ARTIFICIAL REEF PROGRAMMES IN SINGAPORE

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ABSTRACT

Artificial reef projects were initiated in Singapore in 1989 using tyre pyramids and hollow concrete modules. These were deployed at depths of 15m and were aimed at improving fish stocks. Larger-sized fish preferred the concrete modules while juveniles favoured the tyre reefs. Fish abundance and diversity increased over 7 years before reaching equilibrium. In recent years, fibreglass modules referred to as "Reef Enhancement Units" were established in shallow reef areas to investigate their effectiveness in reef restoration. Early results showed that they provided suitable substrata for the settlement and development of coral recruits and other reef-associated species, as well as for coral transplants.

INTRODUCTION

The Republic of Singapore has over 60 small offshore islands located mostly south of the main island. Fringing and patch reefs are associated with these offshore islands. It has a combined land area of approximately 660 km^2, and its marine territory covers 630 km^2. With a human population of 3.9 million, it supports 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, but it has undergone tremendous change over the years. It 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).

With its highly urbanised setting, fishing pressure on the reefs, 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 are practically non-existent. Trawling is prohibited in territorial waters due to limited space and risk to navigational safety. Local fish catch comes mainly from the diminishign numbers of licensed commercial palisade trap operations and local production from marine aquaculture (Chou, 2002). The country 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 where high diversity still exists. Efforts aimed at enhancing the marine resources in the past two decades through artificial reef programmes have been implemented. These include concrete blocks and tyre modules as artificial reef sturctures in the 1980s (Chua & Chou, 1994; Chou, 1991) and the present project using fibreglass strutures (Loh & Chou, 2002).

MARINE RESOURCE ENHANCEMENT AND PROTECTION

Coastal fisheries production of 40,000 tonnes annually declined 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 system 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 aimed at enhancing 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. It was thought that introduced seabass and banana shrimps may have established themselves. Further in vestigations 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 monitoring had to be abandoned. Besides these studies, no other re-stocking efforts are know, except for giant clam re-stocking research currently conducted by the Tropical Marine Science Institute of the National University of Singapore.

There are some coastal protected areas in Singapore (Sungei Buloh Wetlands Reserve and Labrador Nature Reserve) but none that covers reef systems. There are no national policies on coral reefs and neither is there a government agency with the distinct responsibility of managing reef resources. 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

Intensive development of coastal areas since the 1960s resulted in the degradation of the coral reef ecosystem. The earliest artificial reef project was initiated in the late 1980s under the ASEAN-USAID Coastal Resources Management Programme. Several sites were identified for artificial reef establishment. Reef resources (Hsu & Chou, 1991), fish fauna (Lim & Chou, 1991) and physical parameters (Hsu & Chou, 1987) of these sites were assessed to determine the potential of establishing artificial reefs. In mid-1989, the first artificial reef was launched (Chua & Chou, 1994), using hollow concrete cubes and tyre-pyramid modules. These structures were established at 15m depth of the sea floor adjacent to a natural patch reef (Terumbu Pempang Tengah) west of Pulau Hantu. The purpose was to test the effectiveness at restoring and enhancing fish communities.

Observations indicated growth of a layer of filamentous algae over the surface of materials within the first few weeks. This was followed by a diversity of encrusting organisms such as hydroids, tunicates, barnacles, developing 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 types of artificial reefs – 55 species from 22 families at the concrete and 48 species from 24 families at the tyre reef.

Generally, both concrete and tyre artificial reefs contributed to 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 were greater at the concrete than the tyre reef. This is because fishes prefer to inhabit crevices similar to their body sizes (Hixon & Beets, 1989; Randall, 1963; Shulman, 1984). Adult batfish (*Platax)* and snappers were observed residing at the concrete modules while the juvenile stages of various fish species preferred the tyre reef, which offered tighter crevices.

Concrete and tyre reefs could only be placed at deep areas (15m depth) and served only for fish enhancement. Coral and other reef invertebrates do not extend to these depths due to high sedimentation levels and low light penetration. For reef restoration, artificial reef structures had to be designed for deployment in shallow reef locations.

The National University of Singapore (NUS) and Singapore Tourism Board (STB) initiated a research project in 2001 on the use of artificial reefs to promote coastal tourism. As Singapore reefs are shallow, fringing and not extending deeper than 10m (Lim *et al*, 1990), the earlier concrete and tyre reefs were unsuitable and cannot be placed in shallow waters as they required a large vessel for deployment. A specially fabricated module, termed as "Reef Enhancement Unit" (REU) was then designed (Loh & Chou, 2002). The REUs are made of fibreglass coated with sand and calcium carbonate to roughen the exterior surface and a suitable settlement substrate to coral recruits. Each module is light enough for divers to handle in the water and relatively easy to manoeuvre. They can then be carried on smaller boats to shallow parts of the reef and moved by divers to precise locations for deployment.

These REUs were deployed at 3m depth of various reefs. Algal assemblages exceeded 90% of surface area in the first month followed by settlement and growth of other organisms such as ascidians, coralline algae, hydroids and bryozoans. Coral recruits were detected on the REUs in the 9^{th} month. These results showed that fibreglass is a suitable structure for artificial reefs. In addition, artificial substrates can provide the stable surfaces for coral recruitment (Chou & Lim, 1986). The project is now in the second phase focusing on maximising the effectiveness of REUs for reef rehabilitation. On-going investigations include attachment of coral transplants, the use of sea urchins to remove algae and the development of the fish community at REUs.

The earlier experience with tyre and concrete structures in deeper waters demonstrated their suitability for fish community enhancement. 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).

Artificial reefs have a role in enhancing fish and reef resources in Singapore. Reef rehabilitation is needed to restore many of the reefs, which have been affected by sedimentation impacts and to compensate for reefs lost through land reclamation. The ultimate goalis to have a coordinated effort at connecting marine resource enhancement programmes to coral reef rehabilitation. The effectiveness of the REUs can be maximised with a better understanding of the most appropriate time for deployment, e.g. to coincide with local mass coral spawning events. Guest *et al* (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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