ARTIFICIAL REEFS & MARINE RE-STOCKING EFFORTS IN SINGAPORE

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■ INTRODUCTION

The Republic of Singapore consists of a main island and over 60 small offshore islands with fringing and patch reefs. It has a combined land area of approximately 660 km^2, and its territorial waters cover 630 km^2. The human population of 3.9 million gives a high density of 5,900 persons per km^2 (Anon, 2000). Its marine environment continues to be an important resource, playing an important role in economic growth and prosperity. The marine environment has undergone tremendous change over the years, and now supports one of the world's busiest ports and one of the largest oil refining centres. Close to 60% of the total coral reef areas have been lost through foreshore reclamation (Chou, 1995; Chou & Goh, 1998).

In Singapore's highly urbanised society, fishing and collecting from reefs and other coastal areas, either from aquarium trade or for subsistence, declined steadily since the 1980s. Records are not available of coral reef fish harvested from reefs, as reef fisheries is practically non-existent. Boat-operated commercial fishing is prohibited in territorial waters due to limited space and risk to navigational safety. Local fish catch comes mainly from the diminishing numbers of licensed commercial palisade trap operations and local production from marine aquaculture (Chou, 2002). Thus, with the declining numbers, Singapore does not have any extensive monitoring programmes for fish re-stocking and stationary fishing gear.

Illegal collection of corals and other reef invertebrates stopped with stronger enforcement by the Police Coast Guard in the 1990s. Effective regulatory measures prevent marine pollution. The greatest impact however, is the high sediment load generated by land reclamation, the regular dredging of rivers and shipping lanes, and the dumping of these material out at sea. In the past three decades, the high sedimentation levels generated by these activities have reduced the abundance but not the diversity of the coral reef life-forms (Hsu & Chou, 1991). Coral growth zone is reduced to shallower depths. Higher diversity of hermatypic corals is found at the 3m depth compared to the 10m depth (Chou, 1991). There were organised efforts on enhancing the marine resources in the past two decades through artificial reef programmes. These include concrete blocks and tyre modules as artificial reef structures in the 1980s (Chua & Chou, 1994; Chou, 1991) and the present project using fibreglass structures (Loh & Chou, 2002).

■ STATIONARY FISHING GEAR & RE-STOCKING

Coastal fisheries production of 40,000 tonnes annually declined drastically since the late 1940s, due to increased shipping activities, loss of original coastal habitats and fishing grounds to land reclamation, and better alternative employment opportunities. Palisade traps ("kelongs") which were located at the nearshore were phased out particularly along the southern coast as they posed a threat to navigational safety (Chou & Chan, 2001). The use of simple fish traps such as the "bubu" has decreased over the years. Coastal aquaculture practices have shifted from traditional to intensive systems while mariculture, using floating net cages, has been actively promoted.

In 1977, the Singapore Government initiated a 10-year River Clean-up programme to improve the water quality of the Singapore River to transform the riverbanks into beautiful parks and walkways with clean river water. The fauna returned to the river after the water quality improved. The Primary Production Department (the now Agri-Food & Veterinary Authority) launched a 10-year stocking programme in 1986, with the aim to enhance the fish population. The stocked fish would establish as resident fish and promote game fishing (Lee & Low, 1991). Over 80,000 seabass (*Lates calcarifer*), 8,500 cherry snappers (*Oreochromis niloticus*) and 630,000 banana shrimp (*Penaeus merguiensis*) were released into the river as stock.

Khin & Chou (1991) studied the effects of stocking in the river during the period April 1986 – October 1988. They speculated that seabass and banana shrimps might have established their ecological niche. Further investigations revealed that only seabass had established well in the river but not the snappers and banana shrimps (Lee & Low, 1991). Seabass had also been found to have a preference for the artificial seagrass, which Lee & Low (1991) speculated made a good ecological niche for the stocked seabass. However, due to multi-sectoral conflicts in the use of the site, follow-up work was shelved. Besides these studies, there were no other re-stocking efforts, except a giant clam re-stocking research currently conducted by the Tropical Marine Science Institute of the National University of Singapore.

■ MARINE PROTECTED AREA & POLICIES

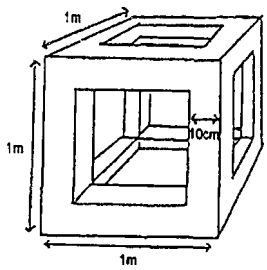
Among the nature reserve areas in Singapore, only Sungei Buloh Wetlands Reserve (SNWR) and Labrador Nature Reserve are coastal related nature areas. However, as far as marine protected areas are concerned, there are none in Singapore. There are no national policies on coral reefs and neither is there a government agency with the distinct responsibility of managing reef resources. Although Labrador is a rocky shore, only the beach and terrestrial area are under the jurisdiction of National Parks Board.

The protection and conservation of fisheries are regulated by the Fisheries Act (Chapter 111). The Act has strict prohibitions on the use of poisons or explosives, as well as trawl net fishing.

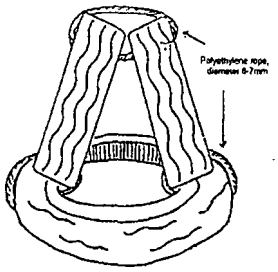
■ ARTIFICIAL REEFS

Since the 1960s, intensive development of the coastal areas in Singapore has resulted in the degradation of the coral reef ecosystem. Several sites were identified for artificial reef establishment. Pre-establishment surveys were conducted to assess the site potential. Reef resources (Hsu & Chou, 1991 ar13), the fish fauna (Lim & Chou, 1991), physical parameters (Hsu & Chou, 1987), etc of several sites were assessed to determine the site potential of establishing artificial reefs, prior to the study. Of the initial seven sites selected for artificial reefs, Hsu & Chou (1987) revealed that Cyrene reefs, Terumbu Jarat, Terumbu Pempang and Terumbu Bemban were suitable for the establishment of artificial reef. In Hsu & Chou's (1991) later studies, Terumbu Bemban was found to have the highest percentage live coral cover (65.88%), as well as the largest average size of coral colonies, while Pulau Semakau has the lowest average live coral cover, diversity and average coral colony size. Cyrene Reefs has the highest diversity, with 28 genera. The fish species recorded at the sites were generally small, and were mostly pomacentrids and labrids (Lim & Chou, 1991).

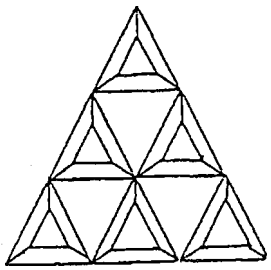
In mid-1989, the first artificial reef was launched in the southern islands of Singapore, under the ASEAN-US Coastal Resources Management Project (Chua & Chou, 1994; Chou, 1991), using of hollow concrete cubes and tyres-pyramids modules (Fig 1). The artificial structures were established on the sea floor, at 15m, adjacent to a natural patch reef (Terumbu Pempang Tengah) west of Pulau Hantu. This is an attempt to restore and enhance the fish communities of degraded reefs.



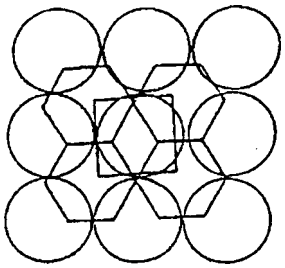
A. Single hollow concrete frame module



B. Subunit of three tyres of the tyre-pyramid module



C. Side view of the tyre-pyramid module



D. Plan view of the tyre-pyramid

Figure 1. Structure and design of hollow concrete module (A) and tyre pyramids (B to D) used in constructing the artificial reefs.

Since the artificial reef establishment, observations showed that a layer of filamentous algae grew over the surface of materials within the first few weeks. Subsequently, a myriad of encrusting organisms such as hydroids, tunicates, barnacles, etc settled and grew on the concrete modules but not on the tyre modules (Han *et al*, 1994).

Initial fish community surveys showed a total of 37 and 32 fish species recorded over a period of 1.5 years at the concrete and tyre reefs respectively (Chua & Chou, 1994). Fish community surveys conducted between September 1989 to January 1996 at the concrete and tyre reefs indicated significant increase in fish abundance and species richness (Low & Chou, 1999). A total of 68 species from 26 families were recorded at both artificial reefs – 55 species (22 families) at the concrete and 48 species (24 families) at the tyre reef.

In general, both concrete and tyre artificial reefs contributed towards an increased fish population. However, the fish communities of both artificial reefs appeared to reach a state of equilibrium by the seventh year after establishment, based on increasing species evenness and the absence of additional new species (Low & Chou, 1999).

Low & Chou (1999) also found that fish abundance, density and size is higher at the concrete reef than at the tyre reef. Several authors have reported that fishes prefer to have hole sizes similar to their body sizes (Hixon & Beets, 1989; Randall, 1963; Shulman, 1984) and Low & Chou (1999) ascertained this. Adult batfish (*Platax*) and snappers have been observed to take residence at the concrete modules while the juvenile stages of various fishes preferred the tyre reef, which have smaller holes.

Artificial reefs of this magnitude can only benefit the fish community, not the coral reefs as Singapore reefs do not extend to depths of 15m due to high sedimentation levels and low light penetration. Should artificial reefs be used as reef restoration tools in Singapore, structures must be designed for shallow reef areas.

In April 2001, National University of Singapore (NUS) and Singapore Tourism Board (STB) established a research collaboration to use artificial reefs to promote coastal tourism. As Singapore reefs are shallow, fringing and not extending any deeper than 10m (Lim *et al*, 1990), the previous concrete and tyre artificial reefs are unsuitable and inconvenient. A specially fabricated artificial unit, called Reef Enhancement Unit (REU) was designed and used (Fig 2) (Loh & Chou, 2002). The REUs are made of fibreglass impregnated with sand and calcium carbonate to roughen the exterior surface and provide coral recruits with suitable settlement substrate. The REU is light enough for divers to handle in the water and easy to manoeuvre, which allows the REUs to be moved to the exact location rather than dropped randomly overboard.

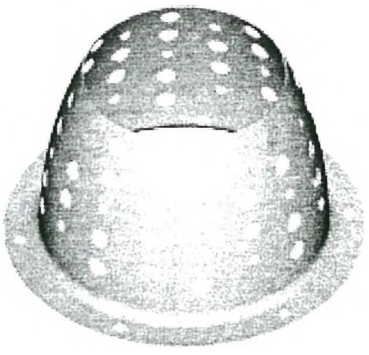


Figure 2. A schematic diagram of Reef Enhancing Unit (REU).

Seventy-six REUs were deployed at a depth of 3m, at three sites, one at Raffles Lighthouse and two at St John's Island. Surveys of flora and fauna settlement on the unit exterior were conducted using modified Line Intersect Transect. Over the one-year study, the percentage cover of algal assemblage exceeded 90% for all three sites in the first month. Gradually, other organisms such as ascidians, coralline algae, hydroids, bryozoans grew on the units. By the 9th month of REU deployment, coral recruits were detected growing on the REUs. Results gathered from this preliminary study showed that fibreglass is a viable alternative material for artificial reefs. In addition, artificial substrates can provide the stable surfaces which corals need to recruit on (Chou & Lim, 1986).

Currently, the artificial reef project using REUs is in its second phase, under a collaboration with Sentosa Development Corporation (SDC). This two-year study will further investigate the dynamics of REUs and reef rehabilitation to maximise their effectiveness.

In comparison, tyres and concrete structures are more suitable materials for artificial reef structures deployed at greater depths for fish community enhancement purposes. The REUs are better suited for reef rehabilitation, particularly in shallow reefs areas. Artificial reefs must be part of programmes to manage fishing effort and resources, to obtain an overall positive effect. If properly planned, executed and managed, artificial reef programmes can enhance the marine environment in the long term (Chou, 1997).

■ BEYOND ARTIFICIAL REEFS

Having artificial reefs in the waters is not sufficient if it is an isolated attempt. The ultimate goal in reef restoration would be a concerted effort for all related marine resource enhancement programmes to tie in with coral reef rehabilitation. The effectiveness of the REUs can be maximised with better understanding of the most appropriate deployment period, such as to coincide unit deployment with the local coral spawning events. Guest (2002) confirmed that coral spawning events occurred in March or April with a smaller event in October. Efforts were made to tie in REU deployment with the mass spawning event.

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