THE STATE OF CORAL REEFS AND CORAL REEF RESEARCH IN SINGAPORE

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ABSTRACT

Singapore's reefs have been subjected to the combined impacts of reclamation, earth spoil dumping, indiscriminate collection and intensive multi-sectoral development of the coastline. Protection and management of coral reefs have been ineffective under the present legislative framework. Research has increased rapidly in the last decade with the inception of the ASEAN-Australia Marine Science Project: Living Coastal Resources. Many of the studies were the direct or indirect result of this project, and included the community structure of the coral reefs, productivity and growth of corals and extraction of bioactive compounds from corals. Management and conservation issues were proposed resulting in some reefs being designated for conservation in the country's Green Plan.

INTRODUCTION

Singapore's coral reefs suffer from many anthropogenic stresses, including heavy sediment loading from land reclamation, dredging and dumping, and recreational activities such as fishing and scuba diving. However, the Port of Singapore Authority (PSA), the Ministry of the Environment (ENV) and other agencies have effectively controlled the discharge of oil, trade effluents and other waste into the sea. Earlier investigations of Singapore reefs consisted mainly of qualitative surveys and reports, notably by Chuang (1961 & 1973) and Tham (1973). In-depth research on reefs was restricted to the studies of *Amphiprion* spp.(Ting 1966; Kwok 1968) and mushroom corals (Goh 1965). The biology and taxonomy of certain groups of corals, the fungiids, the faviids, the dendrophylids, the pocilloporids and the acroporids have also been studied (Tan 1970; Tan 1972; Moll 1977; Williams 1977; Yeo 1977; Krishnaveni 1986; Koh 1988; Krishnaveni *et al.* 1989; Chung 1991; Goh 1991; Lane 1991; Quek 1991; Leow 1993).

The ASEAN-Australia Marine Science Project: Living Coastal Resources (LCR) was the only long-term, systematic quantitative monitoring programme of the reefs and their organisms. The contribution of the LCR project to marine science research in Singapore was discussed by Chou (1991a). Much of the research conducted in the late 1980s stemmed directly or indirectly from this project.

Twelve sites on six islands to the south of Singapore were monitored between 1986 and 1993 (Fig. 1). The sites have been described by Chua (1990) and Goh and Chou (1992) for Cyrene Reefs, by Chong (1986) for Pulau Hantu, by Leng and Lim (1990) for Hantu West, Leng *et al.* (1990a) for Pulau Semakau, Leng *et al.* (1990b) for Raffles Lighthouse and Lim and Low (1991) for Lazarus Island.

Data on the distribution and growth of hard corals and other benthic reef organisms were collected using the line intercept transect (LIT) and permanent quadrat. The coral reef fish community was assessed by visual census. Sedimentation on the reefs was also monitored with the use of sediment traps. Methodologies employed under the LCR project are described in Dartnall and Jones (1986) and English *et al.* (1994). Data collected were stored in database structures specially developed for this project, descriptions of which can be found in Licuanan and Tangjaitrong (1989) and Cheshire *et al.* (1994).

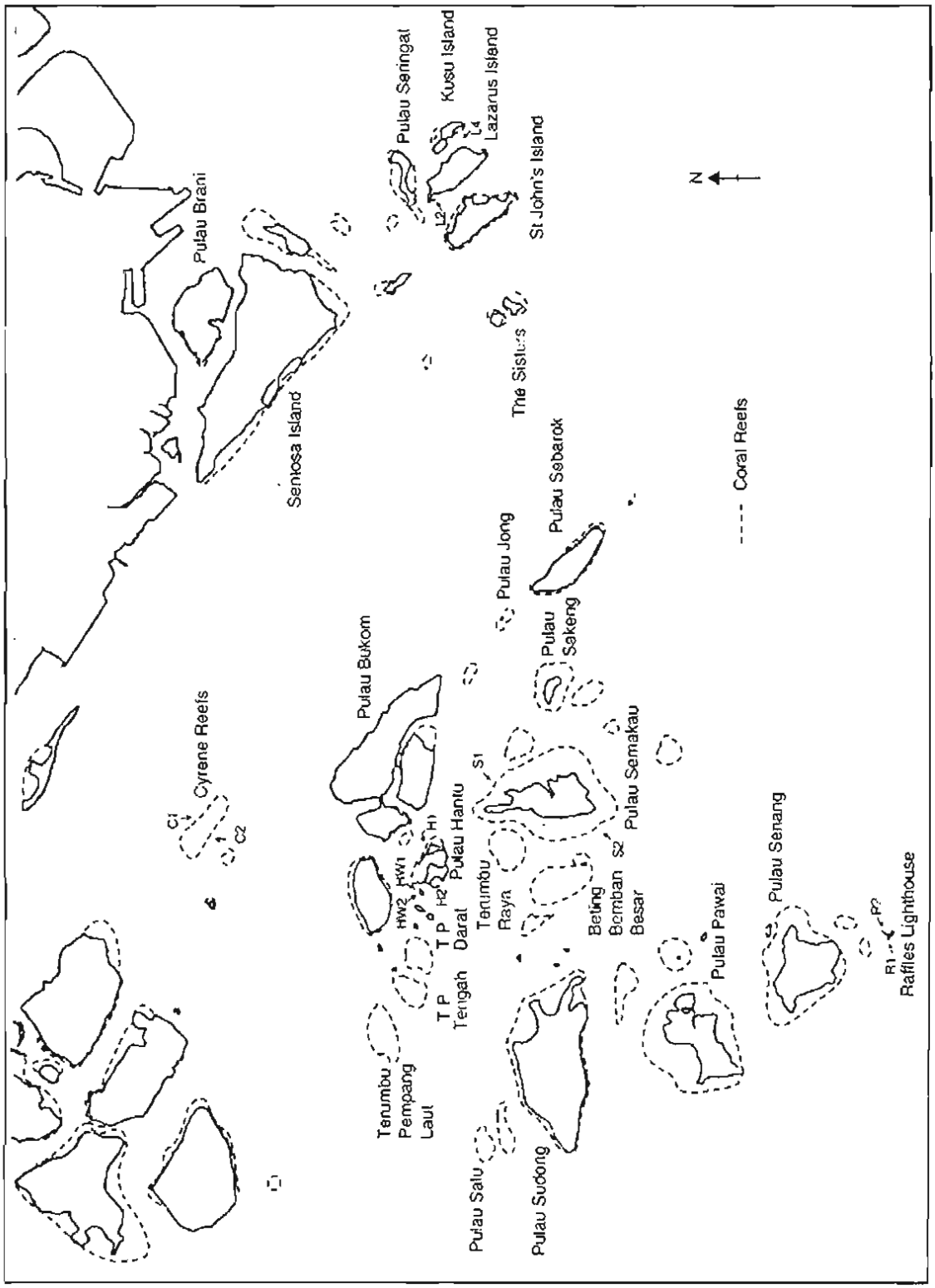

Figure 1. The southern islands of Singapore, showing the 12 survey sites.

REEF HEALTH

Hard corals

The hard coral community of Singapore's reefs has been reported by numerous researchers (Teo 1982; Chou 1985; Chou & Teo 1985; Chou & Wong 1985; Chou 1986a; Chou & Koh 1986; Chou & Wong 1986; Chong 1986; Chou & Lim 1988; Chou 1988a; Chou 1988b; Lim *et al.* 1990; Chua & Chou 1991; Chua & Chou 1992a).

The LCR data, collected in three surveys over a 10-year period showed that 197 hard coral species belonging to 55 genera occur on Singapore reefs (Chou 1993a). Percentage live coral cover ranged from 0% at the 6m and/or 10m depths, to 76% at the 0m and/or 3m depths in the earliest survey (Fig. 2). The upper limit of coral cover subsequently dropped to 72% in survey 2 and 69% in the survey 3. Marked decreases were observed at the shallower transects (0 and 3m depth) for 7 sites (C1, C2, H1, H2, HW1, L2 and S1). These sites have been subjected to anthropogenic and sediment stresses over the years. Anthropogenic stresses included corral fishing and use of fish traps on the reef flat and upper reef slope, removal of corals for the aquarium trade (especially at C1 and C2), and scuba diving and boating activities at H1, H2 and HW1. Sites C1, C2, L2 and S1 were also subject to high levels of sediment. Increasing coastal development has led to increased sedimentation, from 3-6 mg $cm^{-2}d^{-1}$ in 1979 (Chan 1980), to 5-45 mg $cm^{-2}d^{-1}$ (Lane 1991; Low & Chou 1994a). Decreased rates were observed for sites further away from the mainland of Singapore. The settlement and accumulation of sediment, and decreased light penetration at the lower slopes contribute to the decline of the reef community in terms of abundance and species richness. The effect of reef flat reclamation on the live coral cover at the crest and slope was discussed by Chou (1994), who showed that live coral cover at the crest and slope was depressed on reefs with reclaimed flats compared to reefs with intact flats.

Goh *et al.* (1994) found foliose growth forms to be the dominant ecomorph at the reef crest, 3m and 6m below the crest, because of their efficient utilisation of available light and aggressive competition for space. At the deeper zones, however, sediment accumulation seemed to inhibit the growth of foliose corals, allowing other corals with lower energy requirements, greater photosynthetic efficiency and more efficient sediment removal mechanisms to compete successfully.

The growth rates of the fast-growing *Acropora* were found to be lower than those documented elsewhere (Chung 1991). Radial growth rates for massive faviids, however, corresponded to documented averages (Lane 1991). The reduced growth rates of *Acropora* could be due to sediment coverage.

Other benthic fauna

The biology of certain groups, like the crinoids (Lim 1987), gorgonians (Goh 1991; Goh & Chou 1994a), hard coral associates (Goh *et al.* 1989), the tunicates (Lane 1987) and sea urchins (Lee 1968; Hori *et al.* 1987) were also studied. The community structure of other reef fauna and flora were studied by Goh and Chou (1991) and more recently, by Goh and Chou (1994b), who discovered three distinct zones in non-scleractinian distribution. These were the macroalgae at the crest, a mix of soft corals, sponges and 'others' at the 3m and 6m from the crest, and a sponge zone at 10m from the crest. There was an increase in the cover (relative to live coral cover) of non-scleractinian component with depth, but their absolute cover (relative to the area surveyed) remained fairly constant.

Other research

Recently, research into extraction of bioactive compounds from corals (Fung 1993), inter- and intra-specific interaction between coral colonies (Wong & Chou 1993) and productivity of coral organisms (Tun 1994; Tun *et al.* 1994a, 1994b) have produced new insights into the physiology of the reef organisms. Enhancing degraded reefs with the use of artificial substrates has also been investigated (Chong 1985; Chou 1986b; Chou & Hsu 1988; Chou 1988c; Chou 1991b).

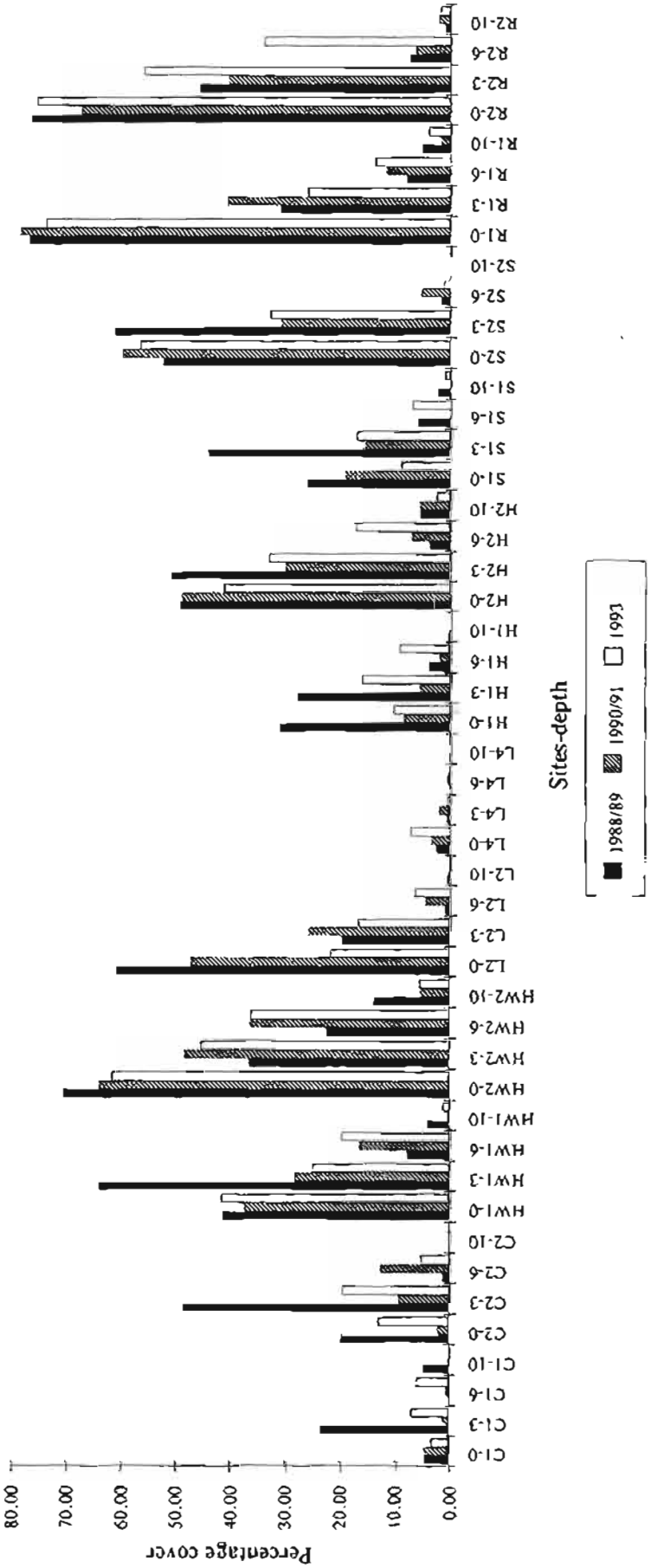

Figure 2. Percentage cover of live coral cover at 12 sites in the southern islands of Singapore, between 1986 and 1993.

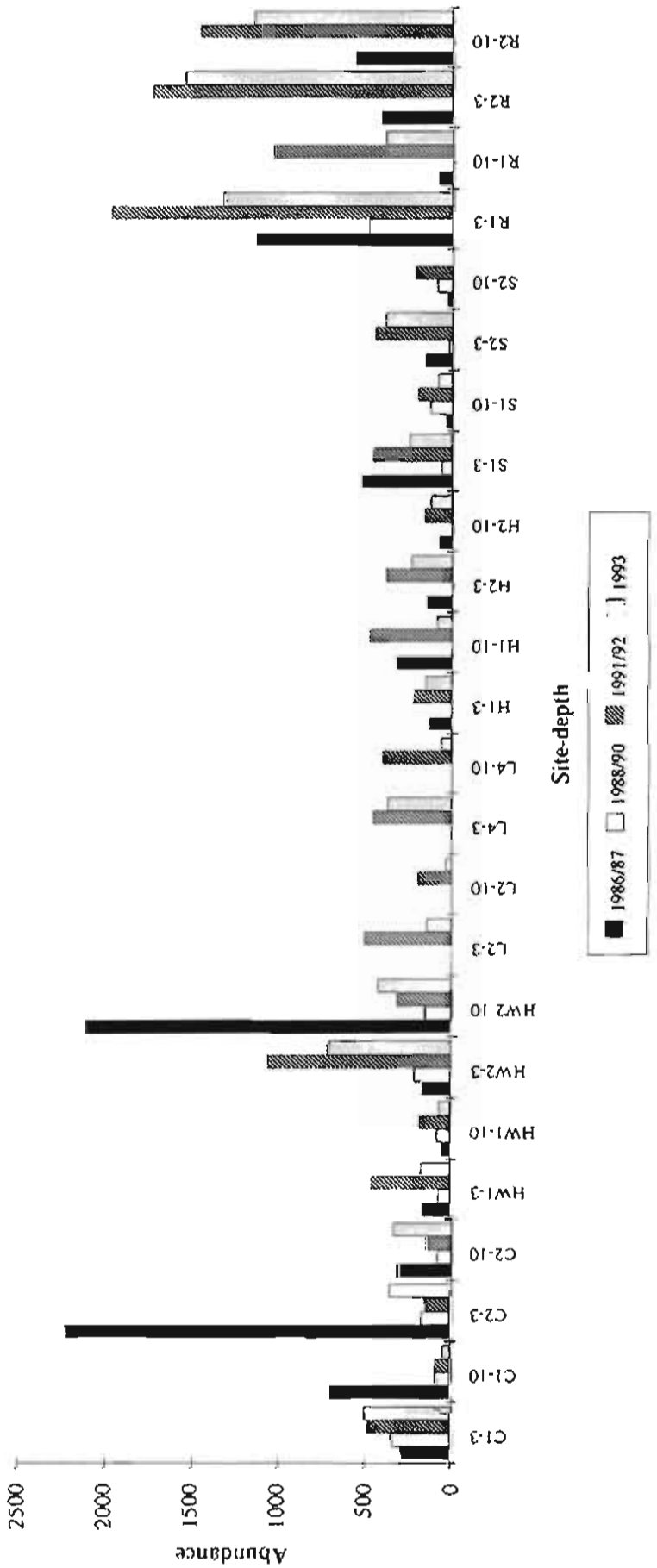

Figure 3. Coral reef fish abundance at 12 sites int he southern islands of Singapore, between 1986 and 1993..

Reef fish

Diversity and abundance of reef fish were recorded using the visual census method, and were previously reported by Lim *et al.* (1990), Lim and Chou (1991) and Low and Chou (1992). These studies showed that abundance and diversity decreased with depth, and increased with distance from the mainland (Fig. 3). More than 107 species of fish occur in Singapore reefs, comparing favourably with studies done in the Gulf of Thailand (90 species - Satumanatpan & Sudara 1992) and in North Bais Bay in the Philippines (135 species - Luchavez & Alcala 1992). The population dynamics of the pomacentrid community at one reef were also investigated (Leng 1990), and a pilot study on the recruitment of fish was conducted (Low & Chou 1994b). The results indicate two recruitment periods, one in April and another in October-November.

MANAGEMENT AND CONSERVATION

In-depth research on anthropogenic impacts on the reefs include the effect of human influence and land reclamation on hard corals (Chan 1980; Chou 1988d), the effect of marine pollution on corals (Goh & Chou 1990), and reef resource utilization and conservation (Chia *et al.* 1990; Chia & Chou 1991; Chou 1991c; Chua & Chou 1992b). In addition, educational posters on 51 hard coral species were produced (Anon 1989), to help the public appreciate the complexity and diversity of the coral reefs. Even the suitability of local corals for aquaria was studied earlier (Chan 1971).

Coral reef protection in the past has been inadequate. The issues concerning threats to the coastal environment have been discussed by Chou (1990, 1992a, 1992b, 1993a, 1993b, 1994). These include impact of reclamation and earth-spoil dumping; lack of appreciation of marine resources in land and sea use planning; indiscriminate removal of corals and other marine fauna; increasing demand on sea space; and ineffective integrated management of the limited resources. The protection of biological resources of the marine environment is thus urgently needed.

The decline of the coral reefs led three non-governmental organisations to launch the Reef Survey and Conservation Project in 1988, and to submit a proposal in 1991 to the Government, identifying 4 areas within the southern islands which supported good reefs for conservation. The proposal was the result of surveys carried out by volunteer sport divers, trained in line intercept transect methods, at 65 sites on 41 reefs in the southern islands (Chou 1991b), and a further detailed study of these sites was later commissioned by the National Parks Board. The results of these surveys were incorporated in the Green Plan aimed at making Singapore a model environment city (Chou 1993a).

The shortage of land space and the intensive use of the coastal areas in Singapore has lead to a rapid decline of coral reefs. While Singapore cannot afford to set aside large areas for conservation, a compromise can and should be reached between environmentalists and developers. The present infrastructure, which allows unisectorial management, remains inadequate for effective management and protection of the coral reefs and needs to be urgently addressed. Lessons learned from the Singapore experience will be useful to other countries facing similar development-conservation problems.

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