are not high enough to influence reef communities. Other studies established that sea urchins effectively reduced algal abundance at densities of 4.0 ± 0.9 urchins/m^2 (or approximately 400 urchins / 100 m^2; Edmunds and Carpenter 2001).

Similar conclusions can be made that urchin numbers in Singapore are too low to affect bioerosion in coral reefs. Other studies that have produced evidence of sea urchins as bioeroders reported densities of between 3 - 156 ind/m^2 (Herrera-Escalante et al. 2005).

Overall, a significant negative linear relationship was observed between algal cover and live coral cover (Table 2, Fig. 7), indicating that algal cover plays a role in influencing live coral cover in Singapore reefs.

Other herbivores likely play a more significant role in moderating algal communities. One of the more important herbivores in reefs is fish. Four families of marine fish are considered to be ecologically important: Acanthuridae, Scaridae, Siganidae and Pomacentridae. Acanthuridae and Scaridae fish abundance have been reported to be low in Singapore (Lim and Chou 1991). Pomacentridae (angelfishes) are the most abundant and diverse fishes in Singapore. However, they are territorial and likely moderate algal communities in localised areas. Hence, they may not exert a great influence on algal growth on coral reefs in Singapore (Low et al. 1997). Siganidae (rabbitfishes) are often observed by divers in Singapore waters in schools of 5 - 20 or more, feeding on algal communities. Siganidae have a large consumption rate and are thus one of the more important groups within the local herbivorous guild that may play a role in controlling macroalgal growth (Perrig 2008).

In conclusion, this study has established the distribution and abundance of the sea urchin *Diadema setosum* of the reefs of Singapore as well as the distribution and abundance of algal cover, algal biomass, algal species and live coral cover. Although the results indicate that sea urchins likely do not play a role in regulating algal cover, a negative linear relationship between algal cover and live coral cover was observed. The results in this study may be a useful baseline for assessing any short term or long term physical changes on reef associated liveforms in Singapore.

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