Galaxea, 13:85-92. (1996)

RESPONSE OF SINGAPORE REEFS TO LAND RECLAMATION

L. M. Chou

Department of Zoology, National University of Singapore,
10 Kent Ridge Crescent, Singapore 0511

ABSTRACT - Coral reefs of Singapore have been subjected to high sedimentation levels caused by extensive land reclamation over the past 30 years, resulting in a decline of life on the reef flat (due to settlement and accumulation of sediment), and the lower reef slope (due to light penetration reduction). The upper reef slope of some reefs, which remains the zone of active growth, supports live coral cover of up to 74.8% and scleractinian species diversity of 44 per 100 m line transect. The dominant coral growth forms on the slope are encrusting, foliose and massive. The slope of two reefs which had their reef flats reclaimed showed comparable scleractinian species richness, algal and live coral cover to three which remained unaffected. However, live coral cover data for the crest and 3 m depth of the slope of 41 reefs showed a significant difference between reefs with reclaimed flats and those that remained intact.

INTRODUCTION

Land reclamation in Singapore began as early as the 19th century when its founder, Sir Stamford Raffles, ordered the filling of swamps around the main harbour in 1891. By the turn of the century, the sea around the southern tip of the country was reclaimed. In the 1930s, estuaries of the Kallang and Geylang rivers also in the south, were reclaimed for the construction of a civilian airport. Land reclamation in modern Singapore began in 1964 with the Kallang River Basin Reclamation project, and since then, extensive reclamation has been carried out along almost the entire stretch of the southern coastline of the main island (Fig. 1). Some stretches along the northern coastline as well as a few of the northern and southern offshore islands have also been reclaimed. To date, reclamation has increased the land area of Singapore by 10% of its original size of 581 km^2 in 1966. Future reclamation plans will add a further 15% of land area (Yong et al., 1991).

Reefs that have been filled in through reclamation are directly eliminated as is the case with fringing reefs along the south-western shores of the main island. Reefs of the southern offshore islands are affected by reduced sunlight penetration through the heavily sedimented waters. On some of the southern islands, only the reef flats have been reclaimed with the filled material retained by a rock bund, and the reef slope left intact.

Land reclamation has contributed to high levels of sedimentation which reduced the average visibility of the waters from 10 m in the early 1960s to 2m today. Coral reefs of Singapore have been subjected to this high sediment level for almost three decades. Recent studies of the reefs indicated that the upper reef slope zone still exhibits good species diversity and active growth of scleractinian corals as well as other reef-associated life (Chua & Chou, 1991; Goh & Chou, 1991). The lower reef

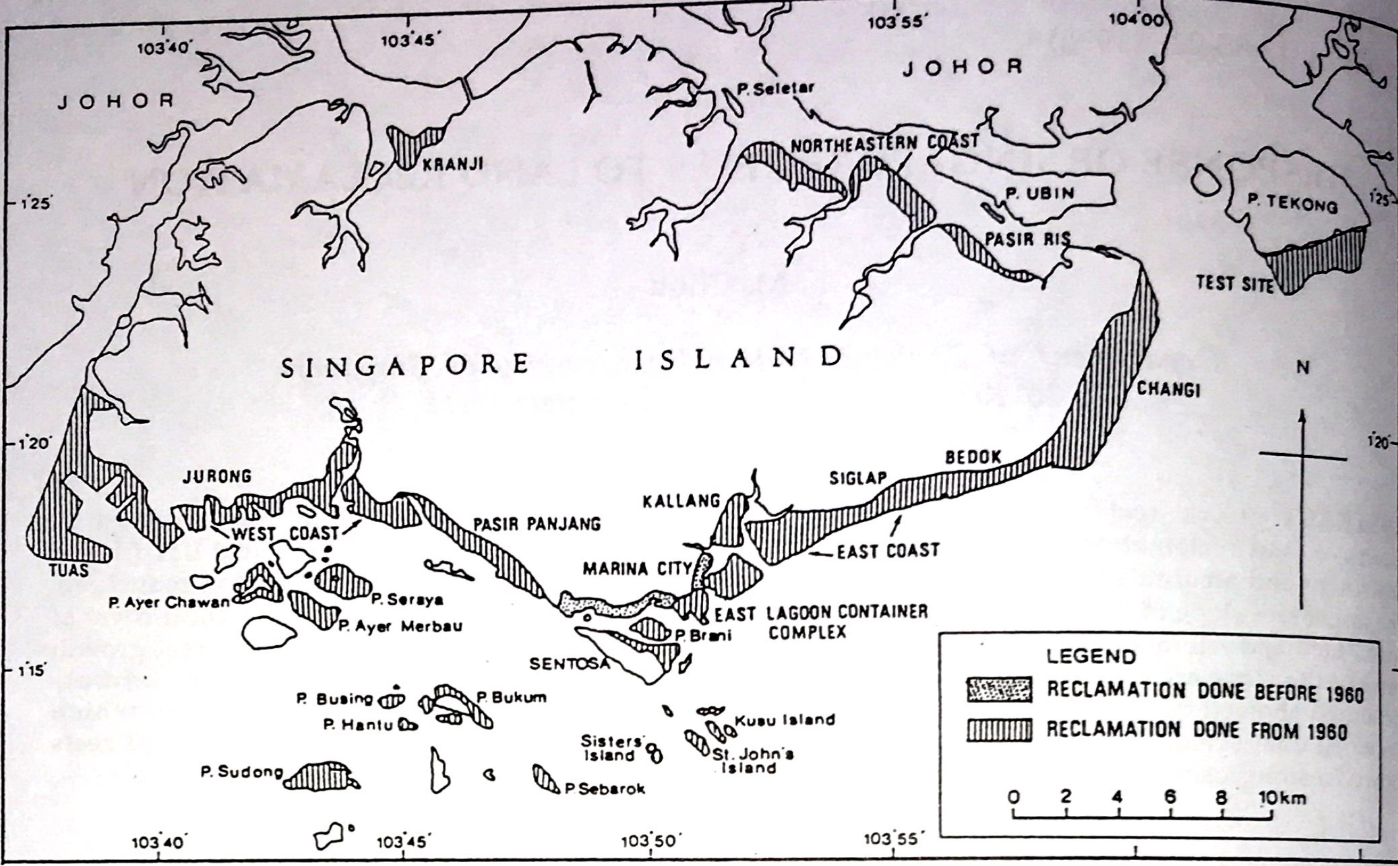

Fig. 1. Land reclamation in Singapore indicating changed coastlines on the main island and the offshore islands.

slopes and reef flats do not support much coral cover (Chou & Teo, 1985; Chou & Wong. 1985). The upper reef slope of reefs with their flats reclaimed, also exhibited good coral diversity and cover (Chou, 1988).

This paper reviews the data obtained through surveys of various reefs to see how they have responded to increased sedimentation caused by land reclamation, and also compares reef slope community structure between reefs with reclaimed flats and those with intact flats.

MATERIALS AND METHOD

Surveys of reefs involved the use of parallel-to-shore 100 m line transect placed along a specific depth of the reef slope, as described in Dartnall & Jones (1986). Depths of the reef slope surveyed were usually the reef crest itself, and the 3 m, 6 m and 10 m with respect to the reef crest.

All living and non-living components lying directly beneath the transect line were recorded in pre-determined codes together with a measure of the intercept amount. Hard corals of 5 reefs (Raffles, Hantu, Hantu West, Semakau, Cyrene) selected for long-term detailed monitoring were identified to species, while other reef-associated organisms were placed into broader taxonomic categories. For these reefs, studies were carried out at the crest, 3 m, 6 m and 10 m depths of the slope.

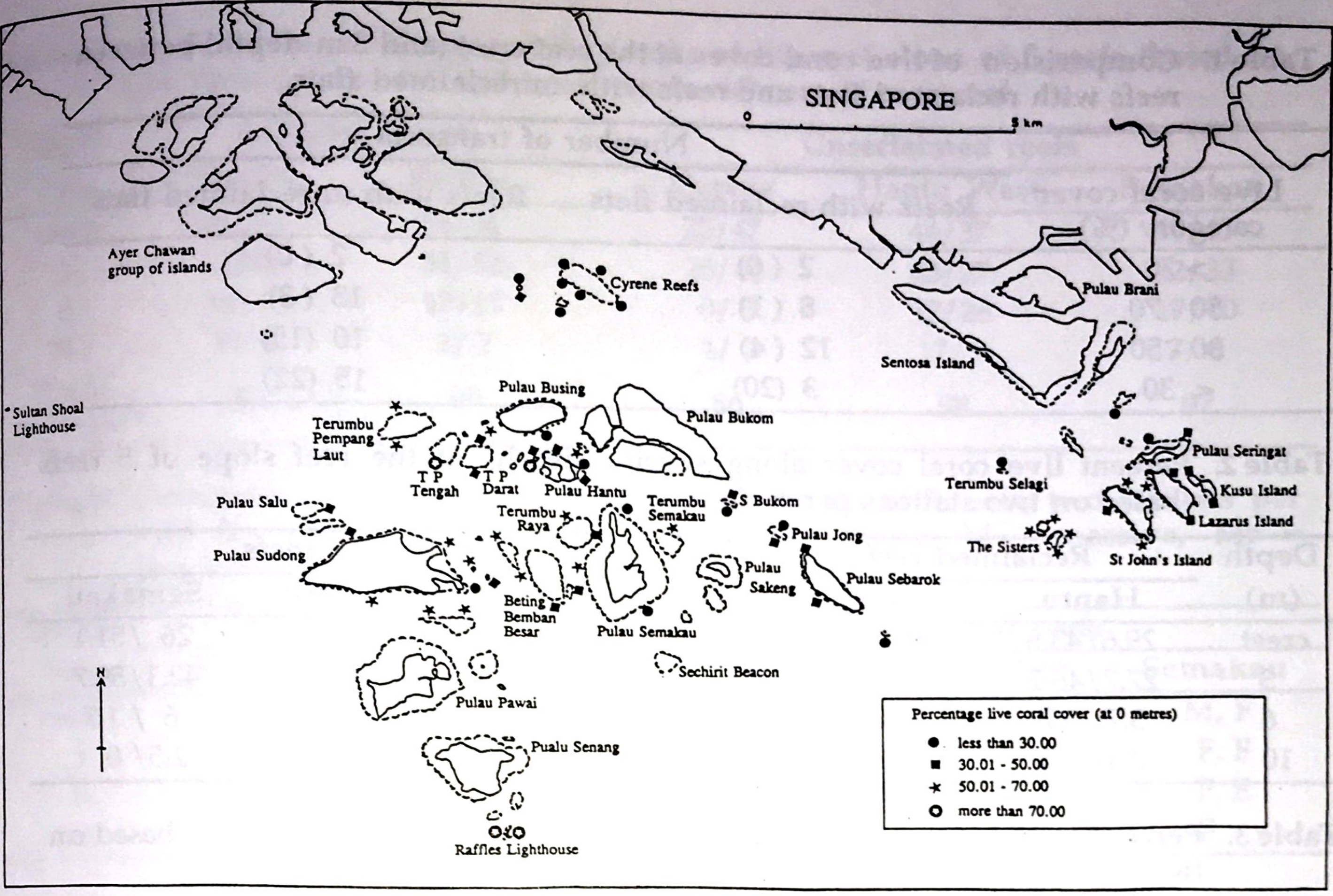

Fig. 2. Coral reef condition based on live coral cover at the reef crest of Singapore's southern offshore islands.

On reefs which were not selected for detailed monitoring, no attempt was made to identify the hard corals, as the survey was carried out by trained volunteer divers without any background in biology (Chou, 1990). Growth forms of the hard corals were however noted in all surveys. Abiotic components were categorised as sand, silt, or rubble.

RESULTS

In a broad survey of the reef crest zone conducted during 1989 and early 1990 covering 65 locations of 41 reefs, 18 sites were found to support live hard coral cover of less than 30% while 4 had live cover in excess of 70%. Live coral cover between 30 and 50% occurred at 22 sites while between 50 and 70%, 21 sites (Fig. 2). At the 3 m depth, 42 sites had less than 30% live coral cover, 19 sites had coral cover of between 30 and 50%, and the remaining 4 sites had a cover of between 50 and 70%.

Of the 65 transect sites, 25 were on reefs with reclaimed reef flats. The reef crest of two sites supported live coral cover of more than 70% while 8 had live cover of between 50 to 70% (Table 1). Thus on reefs with reclaimed reef flats, 40% of the sites surveyed supported coral cover of above 50% compared to 37.5% on reefs with

Table 1. Comparision of live coral cover at the reef crest (and 3 m depth) between reefs with reclaimed flats and reefs with unreclaimed flats.

Live coral cover category (%)	Number of transects	
	Reefs with reclaimed flats	Reefs with unreclaimed flats
>70	2 (0)	2 (0)
50 - 70	8 (1)	13 (3)
30 - 50	12 (4)	10 (15)
< 30	3 (20)	15 (22)

Table 2. Percent live coral cover along specific depths of the reef slope of 5 reefs (based on two stations per reef).

Depth (m)	Reclaimed reefs		Unreclaimed reefs		
	Hantu	Raffles	Cyrene	Hantu West	Semakau
crest	29.6/43.8	74.8/73.3	4.4/19.3	41.5/70.1	26 /51.1
3	27.7/46.2	28.7/45.2	23.5/48.1	62 /35	42.1/59.7
6	3.7/ 3.7	7.4/ 7.4	0 /1.3	7.7/22.5	6 / 1.7
10	0.4/ 5.5	5.4/ 1	4.5/0	4 /14	2.5/ 0

Table 3. Percent algal cover along specific depths of the reef slope of 5 reefs (based on two stations per reef).

Depth (m)	Reclaimed reef		Unreclaimed reefs		
	Hantu	Raffles	Cyrene	Hantu West	Semakau
crest	13.5/ 6.2	0 / 0	21.8/18.4	12.5/ 0.2	6 /13.7
3	0.2/11.3	0 / 0.2	3.5/ 1.6	0 / 0.1	8.3/ 0
6	1.1/ 0.6	0.2/ 4.7	9.9/ 1.4	4.2/ 0.8	5.2/ 9.2
10	2 / 0.7	0 / 0	0 / 3.8	0 / 0	0 / 4.1

unreclaimed flats. At the 3 m depth of the reef slope, 4% of the reclaimed reefs (representing only one site) and 7.5% of unreclaimed reefs had coral cover of more than 50%. However at the other end of the scale, 80% of reclaimed reefs and 55% of unreclaimed reefs showed live coral cover of less than 30% at the 3 m depth.

Statistical analysis on live coral cover using Student's t test, showed no significant difference between the reef crest and the 3 m depth of reclaimed reefs. However, significant differences were obtained between the reef crest and the 3 m depth of unreclaimed reefs ($p < 0.05$). Significant differences were also obtained between the crests of reclaimed and unreclaimed reefs, and between the 3 m depths of reclaimed and unreclaimed reefs.

In a more detailed study of 5 reefs, two of which had reclaimed reef flats, no significant differences ($p < 0.05$) were found between the live coral cover at similar depths of the reefs with reclaimed flats and those without (Table 2). Algal cover (Table 3) and scleractinian species richness (Table 4) at the same depths also showed

Table 4. Species richness along specific depths of the reef slope of 5 reefs (based on two stations per reef) and total species richness of each reef.

Depth (m)	Reclaimed reefs		Unreclaimed reefs		
	Hantu	Raffles	Cyrene	Hantu West	Semakau
crest	26/52	53/36	25/47	44/37	40/43
3	34/48	31/52	25/44	43/27	42/33
6	14/14	17/15	0/ 5	17/26	17/10
10	2/14	2/ 2	4/ 0	17/9	7/0
Total richness	93	99	86	98	97

Table 5. Dominant coral growth form at specific depths of 5 reefs, two stations per reef (B = branching, E = encrusting, F = foliose, M = massive, Mr = mushroom, S= submassive).

Depth (m)	Reclaimed reef		Unreclaimed reefs		
	Hantu	Raffles	Cyrene	Hantu West	Semakau
crest	B, F	E, F	M, F	F, F	M, F
3	F, F	E, F	M, F	F, E	F, F
6	M, Mr	S, F	-, E	F, F	F, E
10	F, Mr	S, E	E, -	E, M	F, -

no significant difference ($p < 0.05$) between reefs with reclaimed reef flats and those with intact reef flats.

Foliose coral growth form dominated the crest and 3 m depth of the reef slope of both reef categories (Table 5). In addition, branching and encrusting growth forms were also abundant at these zones of reefs with reclaimed flats while massive and encrusting forms were abundant on reefs with intact reef flats. At the lower depths of 6 and 10 m, mushroom, submassive and foliose forms were dominant on reefs with reclaimed flats while encrusting and foliose forms dominated reefs with intact reef flats.

DISCUSSION

High levels of sedimentation cause corals and other sessile invertebrates to expend energy in ridding themselves of the fine sediment, thus weakening them in their other functions (Salvat, 1987). Such stress imposed on the ecosystem causes some species to die out eg. *Porites astreoides* under sedimentation stress caused by dredging (Bak, 1978), and the entire reef system to lose population diversity. In severe cases, the reef gets degraded beyond natural repair (Marshall, 1982).

Coral species have different abilities to deal with sedimentation stress (Brown, 1972; Endean, 1976). At the level of larval settlement, a 50% coverage of the substratum by sediment was found to inhibit settlement of *Pocillopora damicornis* larvae (Hodgson, 1990). Even after the sources of sedimentation have been removed, lag effects caused by the release of nutrients stored in sediments may delay recovery (Smith, 1977).

The generally high sediment level of the waters caused by extensive land reclamation projects have affected all reefs by narrowing the suitable coral growth zone to the reef crest and upper slope. Sediment rates of 3.2 - 5.9 mg cm^{-2} d^{-1} have been recorded by Chan (1980) from the southern islands. More recently, Lane (1991) measured higher rates of 15 - 30 mg cm^{-2} d^{-1}. From the survey of the 65 sites, the percentage of sites supporting more than 50% live coral cover dropped significantly from 38.5% at the reef crest to 6.2% at the 3 m depth of the reef slope. The indirect effect of land reclamation on coral reefs through the reduction in light penetration has been well documented (eg Roy & Smith, 1971; Bak, 1978).

Marszalek (1981) stressed that the impact of turbidity extended far beyond the localised site of stirring up of sediments where the impacts are due more to mechanical damage or sediment smothering. This satisfactorily explains the narrowing of the suitable growth zone on most of the Singapore reefs. Depressed coral growth at the lower depths of the slope confirms this observation.

Data on the 5 selected reefs indicate that reclamation of reef flats did not affect live coral cover, algal cover and scleractinian species richness at the crest and slope of such reefs. No significant differences were observed in these parameters between intact reefs and reefs with reclaimed flats. However, when the sample size increased, a significant difference was detected in live coral cover of the reef crest and 3 m depth of the slope between reefs with reclaimed flats and those that were unaffected. This showed that reclamation of reef flats had an impact on live coral cover of the crest and slope of these reefs.

High sedimentation resulting from general land reclamation programmes has favoured the development of foliose coral species in the upper slope zone. Differences in other dominant growth forms of the upper slope as well as those of the lower slope, between reefs with reclaimed flats and those without, showed the more direct effect of reef flat reclamation.

ACKNOWLEDGMENTS

Studies of the 5 reefs selected for detailed monitoring were carried out under the ASEAN-Australia Marine Science Project: Living Coastal Resources, while the general surveys of 41 reefs were carried out under the Singapore Reef Survey and Conservation Project. Both projects involved the Reef Ecology Study Team of the Department of Zoology, National University of Singapore. The author would like to express his deepest appreciation to professor Kiyoshi Yamazato for the invitation to participate in the Symposium and the arrangement of financial support.

REFERENCES

Bak, R.P.M. 1978. Lethal and sublethal effects of dredging on reef corals. Mar. Pollut. Bull. 9:14-16.

Brown, T.W. 1972. Silt pollution: the destruction of Magnetic Island's coral fringing reefs. Magnetic Island, Australia. 62 pp. (mimeograph).

Chan, L.T. 1980. A preliminary study of the effects of land reclamation on the marine fauna of Singapore, with particular reference to the hard corals (Scleractinians). Unpublished Honours thesis, Department of Zoology, University of Singapore. 130 pp.

Chou, L.M. 1988. The impact of human influence on the fringing reef of Pulau Hantu, Singapore. Proc. 6th Internatl. Coral Reef Symposium, Australia, 2:201-205.

Chou, L.M. 1990. A reef conservation project involving sport divers in Singapore. Coastal Zone '91. Proc. 7th Symposium on Coastal and Ocean Management, California. pp. 1990-1994.

Chou, L.M. & Y.H. Teo. 1985. An ecological study on the sclerac tinian corals of Pulau Salu reef, Singapore. Asian Marine Biology, 2:11-20.

Chou, L.M. & F.J. Wong. 1985. Reef community structure of Pulau Salu (Singapore). Proc. 5th Internatl. Coral Reef Congress, Tahiti, 6:285-290.

Chua, C.Y.Y. & L.M. Chou. 1991. The scleractinian community of southern islands' reefs, Singapore. *In:* Alcala, A.C. (ed.) Proc. of the Regional Symposium on Living Resources in Coastal Areas, Manila. Marine Science Institute, University of the Philippines. pp. 41-46.

Dartnall, A.J. & M. Jones (eds.). 1986. A manual of survey methods for living resources in coastal areas. Australian Institute of Marine Science, Townsville.

Endean, R.E. 1976. Destruction and recovery of coral reef communities. *In:* Jones, O.A. & R. Endean (eds.) Biology and Geology of Coral Reefs, Vol. III:215-254.

Goh, B.P.L. & L.M. Chou. 1991. Coral reef-associated flora and fauna of Singapore. *In:* Alcala, A.C. (ed.). Proc. of the Regional Symposium on Living Resources in Coastal Areas, Manila. Marine Science Institute, University of the Philippines. pp. 47-53.

Lane, D.W.J. 1991. Growth of scleractinian corals on sediment-stressed reefs at Singapore. *In:* Alcala, A.C. (ed.). Proc. of the Regional Symposium on Living Resources in Coastal Areas, Manila. Marine Science Institute, University of the Philippines. pp. 97-106.

Marshall, N. 1982. Coral reef dynamics and coastal zone management. *In:* Soysa, C.H., Chia, L.S. & W.L. Collier (eds.) Man, Land and Sea: Coastal Resource Use and Management in Asia and the Pacific. The Agricultural Development Council, Bangkok. pp 37-41.

Marszalek, D.S. 1981. Impact of dredging on a subtropical reef community, southeast Florida, U.S.A. Proc. 4th Internat. Coral Reef Symp. 1:147-153.

Roy, K.J. & S.V. Smith. 1971. Sedimentation and coral reef development in turbid water: Fanning Lagoon. Pac. Sci. 25:234-248.

Salvat, B. 1987. Dredging in coral reefs. *In:* Salvat, B. (ed.) Human Impacts on Coral Reefs: Facts and Recommendations. Antenne Museum E.P.H.E., French

Polynesia. pp 165-184.

Smith, S.V. 1977. Kaneohe Bay: a preliminary report on the responses of a coral reef/estuary ecosystem to relaxation of sewage stress. Proc. 3rd. Internat. Coral Reef Symp. :578-583.

Yong, K.Y., Lee, S.L. & G.P. Karunaratne. 1991. Coastal reclamation in Singapore: a review. *In:* Chia, L.S. & L.M. Chou (eds.) Urban coastal area management: the experience of Singapore. ICLARM Conference Proceedings 25. International Center for Living Aquatic Resources Management, Philippines. pp. 59-67.