

**REEF COMMUNITY STRUCTURE
OF PULAU SALU (Singapore)**

**LA STRUCTURE DES COMMUNAUTES
RECIFALES DE PULAU SALU (Singapour)**

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ABSTRACT

Studies on the community structure of the fringing reef of Pulau Salu, an uninhabited island 12 km south of the Singapore mainland, were carried out along two 1-metre wide, perpendicular to shoreline, belt transects, one south (transect A) and the other north (transect B), of the island. Both transects can be divided into the 3 distinct zones of reef flat, reef edge and reef slope, on the basis of biological and geological characteristics. The reef flat has a slight gradient while the reef slope is steep. Forty-two species of hard corals were recorded and their distribution patterns indicated that only 5 species, Goniastrea pectinata, G. retiformis, Favia speciosa, Favites abdita and Porites lutea, extended into the shallow regions of the reef flat, the rest being confined to the deeper parts of the flat, edge and slope. Individual coral species cover a range from 0.02 to 2.59%. Total live coral cover on the reef was low (transect A - 12.05%, transect B - 11.00%), but if considered separately, the reef slope registered higher values (transect A - 39.37%; transect B - 53.36%). Macroalgae, abundant on the reef flat, were dominated by the brown algae, Sargassum, Padina and Turbinaria, and the green algae Enteromorpha. Distribution patterns of the other reef-associated organisms (7 spp. sponges, 1 sp. hydrozoan, 6 spp. anthozoans, 1 sp. annelid, 5 spp. molluscs, 1 sp. platyhelminth, 1 sp. crustacean, 2 spp. echinoderms) showed well defined zones throughout the reef from the intertidal to the subtidal levels.

RESUME

Des études de la structure des communautés du récif frangeant de Pulau Salu, une île inhabitée à 12 km au sud de Singapour, ont été réalisées à partir de deux radiales de 1 mètre de large, perpendiculaires au rivage. L'une est située au sud de l'île (radiale A), l'autre au nord (radiale B). Les deux radiales coupent trois zones récifales distinctes du point de vue biologique et géologique : le platier récifal, le front récifal et la pente externe. Le platier récifal présente une faible pente tandis que la pente externe est accore. Quarante deux espèces de coraux ont été relevées. Seules 5 espèces, Goniastrea pectinata, G. retiformis, Favia speciosa, Favites abdita and Porites lutea, se distribuent sur le platier récifal, à faible profondeur, les autres étant confinées dans les eaux plus profondes du platier, du front et de la pente récifale. Chaque espèce a un pourcentage de recouvrement compris entre 0,02 et 2,59 %. Le pourcentage total de recouvrement en coraux vivants est faible (radiale A : 12,05 %, radiale B : 11 %) ; si l'on considère la pente externe séparément, celle-ci présente les taux de recouvrement les plus forts (radiale A : 39,37 % ; radiale B : 53,36 %).

Les macroalgues, abondantes sur le platier récifal sont dominées par les algues brunes, Sargassum, Padina et Turbinaria, et l'algue verte Enteromorpha. Le schéma de distribution des autres organismes associés au récif (7 espèces d'éponges, 1 espèce d'hydrozoaire, 6 espèces d'anthozoaires, 1 espèce de plathelminthe, 1 espèce de crustacé, 2 espèces d'échinodermes) est bien défini sur le récif, depuis la zone intertidale à la zone subtidale.

INTRODUCTION

Pulau Salu ($1^{\circ}13'N$, $103^{\circ}42'5''E$) is a small uninhabited island 12 km south of the Singapore mainland. A luxuriant vegetation covers the hillslopes and hilltop of the island. A fringing reef comprising a thin, superficial layer of coral material resting on various substrates, completely surrounds the island. This is typical of the southern islands' reefs off Singapore (Chuang, 1977). The gentle sloping reef flat is of varying widths bordered by a rather steep subtidal reef slope. This survey is a continuation of 2 earlier studies. The first one by Tay (1978), was on the biology and ecology of coral reef fishes, while the second by Chou & Teo (1983) was on the community structure of the hard corals. A study of the distribution of the marine macroalgae carried out with this survey has been reported in a separate paper (Chou & Wong, in press). The present work is a quantitative study of the species composition of the coral reef community excluding the fishes and was carried out between May and December of 1982.

MATERIALS AND METHOD

Two perpendicular-to-shore transects were set up on opposite sides of the island, one facing south (transect A) and the other facing north (transect B), as shown in fig. 1. They

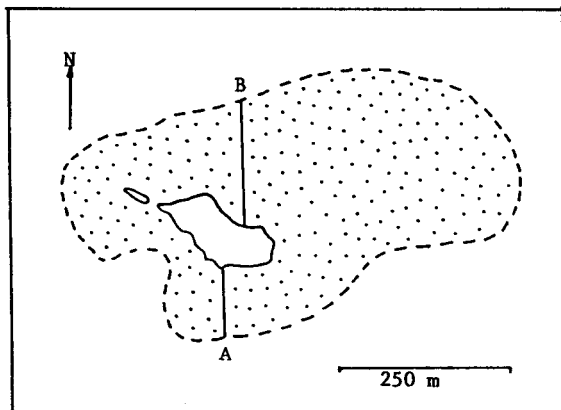


Fig. 1. Map of Pulau Salu and its fringing reefs with locations of transects.

were different in location to those studied by Chou & Teo (1983). Each transect stretched from the shoreline to the bottom of the reef slope. A one-metre quadrat subdivided into 100 squares of 100 cm^2 each was placed on one side of the transect line and moved at one-metre intervals along its entire length from shore to slope.

The cover of hard and soft corals, sponges and other reef-associated organisms were estimated directly from the quadrat. Small organisms were recorded in terms of number of individuals. The reef profile was determined by measuring the depth of the water with a plumb-line at 2-metre intervals along the entire transect. Scuba diving was used throughout the study.

RESULTS

The reef profile of transect A has a shorter reef flat (80 metres) and a steeper reef slope than that of transect B (reef flat 150 metres) as shown in fig. 2. Common to both

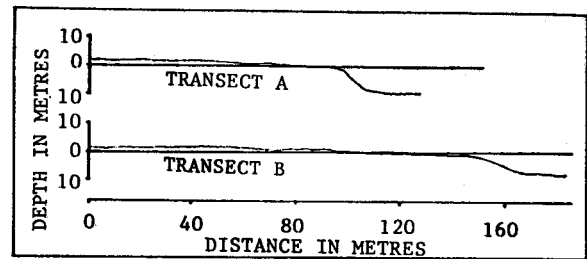


Fig. 2. Reef profiles of transects.

reef flats is the very slight gradient. Both transects have short reef slopes.

Sargassum spp. were the most dominant macroalgae on both transects, being distributed throughout the reef flat from the shore end to the upper part of the reef slope. This was followed next by another brown algae, *Padina tenuis* Bory, also distributed throughout the reef flat. These two species were the only macroalgae common to both transects. Six other species of macroalgae were found along the two transects combined. They were the green algae *Caulerpa sertularoides* (Gmelin), *Codium geppii* Schmidt, *Enteromorpha clathrata* (Roth), *Halimeda opuntia* (Linn.), *Ulva reticulata* (Forskal), and the brown algae *Turbinaria ornata* (Turner). The majority of the macroalgae occurred on the sandy patches of the reef flat. None were found beyond the reef edge. The sea grass, *Enhalus acoroides* Rich. & Steud., was limited in distribution and present only at the 87th metre quadrat (from shore) of transect B covering a surface of less than 1000 cm^2 .

The abundance and frequency occurrence of other reef-associated organisms are shown in table 1. A total of 7 sponge species belonging to the class Demospongiae were encountered in both transects. Each transect had 6 species. *Suberites inconstans* Dendy was dominant on sandy patches of the reef flat. All species were confined to the reef flat except for the green spikey sponge, *Dysidea* sp. which extended down the reef slope, growing amongst the hard corals.

Of the soft corals, *Sarcophyton* sp., *Lobularia pachyclados* (Klunzinger) and *Sinularia leptoclados* (Ehrenberg) were all common on the reef flat. None of the soft corals were found on the reef slope. The colonies present at transect A were larger than those at transect B. Gorgonians comprising the sea fan, *Melithaea* sp. and the sea whip, *Junceela* sp., were found only on the reef slope of transect A. The former occupied the reef edge and upper part of the slope while the latter occurred in the deeper part of the slope below the 5 metre depth level. The sea anemone, *Stoichactis* sp., was present on the lower half of the reef flat of transect B and on the bottom of the reef slope of transect A. The hydroid, *Lytocarpus* sp. was

Table 1. Abundance, frequency and size index of reef associated organisms at Pulau Salu, Singapore. (Size index is calculated by dividing total absolute cover in cm² of species by number of individuals and dividing again by 100).

Species	TRANSECT A (length 114 metres)				TRANSECT B (length 179 metres)				
	Abundance % cover/indiv. per m ²	Frequency No. of quadrats present	Size /No.of Index indiv.	Abundance % cover/indiv. per m ²	Frequency No. of quadrats present	Size /No.of Index indiv.	Abundance % cover/indiv. per m ²	Frequency No. of quadrats present	Size /No.of Index indiv.
PHYLUM PORIFERA									
<u>Dysidea</u> sp.	0.008	1	1.00	0.006	1	1.00			1.00
<u>Haliciona</u> sp.	0.25	3	15.00	0.03	3	2.00			2.00
<u>Hyattella clathrata</u> (Carter)	0.22	6	4.33	0.09	5	3.00			3.00
<u>Ircinia ramosa</u> Keller				0.06	4	2.75			2.75
<u>Spirastrella purpurea</u> (Lamarck)	0.10	4	3.00	0.07	4	3.25			3.25
<u>Suberites inconstans</u> Dendy	0.38	13	3.50	0.29	18	3.00			3.00
<u>Verongia</u> sp.	0.61	9	8.11						
PHYLUM COELENTERATA									
<u>Lytocarpus</u> sp.	0.008	1	1.00						
<u>Stoichactis</u> sp.	0.08	1	9.00	0.05	1	9.00			
<u>Melithaea</u> sp.	0.03	1	4.00						
<u>Junceella</u> sp.	0.05	1	6.00						
<u>Lobularia pachyclados</u> (Klunzinger)	0.45	5	11.20	0.15	4	7.67			
<u>Sinularia leptoclados</u> (Ehrenberg)	0.58	3	23.33						
<u>Sarcophyton</u> sp.	0.50	3	20.00	0.04	2	4.00			
PHYLUM ANNELIDA									
<u>Sabellastarte indica</u> (Savigny)				0.006	1	1.00			
PHYLUM PLATYHELMINTHES									
<u>Pseudocercid polyclad</u>	0.008	1							
PHYLUM MOLLUSCA									
<u>Planaxis sulcatus</u> (Born)							0.05	2	9
<u>Siphonaria atra</u> (Quoy & Gaimard)	0.33	2	40				0.03	2	6
<u>Strombus urceus</u> Linnaeus							0.02	3	3
<u>Malleus malleus</u> (Linnaeus)	0.06	5	7						
<u>Tridacna squamosa</u> Lamarck				0.01	1	2.00			
PHYLUM ARTHROPODA									
<u>Pilumnus vespertilia</u> (Fabricius)	0.008	1							
PHYLUM ECHINODERMATA									
<u>Diadema setosum</u> (Leske)				0.01	1	2.00			
<u>Stephanometra</u> sp.				0.01	1	2.00			

Table 2. Abundance, frequency and growth forms of hard corals at Pulau Salu, Singapore.
(Growth forms: B = branching, F = foliaceous, L = laminate, M = massive)

Species	Growth form	TRANSECT A (length 114 metres)			TRANSECT B (length 179 metres)		
		Abundance % Cover	Colony No.	Frequency No. of quadrats present	Abundance % Cover	Colony No.	Frequency No. of quadrats present
<i>Acropora tubicinaria</i> (Dana)	B	0.12	2	2			
<i>A. valida</i> (Dana)	B	0.06	1	1			
<i>Montipora digitata</i> (Dana)	B				0.73	9	9
<i>M. efflorescens</i> Bern.	L	0.20	1	1	0.42	4	4
<i>M. informis</i> Bern.	L	2.19	10	8			
<i>M. prolifera</i> Brugg.	L				0.18	2	2
<i>M. solanderi</i> Bern.	L	0.68	5	5			
<i>M. sulcata</i> Cross.	L	0.10	1	1			
<i>Montipora</i> sp.	L				0.21	1	1
<i>Pavona decussata</i> (Dana)	F	0.06	2	2			
<i>P. frondifera</i> Lam.	F				1.44	9	9
<i>Pavona</i> sp.	F	0.44	4	4			
<i>Pachyseris speciosa</i> (Dana)	L	0.91	5	5	2.59	13	13
<i>Psammocora contigua</i> (Esper)	F				0.70	5	5
<i>Fungia fungites</i> Linn.	M	0.67	10	10	0.05	3	2
<i>Herpolitha limax</i> (Esper)	M	0.04	1	1			
<i>Goniopora lobata</i> M.Ed. & H.	M	0.10	2	1	0.31	2	2
<i>G. stutchburyi</i> Wells	M				0.04	1	1
<i>Porites lutea</i> M.Ed. & H.	M	0.55	10	9	1.09	19	19
<i>P. nigrescens</i> Dana	B				0.31	3	3
<i>P. (synaraea) rus</i> (Fors.)	B				0.33	4	3
<i>Favia fava</i> (Fors.)	M	0.03	1	1			
<i>F. speciosa</i> (Dana)	M	0.02	1	1	0.10	4	4
<i>Favites abdita</i> (El. & Sol.)	M	0.16	2	2	0.21	6	6
<i>F. chinensis</i> (Verr.)	M	0.04	1	1			
<i>Favites</i> sp. 1	M	0.72	10	10			
<i>Favites</i> sp. 2	M				0.17	3	3
<i>Goniastrea australensis</i> (M.Ed. & H.)	M	0.03	2	2	0.13	3	3
<i>G. palauensis</i> (Ya., Su. & Eg.)	M				0.02	1	1
<i>G. pectinata</i> (Ehr.)	M	0.72	12	11	0.02	1	1
<i>G. retiformis</i> (Lam.)	M	2.02	37	32	0.47	19	19
<i>Platygyra daedalea</i> (El. & Sol.)	M	0.08	2	2	0.16	1	1
<i>Hydnophora rigida</i> (Dana)	B				0.15	2	2
<i>Cyphastrea chalcidicum</i> (Fors.)	M				0.12	1	1
<i>Echinopora lamellosa</i> (Esp.)	L	1.38	5	5			
<i>Galaxea fascicularis</i> (Linn.)	M	0.04	1	1	0.12	1	1
<i>Symphyllia nobilis</i> (Dana)	M				0.35	3	3
<i>Oxypora lacera</i> Verr.	L	0.31	10	10	0.20	2	2
<i>Mycedium elephantotus</i> (Pall.)	L	0.26	3	3	0.08	2	2
<i>Pectina lactuca</i> (Pall.)	F	0.09	1	1			
<i>Tubastrea aurea</i> (Quoy & G.)	B	0.03	1	1			
<i>Turbinaria mollis</i> Bern.	M				0.30	2	2

present on the upper reef slope of transect A only.

Five species of molluscs were accounted for in the two transects. The bivalve, Malleus malleus (Linnaeus) was present throughout the reef flat of transect A, while the pulmonate, Siphonaria atra (Quoy & Gaimard), was common on the rocks near the shore end of the reef flat of the same transect. At transect B, S. atra together with two other gastropods, Planaxis sulcatus (Born) and Strombus urceus Linnaeus, and the giant clam, Tridacna squamosa Lamarck, were present. Siphonaria atra and P. sulcatus were confined to the rocky shore end of the flat while S. urceus occurred on the sandy areas throughout the reef flat. The single T. squamosa individual was found at the reef crest.

Other reef-associated organisms were limited to single individuals. On transect A, a pseudocercid polyclad worm and the crab, Pilumnus vespertilia (Fabricius) were present at the lower third of the flat. On transect B, the tube-worm, Sabellastarte indica (Savigny), the sea urchin, Diadema setosum (Leske), and the feather star, Stephanometra sp. were all located between the lower part of the reef crest and upper level of the slope.

Of the 42 species of hard corals, 28 occurred in transect A and 27 in transect B (table 2). 15 coral species were common to both transects. Total living coral coverage on the reef was low, being 12.05% for transect A and 11.00% for transect B. However, if the 3 zones of reef flat, reef edge and reef slope were considered separately, the reef slope registered higher values of 39.37% for transect A and 53.36% for transect B. Coral cover on the reef flat was extremely low at 1.34% for transect A and 0.97% for transect B.

The majority of the corals were concentrated at the reef slope and edge of both transects. Only 5 species, Favia speciosa (Dana), Favites abdita (El. & Sol.), Goniastrea pectinata (Ehr.), G. retiformis (Lam.) and Porites lutea M. Ed. & H., extended deeply into the reef flat. Among these, G. retiformis was the most dominant making up 52.05% of total reef flat coral cover at transect A and 43.34% at transect B. The reef edge zone of both transects is dominated by the various Montipora species, contributing 40.71% of total coral cover at transect A and 32.04% at transect B. The reef slope of transect A is again clearly dominated by Montipora (28.16% of reef slope coral cover), while that of transect B had three almost equally abundant species. They are Pachyseris speciosa (Dana) (22.01%), Psammocora contigua (Esper) 18.53% and Pavona frondifera Lam. (17.63%).

All the 5 species which extended into the shallower ends of the reef flat were massive in form and restricted to small colonies not exceeding 800 cm². Corals of branching, laminate and foliaceous growth forms were confined to the reef edge and slope. Colony size was largest on the reef slope with maximum surface areas of 5000 sq. cm. attained by Echinopora lamellosa (Esper), Montipora informis Bernard and Pachyseris speciosa at transect A and 8000 sq. cm. by P. speciosa at transect B. Colony number, species richness and Shannon & Weaver's Diversity Index increased from reef flat to reef slope of both transects. Average colony number per sq. m.

on transect A and transect B (in parenthesis) was 0.54 (0.39) on the reef flat, 2.0 (1.47) on the edge and 4.5 (4.64) on the slope. Species richness (number of species per sq. m.) with figures for transect B in parenthesis) increased from 0.31 (0.30) on the flat to 1.15 (1.33) on the edge and 2.64 (2.64) on the slope. Shannon & Weaver's Diversity Index increased from 1.299 (1.013) on the flat to 1.945 (1.700) on the edge and 2.250 (2.060) on the slope. Pielou's Evenness Index showed a more even distribution on the flat (transect A = 0.82, B = 0.77) than on the edge (A = 0.66, B = 0.74) and slope (A = 0.57, B = 0.60).

DISCUSSION

The reef as well as the living community can be divided into 3 zones of the reef flat, reef edge and reef slope. Beneath the 8-metre depth on the reef slope, low light intensity caused by the high sedimentation load, restricted coral growth.

The reef slope itself, above the 8 metre level, has the greatest diversity and species richness compared to other zones. The relatively poor coral growth on the reef flats can be attributed to sedimentation as well as emersion at low spring tides. The sedimentation has resulted from the various large-scale land reclamation projects along the southern coastline of the mainland which have been in progress for 2 decades. The very slight gradient of the reef flat enables sediment to settle easily making it unfavourable to coral recruitment. The reef flat however favours growth of Sargassum which is seasonal, with maximum cover during the cooler months between October and January (Chuang, 1977). The cyclical growth of this algae may have an effect on the animals associated with it, especially the herbivores.

There is a general lack of branching corals here unlike, for example in Eilat where branching corals dominate in waters with high sedimentation load (Loya, 1972).

From preliminary observations of the reefs of the other southern islands, similarities in the profiles and also distribution and diversity of reef-associated organisms exist. The ecology of Pulau Salu's reef can be used as a model of an equatorial sediment-stressed Sargassum-reef.

ACKNOWLEDGEMENTS

This work forms part of a research project on the reef ecology of Pulau Salu which is supported by a grant from the Singapore Institute of Biology. We are grateful to Mrs Jessie Mui and Mrs Chan Yee Ngoh for typing the manuscript.

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