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A COMPARISON OF BENTHIC LIFE-FORM CHARACTERISTICS OF A REEF (CYRENE) NEAREST TO AND A REEF (RAFFLES LIGHTHOUSE) FURTHEST FROM MAINLAND SINGAPORE

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ABSTRACT

Two reefs experiencing different environmental conditions and human influences are compared using the line intercept transect method at the 0m, 3m, 6m and 10m depths of the reef slope. Cyrene (Terumbu Pandan), a patch reef just south of the mainland of Singapore had a much lower average live coral cover (6.32%) compared to the fringing reef at Raffles Lighthouse (Pulau Satumu) which supported an average live coral cover of 15.23%. Both foliose and encrusting hard coral growth forms were dominant at the crests and the 6m depths of both reefs. At Cyrene, however, the encrusting growth form gave way to the massive growth form at the 3m depth. At the 10m depth at both reefs, the branching form dominated. Generic diversity was similar at both reefs, with 37 genera at Cyrene and 34 genera at Raffles Lighthouse, and 31 genera common to both reefs. Corals of the family Faviidae made up almost a third of the corals at Cyrene, and the Fungiidae were also more common here. However, the family Acroporidae was poorly represented and the Pocilloporidae was unrepresented at this reef compared to Raffles Lighthouse.

INTRODUCTION

The southern coast of Singapore supports many fringing and patch reefs (Fig. 1). Of these, the reefs at Raffles Lighthouse (Pulau Satumu) and Cyrene (Terumbu Pandan) are significant in that the former is geographically the most distant (15 km) from the main island of Singapore while the latter is the closest (4 km). Besides distance from the mainland, each reef is subjected to different conditions and degrees of human interference.

The main patch reef at Cyrene is adjacent to a major shipping fairway to the north and surrounded on the north-west and south by oil-refining complexes (on the Ayer Chawan group of islands and Pulau Bukom respectively). In addition, the reef is located near the mouths of two relatively major rivers - Sungei Jurong and Sungei Pandan. The efflux of water brings with it suspended sediments from land, especially after heavy rainfall. Local fishermen are also known to frequent this reef using submerged fish traps on the reef slope and nets on the reef flat. The conditions at Raffles Lighthouse are quite different. The island of Pulau Satumu is located just south of a group of islands designated for military use, and visits to the island and to its fringing reef is restricted. No major sources of siltation or pollution are evident in the vicinity of the island. The island is also located close to the open sea to its south. Fish abundance, however, has been observed to be similar on both reefs (Lim & Chou, 1991).

There have been two recent studies on the reef at Cyrene. The study by Chua (1990) covered transects at the 3m and 10m depths, while that of Low & Chou (in prep.) investigated reef life at the 0m and 6m depths. Similarly, two recent studies have been made of the coral community at Raffles Lighthouse (Leng *et al.*, 1990 and Goh & Chou, in prep.). This paper refers to the data collected in these four studies and compares these reefs at the 0m, 3m, 6m and 10m depths.

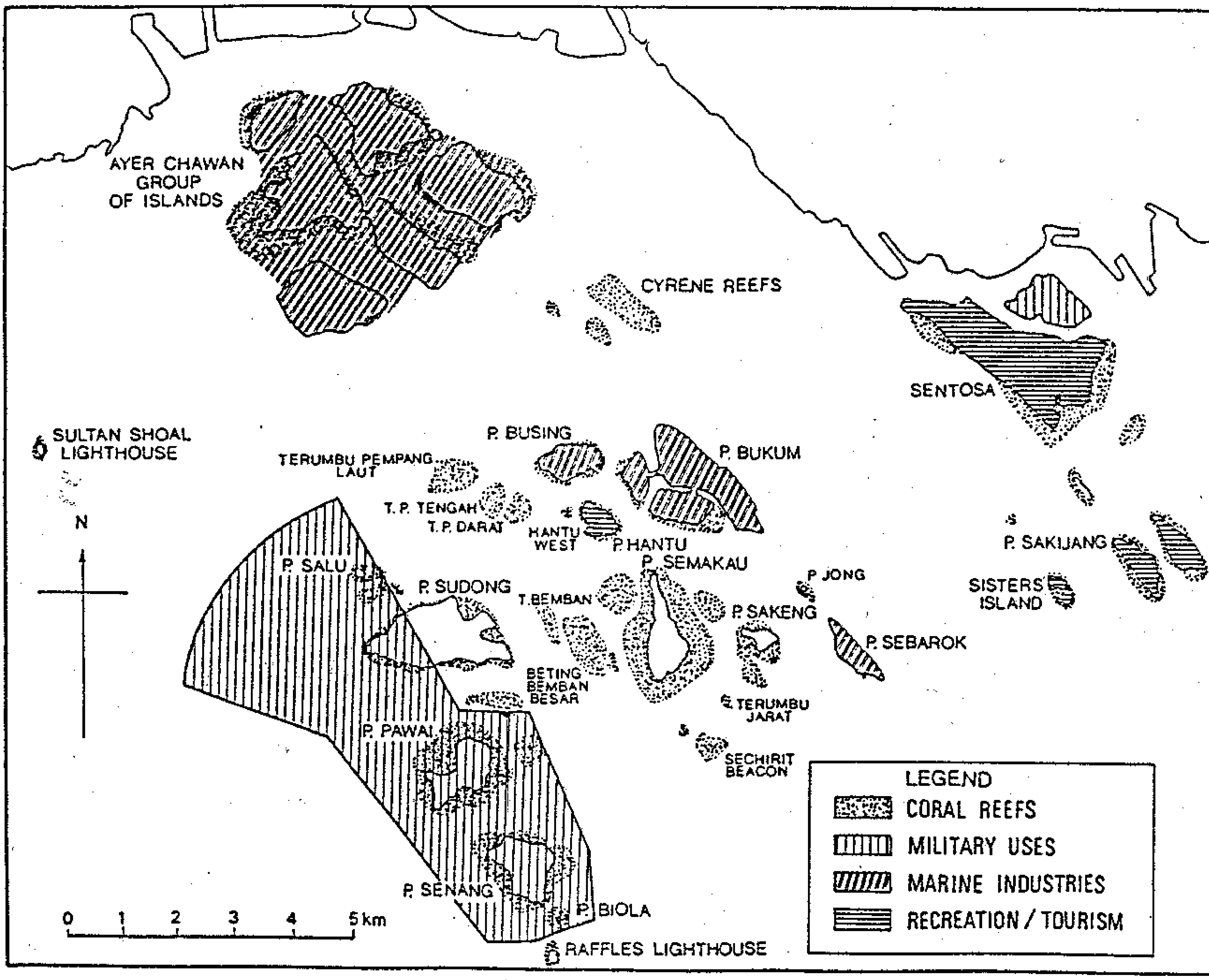

Fig. 1. The southern islands of Singapore showing their different uses and the locations of the reefs at Raffles Lighthouse and Cyrene.

MATERIALS AND METHODS

Surveys for both Raffles Lighthouse and Cyrene were conducted using the 100m line transect method (Dartnall and Jones, 1986) at the 0m (reef crest), 3m, 6m and 10m depths of the reef slope. All depths were measured with reference to the reef crest. The four depths were studied at two sites on each reef. For the purpose of comparison, the results of both transects at each depth on each reef were averaged.

RESULTS

Table 1 shows the results of all the transects at Raffles Lighthouse and Cyrene and summarizes them by depth and reef in terms of percentage cover of benthos. Corals of the genus *Acropora* were represented at Cyrene by only one colony, making up only 0.23% of the benthos transected at the 3m depth. These corals were absent on all other transects at Cyrene. At Raffles Lighthouse, *Acropora* was found at both 0m and 3m depths, with percentage covers of 6.48% and 0.73% respectively. Considering the non-*Acropora* scleractinia, the percentage cover at Raffles Lighthouse was higher at all depths except at 3m, where the percentages were almost equal (36.2% at Raffles Lighthouse and 35.56% at Cyrene). At the intermediate depths (3m and 6m), the percentage cover of dead coral with algal covering (DCA) was greater at Raffles Lighthouse than at Cyrene. However, at 0m and 10m, Cyrene had a higher DCA cover.

Algae (consisting of macroalgae, turf algae, coralline algae, *Halimeda* sp. and algal assemblages) were very limited at Raffles

Table 1. Percentage cover of benthos at different depths of the reef slope at Raffles Lighthouse and Cyrene.

	Raffles Lighthouse				Cyrene			
	0m	3m	6m	10m	0m	3m	6m	10m
Acropora	6.48	0.73	0	0	0	0.23	0	0
Other scleractinia	67.82	36.2	7.39	3.19	11.84	35.56	0.65	2.27
Algae covered dead coral (DCA)	12.26	28.53	52.9	20.66	16.09	12.42	25.61	35.06
Algae	0	0.11	2.43	0	20.13	2.52	5.63	1.9
Other lifeforms	2.38	3.99	2.5	22.59	4.73	1.99	2.15	7.31
Abiotic component	11.08	30.42	34.8	53.57	47.22	47.3	65.97	53.48
Predominent abiotic component	Rubble, Sand	Rubble	Rubble	Rock, Rubble	Rubble	Rubble, Sand	Sand, Rubble	Sand

Lighthouse (0.11% at 3m and 2.43% at 6m only). In contrast, high algal cover was found at Cyrene (e.g., 20.13% at 0m). The reef crest at Cyrene harboured more non-scleractinian faunae than Raffles Lighthouse (4.73% at Cyrene compared with 2.38% at Raffles Lighthouse). The intermediate depths were not much different in terms of areal cover of these groups. At the 10m depth, Raffles Lighthouse possessed a very dominant non-scleractinian faunae (22.59%).

The abiotic component of the transects at Cyrene was more prominent, especially at the 0m, 3m and 6m depths. However, at the 10m depth, both reefs exhibit a similar percentage cover of abiotic benthos. In terms of composition, this component at Cyrene consisted mainly of rubble and sand, whereas at Raffles Lighthouse, it was predominantly rubble and rock.

The distribution of coral growth forms in terms of percentage of total number of colonies of hard corals present on each transect depth is shown in Table 2. At the 0m depth, the encrusting and foliose growth forms dominated at both reefs (25.09% and 32.99% respectively at Raffles Lighthouse and 33.33% and 51.35% respectively at Cyrene). At the same depth at Cyrene, massive corals (30.63%) were also frequently found. Along the 3m transect at Raffles Lighthouse, foliose (36.36%) and encrusting (37.45%) colonies were common. At this depth at Cyrene, foliose colonies were also common (37.65%) but the encrusting growth form was encountered infrequently. Instead, massive colonies were more common (35.19%). At 6m below the reef crest at Raffles Lighthouse, encrusting colonies were very dominant (59.57%). On the lower reef slope (10m transect) at both reefs, the branching growth form was dominant (68.97% at Raffles Lighthouse and 75% at Cyrene). These branching corals have been observed to consist of the genera *Tubastraea* and *Dendrophyllia*.

Table 3 shows altogether 34 hard coral genera at Raffles Lighthouse and 37 genera at Cyrene (both including *Heliopora* sp.). Thirty-one genera were common to both reefs, with 3

Table 2. Occurrence of hard coral growth forms at different depths at Raffles Lighthouse and Cyrene as a percentage of total number of colonies of hard corals present per transect.

	Raffles Lighthouse				Cyrene			
	0m	3m	6m	10m	0m	3m	6m	10m
Tabulate	3.44	0.36	0	0	0	0	0	0
Branching	9.97	3.27	4.26	68.97	1.8	1.85	0	75
Massive	5.5	13.45	0	3.45	30.63	35.19	0	0
Encrusting	25.09	37.45	59.57	10.34	33.33	13.58	50	16.67
Submassive	15.46	2.18	12.77	17.24	6.31	4.94	0	8.33
Foliose	32.99	36.36	21.28	0	51.35	37.65	33.33	0
Mushroom	1.72	2.18	2.13	0	10.81	4.94	16.67	0
Heliopora	5.84	4.73	0	0	0	1.85	0	0
Total number of colonies	291	275	47	29	149	162	6	12

Table 3. Distribution of scleractinian genera throughout the reef slope of f Raffles Lighthouse and Cyrene.

		Number of Occurrences									
		Raffles Lighthouse				TOTAL	Cyrene				TOTAL
Family	Genus	0m	3m	6m	10m		0m	3m	6m	10m	
ACROPORIDAE	Acropora	8	5			13		1			1
	Montipora	56	41	4		101	5	3			8
POCILLOPORIDAE	Pocillopora	8				8					
	Madracis	1			1	2					
AGARICIIDAE	Pachyseris	5	16	3		24	2	5	1		8
	Pavona	18	15	3		36	5	2			5
	Leptoseris						3	1			4
FUNGIIDAE	Fungia	4	3			7	12	6	1		19
	Herpolitha	1	1			2	1	1			2
	Podabacia						2	3			5
PORITIDAE	Goniopora		2	1	1	4		4		1	5
	Porites	12	21	12		45	5	6			11
SIDERASTREIDAE	Psammocora	3	3		2	8	1				1
OCULINIDAE	Galaxea	13	1			14	2	8			10
PECTINIIDAE	Echinophyllia		7	1		8	1	5			6
	Oxypora	6	2			8	1	5			6
	Mycedium	7	2			9	3		2		5
	Pectinia	21	22	1		44	32	19	1		52
MUSSIDAE	Lobophyllia	3		1		4		3			3
	Symphyllia	1	4		1	6	3	3			6
TRACHYPHYLIIDAE	Trachyphyllia						1				1
FAVIIDAE	Cyphastrea	2	3	1		6	2	1			3
	Diploastrea	2	1	2		5	2	1			3
	Echinopora	1	1			2	3	7			10
	Favia	8	3	1	2	14	15	11			26
	Favites	8	3	1		12	6	11			17
	Goniastrea	11	6	1		18	5	7		1	13
	Montastrea	1	1			2	2	6			8
	Platygyra	4	11			15	12	14			26
	Leptastrea						1				1
MERULINIDAE	Merulina	13	30	1		44	11	16			27
	Hydnophora	6	5			11	4	2			6
	Scapophyllia	1				1					
CARYOPHYLLIIDAE	Euphyllia	1	2			3	2	3			5
	Plerogyra	1	3	1		5	2	2			4
	Physogyra							2			2
DENDROPHYLLIIDAE	Turbinaria	1	3	1		5	4	1			5
	Tubastraea	1	1	7	19	28				3	3
	Dendrophyllia						1			6	7
HELIOPORIDAE	Heliopora	17	13			30		3			3

genera found only at Raffles Lighthouse (*Pocillopora*, *Madracis* and *Scapophyllia*) and 6 genera found exclusively at Cyrene (*Leptoseris*, *Podabacia*, *Trachyphyllia*, *Leptastrea*, *Physogyra* and *Dendrophyllia*). A total of 544 distinct colonies were transected at Raffles Lighthouse compared with 327 colonies at Cyrene for the same transect distance.

Corals of the family Pocilloporidae, present at Raffles Lighthouse, were totally absent from Cyrene. Similarly, the Acroporidae (*Acropora* spp. and *Montipora* spp.) were particularly well represented at Raffles Lighthouse but not at Cyrene (a total of 114 acroporid colonies at Raffles Lighthouse compared with 9 at Cyrene). In terms of percentage number of colonies, the Acroporidae made up 21% at Raffles Lighthouse and only 2.8% at Cyrene. The faviid corals were very dominant at Cyrene making up 32.7% (107 colonies) of the total number of colonies transected. This contrasted with 13.6% (74 colonies) at Raffles Lighthouse.

Montipora (101 colonies) was the most dominant genus at Raffles Lighthouse, having more than twice the number of colonies of the next dominant genus (*Porites*; 45 colonies). At Cyrene, *Pectinia* (52 colonies) was also very dominant, having almost twice the number of colonies of the next most abundant genus (*Merulina*; 27 colonies). The blue coral *Heliopora* was rarer at Cyrene (3 colonies) than at Raffles Lighthouse (30 colonies).

DISCUSSION

Purchon & Enoch (1954) recorded a tidal range that was 60 cm larger at Raffles Lighthouse than at P. Bukom (just south of Cyrene). They attributed this difference to the sheltering effect of the southern islands that prevents P. Bukom from experiencing the full tidal range that Raffles Lighthouse (exposed directly to the Singapore Strait) does. The scleractinian genus *Acropora* is known to be more sensitive than other hard corals to suspended sediment in the water (Endean, 1976). In particular, branching forms of *Acropora* have been shown to have poor sediment rejection capabilities (Bak & Elgershuizen, 1976). The larger tidal range that Raffles Lighthouse experiences would indicate a corresponding increased flushing of sediments due to tidal currents. This could therefore be a contributing factor to the distinct difference in abundance of corals of this genus at the two reefs.

At most reefs in Singapore, coral cover is highest at the reef crest, decreasing with depth down the reef slope (Chou, 1988a, 1988b). This has also been true of Raffles Lighthouse (Goh & Chou, in prep.). However, at Cyrene, an anomaly to this trend is evident. The crest has almost three times less coral cover than at the 3m depth. Low & Chou (in prep.) have postulated that this observation could be due to the destruction of corals at the crest by strong wave action. In the sheltered waters of the southern islands, this would probably be generated by the passage of ships using the fairway north of the reef. Other reasons include the reported sightings of vessels running aground on this reef (Chua, 1990), and the collection of corals and reef organisms from the shallow parts of this reef.

Chou (1988b) found a clear trend of increasing live coral cover with distance from the mainland. This is supported in this study by the higher overall coral cover at Raffles Lighthouse compared with Cyrene. This could be explained by the stronger tidal currents at Raffles Lighthouse (mentioned above) as well as by the lack of suitable substrata at Cyrene. The abiotic component of Raffles Lighthouse and Cyrene differ both in terms of percentage cover as well as composition. The widespread presence of sand at Cyrene (25% of total benthos transected) precludes the occurrence of high coral cover at this reef. This is because the scouring effect of sand prevents the settlement or survival of coral planulae. At Raffles Lighthouse, rock and rubble (25.3% of total benthos transected) are available for coral settlement and recruitment.

The larger amount of algae-covered dead coral at the intermediate depths at Raffles Lighthouse could indicate that in the past, Raffles Lighthouse hosted a larger coral community (in terms of live coral cover) which subsequently died. The reef at Cyrene could have experienced a similar level of mortality but probably had a lower coral cover to begin with. However, no quantitative studies have been done on these reefs in the past.

There could be two possible reasons for the low algal cover at Raffles Lighthouse compared with that at Cyrene. Firstly, the hard corals, with their various chemical and mechanical defences, could have competitively suppressed the growth of algae at Raffles Lighthouse. Cribb (1973) alluded to the possibility of corals releasing antibiotic substances which inhibit the settlement of algal spores in their vicinity. At Cyrene, the paucity of hard corals could represent unexploited space resources which the algae, with their faster growth rate, could colonise. Endean (1976) has stated that coral-dominated reefs are frequently replaced by reefs dominated by algae. Thus, the algae could represent an early stage in the succession of the reef at Cyrene after the release of substrate caused by coral mortality. The differences in algal cover at the two reefs could also be due to seasonal variation in algal growth. The brown alga *Sargassum*, however, would not be responsible for this observed difference in distribution because of the timings of the surveys. The surveys at Cyrene were conducted in the months between March and June while those at Raffles Lighthouse were conducted between May and December. If this alga was responsible, then Raffles Lighthouse should have the higher algal cover since *Sargassum* is known to grow prolifically during the period of the North-east monsoon from November to March).

Assuming the competitive superiority of hard corals over non-scleractinian faunae, the distribution and abundance of these faunae at Cyrene and Raffles Lighthouse could also be explained by the restriction of the hard corals from the crest at Cyrene and the deeper depths at both reefs. The high cover of these faunae (observed to be dominated by gorgonian corals) at the 10m depth at Raffles Lighthouse would be due to the presence of a rocky substratum, known to be necessary for gorgonian recruitment (Kinzie, 1973).

The dominance of the foliose and encrusting growth forms at the reef crests of Raffles Lighthouse and Cyrene agree with the conclusions of Chua & Chou (1991) for Singapore reefs in general. Goh & Chou (in prep.) discussed the adaptations of these two growth forms to reefs in Singapore. The change in dominant growth form from encrusting to massive on descending from 0m to 3m at Cyrene could be due to the turbidity of the water at Cyrene. Chua & Chou (1991) attributed the observed turbidity of water at Cyrene to the stirring up of bottom sediments by the waves of passing ships. The proximity of Cyrene to the two rivers also compounds this effect. Encrusting colonies present a large upward-facing surface which is prone to smothering by sediment. In a highly sedimented reef like Cyrene, this growth form would not be able to tolerate the conditions as well as corals of other growth forms, e.g., massive corals which, due to their shape, are not prone to passive sediment settlement. The dominance of the branching growth form at the lower reef slope (10m) of both Raffles Lighthouse and Cyrene is attributed to the ahermatypic corals *Tubastraea* and *Dendrophyllia*. These are the only hard corals commonly found at this depth in Singapore reefs, where light levels fall below 5% of ambient surface illumination (Chuang, 1977), close to the limiting light levels needed for hermatypic coral survival (Titlyanov & Latypov, 1991).

There is little difference in coral generic diversity between Raffles Lighthouse (34 genera) and Cyrene (37 genera). However, when these observations are analysed together with live coral cover, several inferences may be made. Firstly, the lower coral cover at Cyrene could be an indication of the limiting effect of substrate availability (discussed earlier). Alternatively, or in combination with the above factor, these observations of live coral cover and diversity could reflect periodic disturbances of the reef at Cyrene. These disturbances prevent the establishment of a relatively small number of dominant species and maintains the diversity at a high level relative to the amount of substrate available. In an undisturbed situation, some species would be competitively excluded, leading to a much lower diversity.

Pocillopora damicornis, found exclusively at Raffles Lighthouse but not at Cyrene, has been shown to have planulae settlement inhibited by only partial (50%) covering of the substratum by fine sediment (Hodgson, 1990). The poor sediment tolerance of *Acropora* has already been discussed, and could explain its distribution patterns on the two reefs. The faviid corals, on the other hand, are generally massive (14 out of 18 Indo-Pacific genera; Veron, 1986), have large corallites and ciliary mechanisms which enable them to tolerate relatively high levels of sedimentation. Marshall & Orr (1931) concluded that corals with large polyps (corallites) are more efficient in removing sediment falling on them than those with small polyps. It is thus not surprising to find this family dominating the sedimented reef at Cyrene.

The distribution patterns of *Montipora*, *Porites*, *Heliopora*, *Pectinia* and *Merulina* at the two reefs suggest a relationship between corallite size, level of sedimentation and relative dominance in space utilisation. At Cyrene, the genera *Pectinia* (52 colonies) and *Merulina* (27 colonies) dominate. These genera are also relatively common at Raffles Lighthouse (44 colonies of each genus) but are not dominant there. The distribution of the genera *Montipora*, *Porites* and the reef-building octocoral *Heliopora* indicate a distinct preference of these genera for the reef at Raffles Lighthouse (*Montipora*: 101 colonies at Raffles Lighthouse and 8 colonies at Cyrene; *Porites*: 45 colonies at Raffles Lighthouse and 11 colonies at Cyrene; *Heliopora*: 30 colonies at Raffles Lighthouse and 3 colonies at Cyrene). These observations show that: (i)*Montipora*, *Porites* and *Heliopora* are relatively poor tolerators of high sedimentation levels (ii)*Montipora* and *Porites* are competitively superior to *Pectinia* and *Merulina* in terms of space utilisation under conditions optimal to coral growth (e.g., at Raffles Lighthouse). It is further noted that *Montipora*, *Porites* and *Heliopora* possess small corallites. This characteristic in corals makes them susceptible to smothering by sediments (Marshall & Orr, 1931). In particular, Bak (1978) has reported that *Porites astreoides* is an inefficient sediment rejector. On the other hand, *Pectinia* possesses tall walls and large valleys in the corallites, structures which enhance sediment removal. *Merulina* is frequently found in lagoonal habitats (Veron, 1986) which are known to have relatively turbid waters (Marshall & Orr, 1931).

Further analysis of the distribution patterns of Singapore corals in relation to levels of sedimentation and corallite size need to be carried out to determine whether the observations reported here can be generalised. Another interesting follow-up study could be made at establishing the competitive heirachy of scleractinians indirectly, using data on their distribution and knowledge of their sediment rejection capabilities.

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