THE CORAL REEF COMMUNITY OF PULAU SATUMU (RAFFLES LIGHTHOUSE), SINGAPORE, WITH EMPHASIS ON THE HARD CORALS

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ABSTRACT

Two sites on the fringing reef at Pulau Satumu (Raffles Lighthouse) were surveyed using 100m depth-specific line transects. Live hard coral cover ranged from 75.29% at the reef crest down to 1% at 10m below the crest. Scleractinians dominated the reefal fauna along all the transects, except at the 10m depth, where gorgonians dominated. For hard corals, the dominant growth forms were foliose and encrusting, with both depth and site specific differences in distribution between the two forms. Thirty-three hard coral genera were recorded in this study. The dominant genera are *Montipora, Porites, Merulina, Pectinia* and *Pavona*. Colony size of these genera was found to decrease with depth. Differences in generic distribution between the two sites were also observed.

INTRODUCTION

Raffles Lighthouse is situated on the island of Pulau Satumu (1° 10'N and 103°45'E). This island is one of a group of islands located south of the main island of Singapore (Fig. 1). Of the southern islands, P. Satumu is geographically the furthest away from the main island of Singapore (and hence most distant from sources of pollution and siltation). It is thus reasonable to assume that the water at P. Satumu is of a higher quality and clarity than at most other reefs in the group although no proper comparative study has been undertaken. The observation of Purchon & Enoch (1954) of a tidal range at Pulau Satumu that was 60 cm larger than at Pulau Bukom (which lies approximately mid-way between the mainland and Pulau Satumu) could also account for the stronger water circulation at Pulau Satumu. Because of the presence of the lighthouse, landing on the island itself is restricted, and a permit is required to dive on its fringing reef. The reef at Pulau Satumu is thus significant from a biological point of view as it is the closest representation of an undisturbed reef in

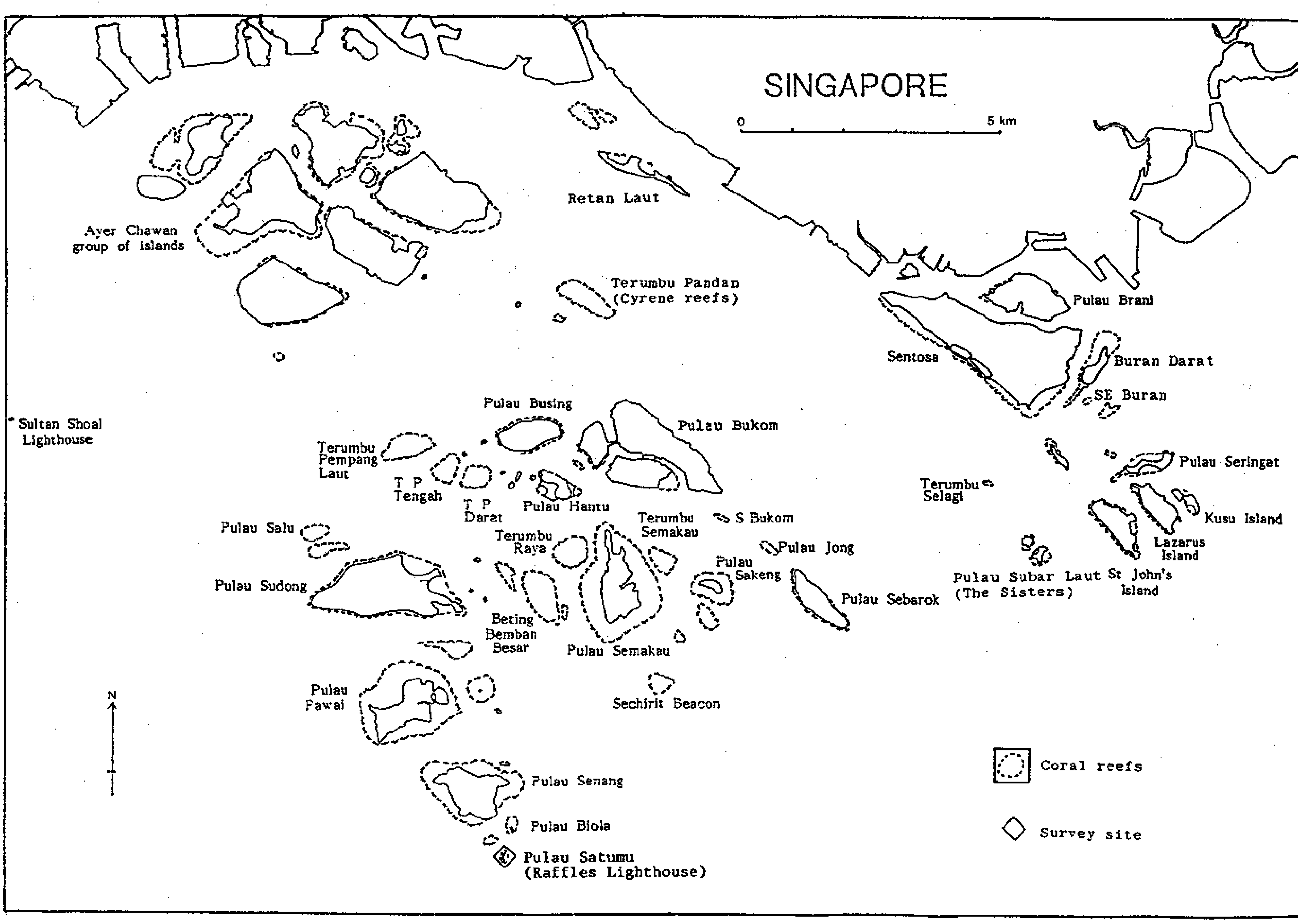

Fig 1. *Map of Singapore and the southern islands showing survey site*

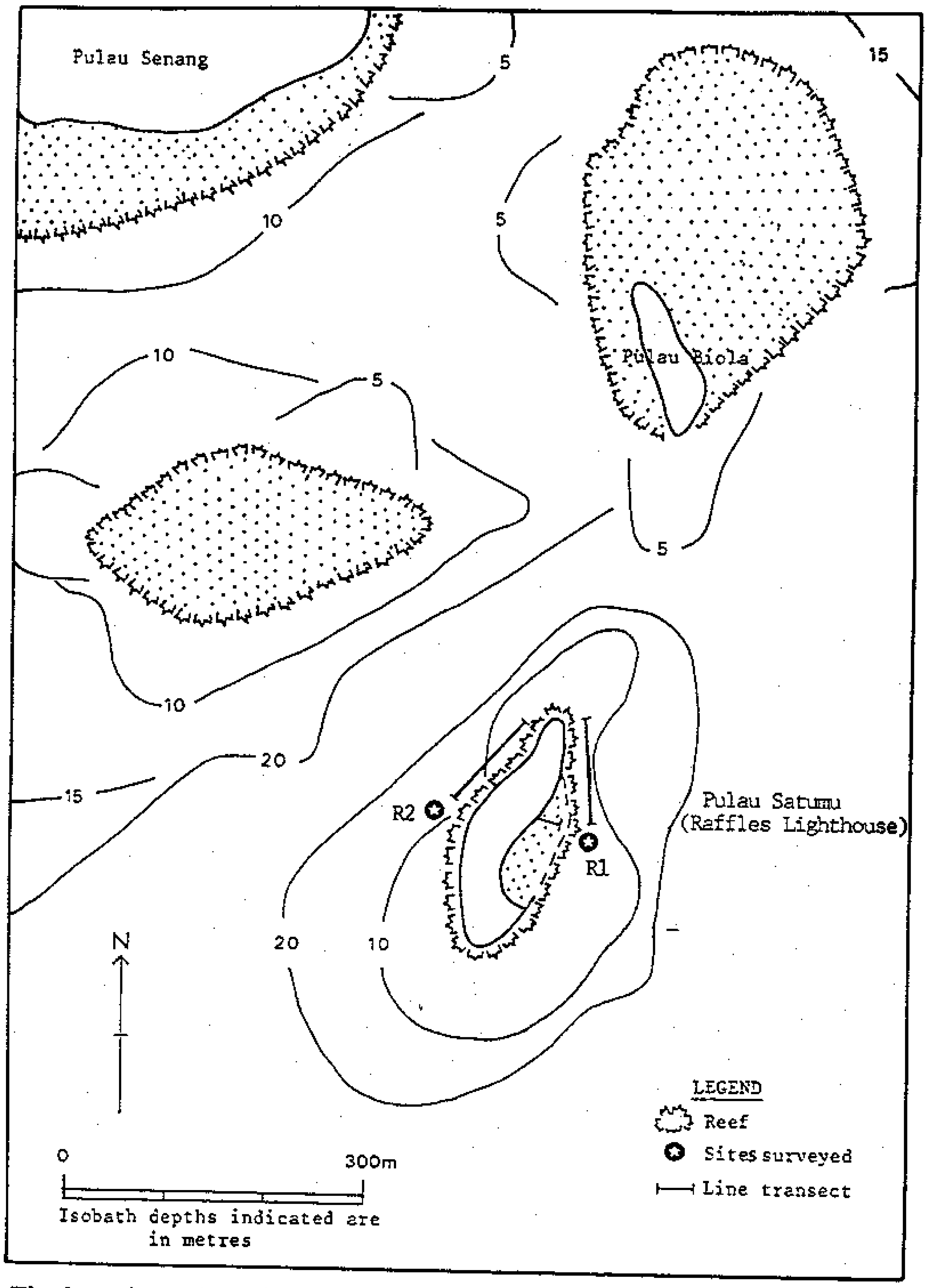

Fig 2. *Location of survey sites at Pulau Satumu*

Singapore.

This paper represents a follow-up study of an earlier paper by Leng et al. (1990). In that study, only the 3m and 10m depths of the reef slope were surveyed. The present study incorporates the data of the previous study and includes new data from the crest (0m) and the 6m depth. No previous survey of this nature has been conducted at the site. Chuang (1977) included the reef at Pulau Satumu as one of the four Singapore reefs he surveyed, but the study was qualitative in nature and did not give specific details of the scleractinian distribution at individual reefs. A similar study of the four depths of reef slope has been carried out at the fringing reef of P. Hantu (Chou, 1988a).

The 3m and 10m depth transects were conducted between September 1987 and June 1988. Transects at the 0m and 6m depths were carried out between May 1988 and December 1988.

MATERIALS AND METHOD

All surveys were conducted using SCUBA. Each involved the use of a graduated 100m transect tape laid parallel to the reef crest at fixed depths (Dartnall & Jones, 1986) of 0m (reef crest), 3m, 6m, and 10m of the reef slope, and recording all benthic lifeforms that the tape transected. Hard corals were identified to generic level. Where necessary, samples were brought back to the laboratory for microscopic examination. Two sites (R1 and R2) were surveyed. Fig. 2 shows the locations of the sites.

RESULTS

Percentage cover data for the various reef components are summarized in Table 1. The percentage of live coral cover (*Acropora* and Non-*Acropora*) showed a general decrease with depth at both sites. The algae-covered dead coral (DCA) had high occurrences at the intermediate and deeper depths. Algal growth on this reef was low, with the highest occurrence of 4.7% at the 6m transect at R2. Flora and fauna other than hard corals or algae were low (1.1% to 3.65%) for the shallow to intermediate depths but became dominant at the 10m transect. These groups were observed to be dominated by gorgonian corals. The percentage cover of the abiotic component of the transects was relatively lower at the shallow depths, and was dominated by coral rubble. At the 10m transect, the substratum consisted mainly of rock (46.53% of total cover at R1 and 17.87% at R2). In addition, the corals of the genus Acropora were found only at the 0m and 3m transects.

Fig. 3 illustrates the areal cover of growth forms as a percentage of the total hard coral cover for all the transects at both sites. The most abundant growth forms were foliose (37.45% of total hard coral cover) and encrusting (31.29%). The mushroom growth form was the most poorly represented (0.7%). The percentage cover of the hard coral growth forms at different depths is compared in Table 2. The difference in percentage cover of the two most dominant growth forms (foliose and encrusting) between R1 and R2 is illustrated in Fig. 4 and indicates an interchange of dominant growth form for the two sites.

Table 1 : Cover of lifeforms at different depths at the two survey sites (R1 and R2) of Raffles Lighthouse as a percentage of total length transected

	R1				R2			
TRANSECT DEPTH	0m	3m	6m	10m	0m	3m	6m	10m
LIFEFORMS:								
Acropora	9.55	1.15	0	0	3.4	0.3	0	0
Non-Acropora	65.74	27.5	7.4	5.37	69.9	44.9	7.37	1
Dead coral with algae (DCA)	9.71	23.5	33.66	10.17	14.8	33.56	72.13	31.15
Algae	0	0	0.15	0	0	0.22	4.7	0
Other lifeforms	3.65	4.2	3.8	32.03	1.1	3.78	1.2	13.15
Abiotic	11.35	43.65	54.99	52.43	10.8	17.18	14.6	54.7
Predominant abiotic substrate (%)	Rubble (7.30)	Rubble (30.40)	Rubble (44.71)	Rock (46.53)	Sand (6.80)	Rubble (12.61)	Rubble (11.90)	Rubble (18.62) Rock

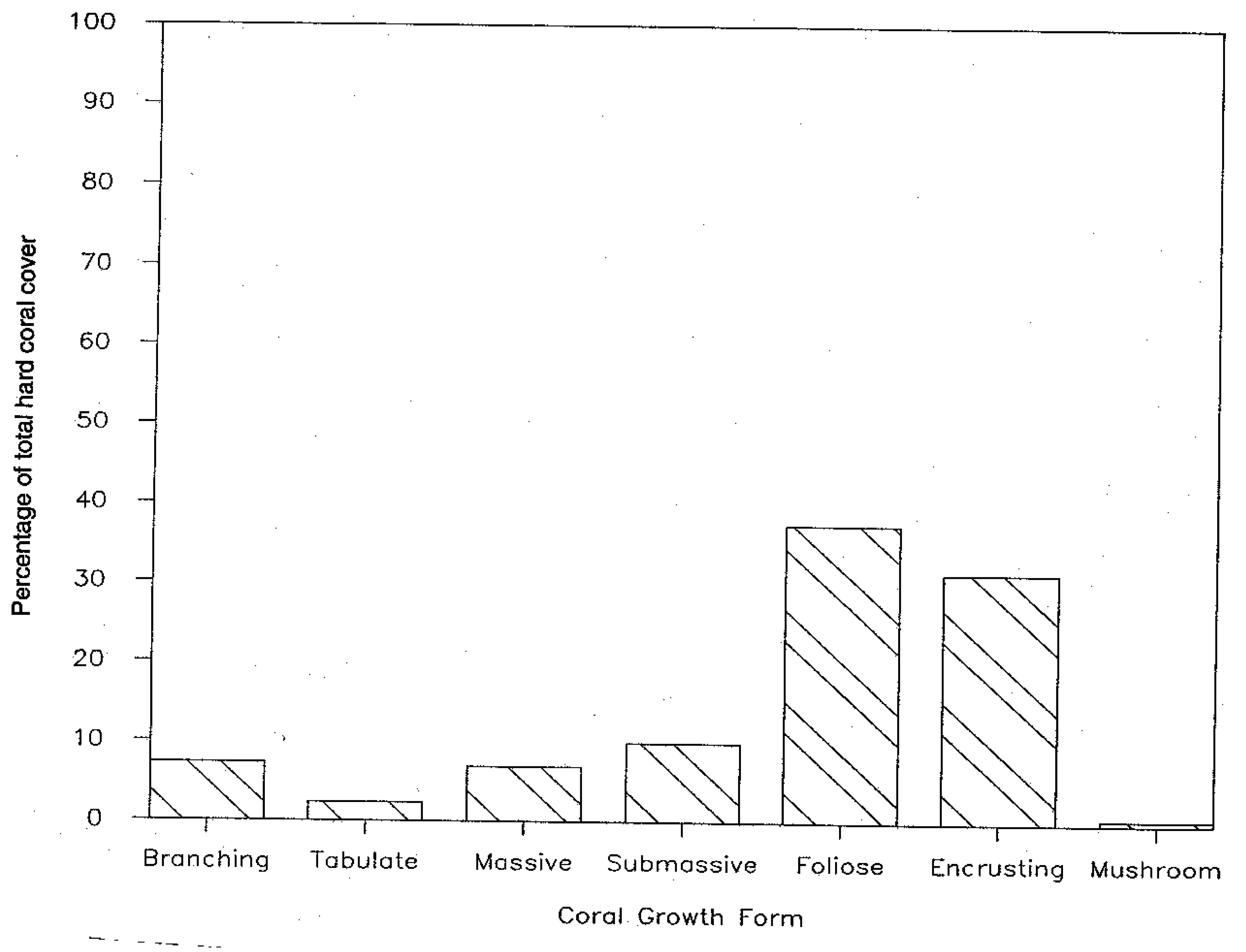

Fig 3. *Occurrence of hard coral growth forms as a percentage of total hard coral cover*

Table 3 summarizes the distribution and average colony sizes of the 33 hard coral genera found at the different transects at the two sites. A decrease in generic diversity with depth is seen (31 genera at 0m; 29 at 3m; 17 at 6m; 6 at 10m).

Montipora was by far the dominant genus in terms of frequency occurrence, with 101 colonies found on the eight transects. *Porites* (45 colonies), *Merulina* (44), *Pectinia* (44) and *Pavona* (36) were also relatively well represented on the upper reef. The ahermatypic coral, *Tubastraea* (28) was common only on the lower reef slope. In addition, the octocoral *Heliopora* (30) was also common at the upper reef slope at R1.

At the 0m and 3m depths, *Montipora* was the dominant genus (56 and 41 colonies respectively). The next most frequently occurring genus at the 0m depth was *Pectinia* (21 colonies), while at the 3m depth, *Merulina* (30 colonies) occurred most commonly after *Montipora*. Porites was common at the intermediate depths (21 colonies at 3m and 11 colonies at 6m). At the latter depth, it was the dominant genus. *Tubastraea* was dominant at the 10m depth (19 colonies). Considering the five commoner upper reef slope genera, a general trend of a decrease in colony size with depth is apparent.

Table 2. Cover of hard coral growth forms at different depths as a percentage of total hard coral cover at each depth

GROWTH FORM	0m	3m	6m	10m
Branching	9.41	3.40	-	-
Tabulate	5.04	0.14	-	-
Massive	4.06	15.15	-	-
Encrusting	26.61	40.47	49.62	53.74
Submassive	12.59	1.25	20.11	46.27
Foliose	41.66	38.68	30.27	-
Mushroom	0.63	0.91	-	-

Note: Values for each depth are based on the sum of coral covers from both sites (R1 and R2).

Several site-specific differences are also noted: *Montipora* is found in great abundance at R1 (89 colonies compared to only 12 colonies at R2). *Pavona* and *Pectinia* were significantly more abundant at R2 than at R1 (*Pavona*: 30 vs. 6 colonies; *Pectinia*; 34 vs. 10). Eight colonies of *Pocillopora* were transected at R1, but none was found at R2.

DISCUSSION

Lane (1991) recorded suspended sediment loads that commonly exceeded 20 mg/cm^2/d in the waters south of Singapore. Light attenuation in these waters has been found to be 60% within the first four metres, 95% at depths of 10m and 99.65% at 16m (Chuang, 1977). The detrimental effect of high sedimentation and water turbidity

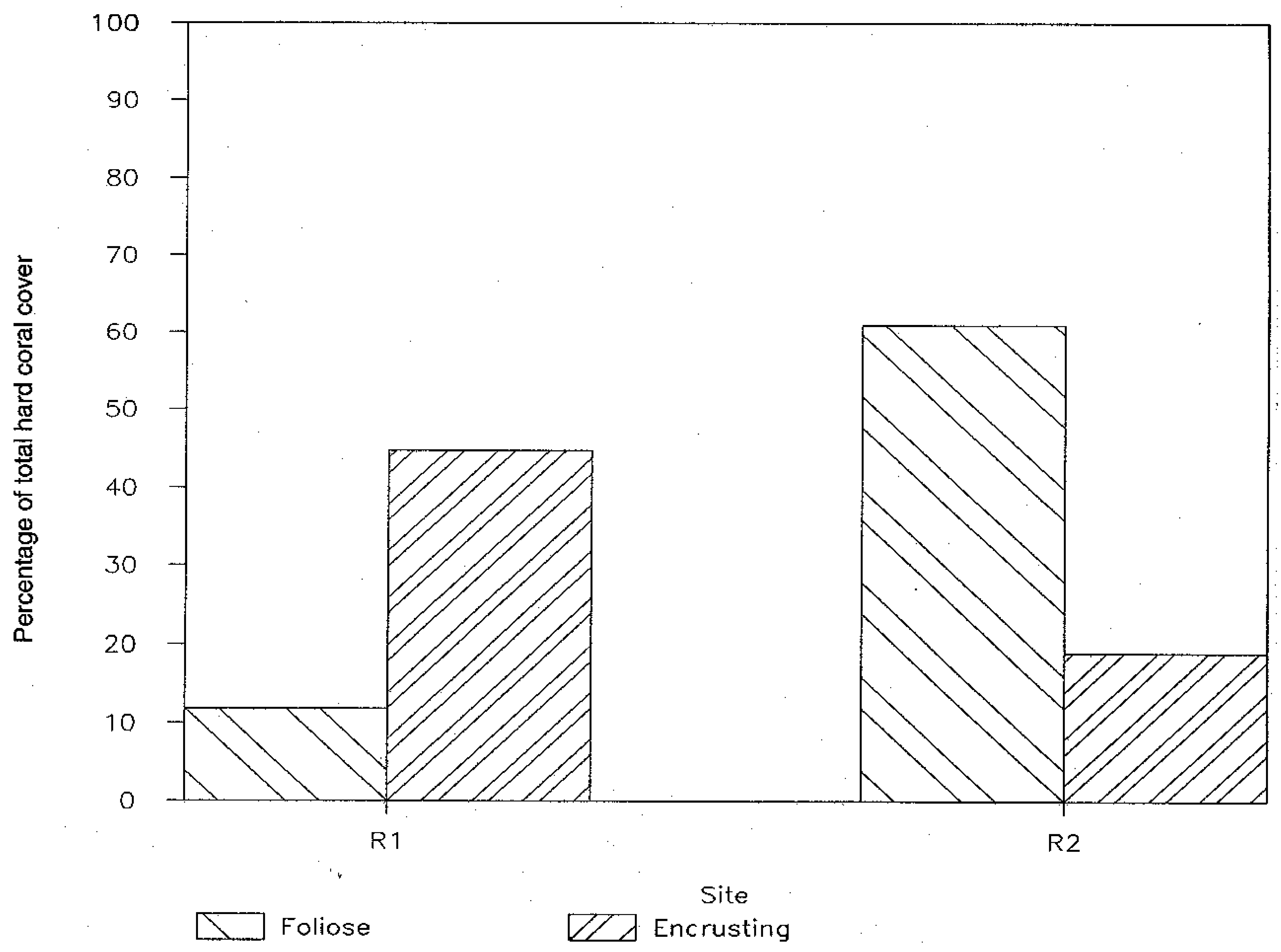

Fig 4. *Cover of foliose and encrusting growth forms at R1 and R2 as a percentage of total hard coral cover at each site*

on live coral cover in Puerto Rico was reported by Loya (1976a). In Table 1, a general decrease in live coral cover with depth that could also be attributed to similar factors is seen. However, in the Singapore context, this effect is more pronounced only from the 3m transect down. Sedimentation is known to have two possible effects on corals: (1) a direct smothering effect and (2) an indirect effect of cutting out the sunlight available to the coral (Roy & smith, 1971). In Table 1, it should also be noted that the main 'band' of scleractinian growth is within the upper three metres of the reef slope. Chou (1988a) found similar results in his survey of the fringing reef at Pulau Hantu, Singapore. This 'compression' of coral distribution is also described in a recent study of scleractinian distribution by Titlyanov & Latypov (1991) in turbid waters off the coast of Vietnam.

The scleractinian representatives on the 10m transect are mainly ahermatypic corals of the genus Tubastraea. The virtual disappearance of the hermatypic corals at the 10m depth can be explained by the fact that at this depth, the light levels fall to 5% of surface irradiance (Chou & Chia, 1991), which approaches the minimum irradiance levels (2 - 0.5% of surface radiation) needed by hermatypic corals for survival (Titlyanov & Latypov, 1991). The dominance of the gorgonian corals on the 10m transect can be attributed to the availability of suitable rocky substrata (Jordan, 1989) and possibly indirectly to the restriction of scleractinians from this depth (Goh & Chou, in press).

The high level of algae-covered dead coral at the intermediate depths at Pulau Satumu points to the existence of healthy coral growth in the recent past. Before massive land reclamation works began in the 1960's, the waters off Singapore were much more transparent, with visibility reaching 10m (Chou & Chia, 1991). The land reclamation resulted in massive sediment loading of the offshore waters (Chou & Chia, 1991) and could have caused lethal effects on the corals similar to those caused by dredging as observed by Bak (1978).

Chua & Chou (1991) found that the two most dominant coral growth forms on Singapore reefs are of the foliose and encrusting type. The results of the present study supports this finding (Fig. 3). Davies (1980) reported that these two growth forms are more efficient than others for calcium deposition in low light conditions. The predominance of foliose growth forms in Singapore reefs has been attributed to several factors: inclination of the reef slope, water turbidity and shelter from strong surface water movement (Chua & Chou, 1991).

In Table 2, a pattern in the depth distribution of foliose and encrusting growth forms is evident. At the 0m transects, the foliose form is clearly dominant. With increasing depth, the encrusting form emerges as the more successful. Loya (1976b) suggested that the encrusting growth form is an advantageous trait in reef areas open to recolonisation after a catastrophe. The rationale behind this idea is that this growth form is the most efficient in occupying space in space-limited coral reefs. It appears reasonable that the heavy siltation caused by extensive land reclamation precipitated the extinction of less tolerant hermatypic corals at the lower depths (3m - 10m). Recolonisation of the space thus made available would then most likely be achieved by

Table 3 : Distribution of hard coral genera at Raffles Lighthouse and their average colony sizes

	Number of Occurrences									Ave. Colony Size (cm)							
	R1				R2				TOTAL	R1				R2			
	0m	3m	6m	10m	0m	3m	6m	10m		0m	3m	6m	10m	0m	3m	6m	10m
Acropora	2	3			6	2			13	42.5	38.3			56.7	15		
Montipora	52	33	4		4	8			101	50.4	33.8	27		161.3	24.5		
Pocillopora	8								8	34.4							
Madracis	1			1					2	60			11				
Pachyseris		5	1		5	11	2		24		29	30		58	22.4	20	
Pavona	4	1	1		14	14	2		36	23.8	40	20		55.7	17.4	20	
Fungia	2				2	3			7	20				10	14.3		
Herpolitha	1					1			2	30					6		
Goniopora		1	1	1		1			4		20	15	1		35		
Porites	4	4	5		8	17	7		45	115	13.8	15.6		23.1	21.9	45	
Psammocora	3			1		3		1	8	116.7			160		15		75
Galaxea	6	1			7				14	80	20			17.1			
Echinophyllia			1			7			8			15			52.6		
Oxypora	6					2			8	15.8					7.5		
Mycedium	1	2			6				9	20	42.5			53.3			
Pectinia	5	4	1		16	18			44	80	28.8	5		53.1	16.3		
Lobophyllia	1		1		2				4	40		10		30			
Symphyllia					1	4		1	6					10	21.5		5
Cyphastrea	2		1			3			6	102.5		5			29.3		
Diploastrea	1				1	1	2		5	25				170	60	90	
Echinopora	1					1			2	5					50		
Favia	3			2	5	3	1		14	40			2.5	24	21.7	20	
Favites	7				1	3	1		12	29.3				20	27.7	10	
Goniastrea	11	3	1			3			18	65.5	25	1			46.7		
Montastrea	1					1			2	30					15		
Platygyra	3				1	11			15	23.3				30	34.5		
Merulina	3	5	1		10	25			44	40	28	10		46	17		
Hydnophora	6	5							11	28.3	68						
Scapophyllia	1								1	30							
Euphyllia		1			1	1			3		20			40	10		
Plerogyra	1	1				2	1		5	20	40				60	5	
Turbinaria	1		1			3			5	70		145			27.7		
Tubastraea	1		3	18		1	4	1	28	5		93	8.3		5	8	10
Heliopora	17	13							30	33.2	25.4						

corals of the encrusting growth form. This could then account for their dominance at the lower depths. Comparative work on the depth distribution of growth forms on other reefs in Singapore will have to be carried out to establish this hypothesis.

Foliose forms are known to be susceptible to breakage in areas of high wave energy. Although no quantitative data are available on the relative wave movements for R1 and R2, the orientation of the site at R1 towards the open sea indicates a more energetic environment. The site at R2 is relatively more sheltered; by P. Satumu itself, P. Biola and P. Senang (Fig 2). Referring to Fig. 4, the dominance of the encrusting growth form over the foliose growth form at R1 could then be attributed to the differences in incident wave energy experienced by each site. In the sheltered site of R2, the foliose form predominates. This form has a greater surface area relative to its volume for trapping light energy, and thus would have a relatively faster growth rate.

Thirty-three hard coral genera were recorded in this survey (Table 3). This diversity is comparable with other reefs in the region, e.g., 26 genera at Cape Rachado, Malaysia (Goh & Sasekumar, 1980), 38 genera at the Sichang Islands, Gulf of Thailand (Sakai et al., 1986) and 41 genera at P. Hantu, Singapore (Chou, 1988a). A decrease in generic diversity with depth is seen in this study. Chou (1988b) reported a similar decrease in the number of genera with depth for four other reefs (Cyrene, Hantu, Hantu West, Semakau) in Singapore. In the same paper, Chou attributed this observation to the importance of water transparency, reasoning that the direct effect of smothering by sediment would affect corals similarly at all depths on the reef, and not just those at the lower slope.

The dominant genera found at Pulau Satumu is generally consistent with the dominant genera (*Montipora, Pectinia, Merulina*) for Singapore reefs (Chua & Chou, 1991), with the addition of *Porites* and *Pavona*. All the dominant genera, with the exception of *Porites*, occur exclusively as foliose or encrusting colonies. The colonies of *Porites* here were mainly of the encrusting form, but some massive and submissive colonies were also present. The dominance of *Porites* at the intermediate depths is consistent with the findings of Chou & Wong (1986).

Chou (1986) noted a gradual decrease in size index of four species of hard corals with depth for Singapore reefs. The trend of decreasing colony size with depth for *Montipora, Porites, Merulina, Pectinia* and *Pavona* in the present study serves to reinforce the general applicability of this trend for Singapore reefs. With reference to particular species, the size of a colony is a function of its age. The observed decrease in colony size thus indicates that colonies at the lower depth are younger than those occurring in shallower water. It is possible that these smaller colonies reflect recolonisation of the deeper depths by sediment-tolerant species after the die-back caused by the initial increase in suspended sediment of the waters in the 1960's.

The differences in distribution of *Montipora, Pocillopora, Pavona* and *Pectinia* at the two sites could be indicative of differences in reef morphology, current regimes, physical parameters of a host of other factors. At the present time, no conclusive explanation can be proposed for these observations.

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