

SEDIMENTATION RATES IN SINGAPORE WATERS

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ABSTRACT

Land reclamation, the constant dredging of harbour and navigational channels, and the dumping of earth spoils in the sea have resulted in increased sedimentation of Singapore's marine environment. Monitoring of sedimentation rates at the southern offshore islands revealed mean rates between 5 to 45 mg cm⁻² day⁻¹. Sites surveyed could be divided into 3 groups based on sedimentation rate. The first group, comprising Cyrene Reefs, Lazarus Island, and the western site of Pulau Semakau, had the highest sedimentation rates. These sites were near the mainland and situated close to reclamation and dumping sites. Pulau Hantu, Hantu West reef and the north-eastern site of P. Semakau, situated further offshore formed the second group, while rates were lowest at Raffles Lighthouse, which was furthest from the mainland and sediment-generating activities, and stood alone in the third group. Significant decreases in sedimentation rates ($p < 0.05$) were evident further from the mainland. No change in rates between the 1989/90 and 1991/93 surveys were detected.

INTRODUCTION

Reclamation along the southern coast of mainland Singapore began in the 1800s for construction of port facilities (Chia *et al.*, 1988), and reached a peak in the 1970s, when land was needed for public housing and industries. Port activities, the constant dredging harbour and navigational channels, have contributed significantly to the sediment load of Singapore waters. Most of the off-shore islands to the north and south of the mainland have also been partially reclaimed (Chia *et al.*, 1988). Recent developments include the linking of Buran Darat with Sentosa, for development of a golf course and resort facilities, and the restoration of rock bunds around the islands of Pulau Hantu, Raffles Lighthouse, and Retan Laut. Major development projects at the offshore islands have commenced or are being planned. A land-fill and waste disposal site will be constructed at P. Semakau (Quek, 1989), while the Ayer Chawan group of islands will be reclaimed to form a large petro-chemical complex (Anon., 1991). Plans for the development of the Lazarus/St. John's Islands into a marine resort, which includes reclamation, have been confirmed (Dhaliwal, 1994).

Sedimentation rates for Singapore waters were previously monitored by Lane (1991) at nine sites of the southern islands between December 1987 and February 1989. He found rates of between 15 - 30 mg cm⁻² day⁻¹ common. The greatest impact of the high sedimentation rates was on scleractinian coral growth. Increased turbidity drastically reduced light penetration, resulting in reefs that have little or no scleractinian corals beyond the 10m depth (Lim *et al.*, 1990). The remaining coral species, however, seemed to have adapted to the low light and sediment conditions (Chou, 1988), although differences in the growth form of corals between reclaimed reefs and intact reefs were evident (Chou, in press).

METHODOLOGY

Sediment traps were used to monitor sedimentation rates at twelve sites (Fig. 1) in the southern islands of Singapore between December 1991 and April 1993, as described by Dartnall & Jones (1986). The traps were collected and replaced at monthly intervals. The contents of the traps were filtered, washed and oven-dried at 60°C and weighed. Mean sedimentation rates at each site were obtained by averaging the weight of the sediment from all traps, divided by the area of the traps and number of days they were set. Following Lane (1991), traps with unusually low sediment levels (<1 mg cm⁻² day⁻¹) were discarded, as these were suspected to

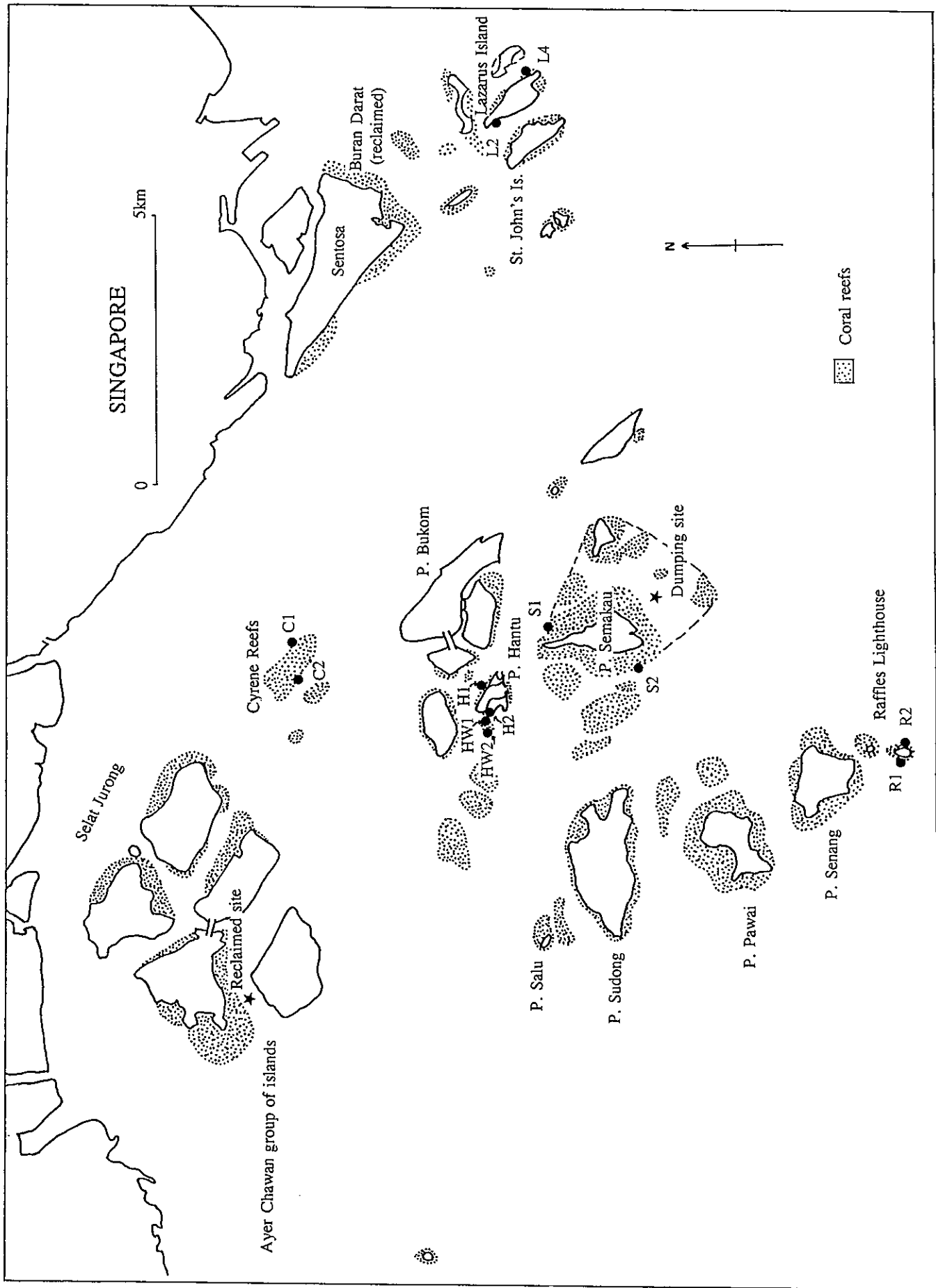


Fig. 1. Map of the southern islands of Singapore. Sedimentation rates monitored at sites marked "●". Area enclosed by dotted lines to be developed into a refuse disposal site.

have been disturbed by fish (damsels or gobies). The monthly sedimentation rates were subjected to statistical analysis using the General Linear Model and site comparisons were done using multiple t-tests.

RESULTS AND DISCUSSION

Mean yearly sedimentation rates in 1991/93 did not vary significantly from rates in 1989/90 ($p < 0.05$), except for sites S2 and R2, where significant changes were detected (Table 1). Overall, rates ranged from 5 to 45 mg cm⁻² day⁻¹. Similar rates were observed at a resort development site at Pulau Redang, West Malaysia (up to 41.1 mg cm⁻² day⁻¹) (Mohd. Ibrahim *et al.*, 1992). In contrast, other sites away from the development site, showed very low rates between 0.01 and 1.38 mg cm⁻² day⁻¹.

The study sites could be divided into three groups, those with the highest rates, Cyrene Reefs (C1 and C2), Lazarus Island (L2 and L4) and the site west of Pulau Semakau (site S2) forming the first. These sites were located near reclamation projects (Cyrene and Lazarus), or near dumping sites (site S2). Sites which were located further from such activities had significantly less sedimentation ($p < 0.05$), and comprised the second group of P. Hantu (H1 and H2), Hantu West reef (HW1 and HW2), and the eastern site of P. Semakau (S1). Sites at Raffles Lighthouse (R1 and R2) were furthest from the mainland and comprised the final group.

Table 1. Mean sedimentation rates (mg/cm²/day) recorded during first and second surveys (⁺¹from Lane, 1991; ⁺²means with different letters are significantly different ($p < 0.05$) ⁺³mean rates in 1991/93 were significantly different ($p < 0.05$) from 1989/90).

Location	Site	1989/90 ⁺¹	1991/93	Mean rate for both surveys	Grouping ⁺²
Cyrene Reefs	C1	-	44.640	44.640	A
	C2	12.784	16.489	14.637	A
Lazarus Island	L2	-	17.875	17.875	A
	L4	-	14.208	14.208	A
Pulau Semakau	S2	11.654	19.623 ⁺³	15.639	A
	S1	16.426	8.685	12.556	B
Pulau Hantu	H1	10.138	7.111	8.625	B
	H2	10.646	9.166	9.906	B
Hantu West reef	HW1	12.931	12.235	12.583	B
	HW2	5.878	5.932	5.905	B
Raffles	R1	8.743	6.252	7.498	C
Lighthouse	R2	7.338	2.352 ⁺³	4.845	C
Mean		10.774	12.707	14.076	

Besides the proximity to a reclamation or dumping project, current dynamics was also an important factor affecting sedimentation rates. Singapore's southern waters are strongly influenced by an east-west current flow. At Cyrene Reefs, the very high rates at site C1 can be attributed to currents carrying suspended sediment from the dredging works at Selat Jurong, northeast of the site. Site C2, however, was more sheltered, as the force of the currents had been dissipated by islands to the west. Currents were also responsible for the rates observed at P. Semakau. Earth spoil dumping southeast of the island commenced in December 1988, resulting in high levels of sediment there. Currents in this area moved in the north-south direction, thus affecting the entire eastern side of the island, and the deposited sediment has formed a deep layer of silt at the sea bed. Dumping activities ceased in the 1990s, but other underwater work continued to the south of the island, this time near site S2, resulting in a significant increase in sediment levels there. Currents, on the other hand, may help reduce sedimentation at a site. The reef flat of P. Semakau was not adversely affected by the dumping, as relatively strong currents flowing perpendicularly away from the shore was observed during receding tide, presumably washing the sediment off the flat. Strong currents also accounted for the low rates at Raffles

Lighthouse, which was not only far from any reclamation work, but was adjacent to the open sea, where sediments could be dispersed.

The effect of extensive reclamation work and other port activities over the past 20 years has resulted in the loss of reef and other coastal habitats. Major reclamation projects spanning the next 10 to 15 years are in progress and more are being planned. However, efforts to prevent further pollution of the marine environment are being enforced (Nathan, 1993a). Among them are the erection of a series of barriers to enclose the refuse disposal site at P. Semakau. Special screens will be used to prevent silt and debris from damaging the reefs during the construction, and a concrete bund will enclose the area to limit the amount of waste seeping into the sea. In addition, water discharged into the sea will meet the standard set by the Ministry on the Environment. On a broader scale, education programmes and community campaigns to recycle as much of the nation's refuse will be encouraged to help improve waste management (Nathan, 1993b).

For a nation as small as Singapore, reclamation of its coastal areas may be the only answer to accommodate its growing population and expanding economy. However, much can be done to reduce the damage of such activities to the environment. Detailed studies of current dynamics, either by direct observation or by modelling (Shanker *et al.*, 1990), and construction of barriers are some of the measures necessary to prevent the spread of sediment and pollutants to the surrounding environment, thus protecting our natural heritage.

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