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HANDBOOK ON HABITAT RESTORATION

GENERAL PRINCIPLES AND CASE STUDIES IN SINGAPORE

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Front cover: Hampstead Wetlands Park (top); Eco-Link@BKE (bottom left); Rifle Range Nature Park (bottom right)

Back cover: Multi-tiered planting of native trees and shrubs along roadside (top left); Bishan-Ang Mo Kio Park (top right); Old Mandai Road (center); Red-Wattled Lapwings at Kranji Marshes (bottom left); Jurong Lake Gardens (bottom right)

CHAPTER 14

High-relief Artificial Reefs at Sisters' Islands Marine Park

Chou Loke Ming, Santosh Srirangam, John Kiong & Karenne Tun

Introduction

Artificial reef history dates back to the 18th century with early attempts aimed at exploiting the fish aggregating ability of structures placed in the sea. Japanese fishers sunk derelict vessels, American fishers sunk wooden logs, and subsistence fishers of developing countries deployed coconut frond structures, all with the common purpose of improving fish catch (White *et al.*, 1990). Since then, artificial reef development has expanded geographically and for increasing purposes including the rehabilitation of degraded reefs and marine ecotourism promotion. A vast range of materials is used, and various designs, configurations, dimensions, and scales are adopted. The contribution of artificial reefs as well as artificial structures in the marine environment to enhance marine biodiversity has been well documented (Chou, 2021).

Singapore lost more than half of its natural reefs to coastal development and various reef restoration initiatives have been implemented since the 1980s (Ng *et al.*, 2016), mainly to improve the condition of existing reefs. Relevant to Singapore's context is the development of new reefs to supplement those that are permanently lost. New reefs can be effectively induced by large, full water-column structures that present vertical aspects of the natural reef slope profile. Such purpose-built structures mimicking natural reef systems were deployed in JTC Corporation's Reef Garden Project at the Sisters' Islands Marine Park in 2018. The purpose of this project is to transform an open water environment above a barren seafloor into a rich, reef-associated biodiversity zone. In terms of size, this is the largest artificial reef structure deployed in Singapore. In terms of vertical reach through the water column, perhaps it is also the highest relief structure in the region, apart from decommissioned oil rigs left to function as artificial reefs.

Project development

The purpose-built reef structure was conceptualised and designed by HSL Constructor Pte Ltd, the National Parks Board (NParks) and JTC Corporation (JTC), with valuable inputs from marine interest groups and academe. Technical design aspects were considered in engineering conditions that favourably support marine life. A key challenge of this project was to select a suitable location for the reef structures in Singapore's tightly zoned sea space. The waters of Small Sister's Island were chosen for JTC's reef project implementation after a vigorous site selection process in consultation with various government agencies.

DHI, commissioned by JTC, performed an Environmental Impact Study (EIS) to determine the impact of these artificial reef structures on various aspects including the seabed, ecology, and navigational safety (DHI, 2016). The EIS identified slight to moderate negative impact on suspended sediment, underwater noise, navigational safety, recreation, macrobenthos and wind waves. However, HSL and JTC followed a strict mitigation and management protocol proposed by DHI to nullify any negative impacts that may arise during and after construction and launching of the artificial reef units.

Another important aspect of this project was that structural stability could be attained without piling but instead using the structure's weight and wide base coupled with steel anchors and counterweights at the base (Fig. 1). This effectively minimised seabed disturbance. The structures were pre-fabricated off-site on land and then lowered slowly and carefully to the seabed (Fig. 2).

Fig. 1. Complete unit of artificial reef structure ready for installation. (Photo credit: Srirangam Santosh Kumar)

Fig. 2. Top section of artificial reef structure being lowered into the sea. (Photo credit: Srirangam Santosh Kumar)

Structural design that mimics reef slopes

A sloping configuration for the artificial reef structures was decided on earlier to be a good representation of the natural reef slope profile in Singapore. Each structure resembled two reef slopes placed back-to-back resulting in a basic A-frame module with a wider base narrowing to the apex. The surface area at the upper section was increased by incorporating rectilinear, fibreglass mesh panels at different levels to reduce shading and allow sediment to fall through. It was also necessary to maximise the surface area for coral growth especially in the upper section where sunlight was adequate. The multi-level configuration took advantage of the varying amount of sunlight penetration through the top six metres of the water column, which was essential for coral survivability and growth. The structure had to be sufficiently tall (12 metres, which was comparable to a three-storey landed house) to optimise the sunlight penetration zone. Interstitial spaces within each artificial reef structure unit as well as the modularity of units allowed for a diverse biological community to develop on and around them. Water flow through the units was not hindered and the modular arrangement of the units reduced alteration of prevailing current flows. The units, however, could be arranged in patterns that would help to reduce wave energy on exposed shores and function as the first line of coastal defence.

Choice of material was another important consideration. The main frame was cast in concrete with rough surfaces to favour coral growth. Small rocks excavated from the Jurong Rock Caverns project were encrusted on the concrete frame to increase textural complexity, necessary for encouraging the settlement and development of diverse biological communities. Apart from the fibreglass mesh panels, fibreglass pipes were also used to reduce overall weight of the structure and to add another type of microhabitat to the artificial reefs. The pipe's curved surface also prevented sediment accumulation. Fibreglass is known to favour coral attachment based on research in Singapore waters (Ng *et al.*, 2017).

Corals from development locations have in the past been translocated to natural reefs, particularly the more degraded ones, but space is running out on those reefs. With their high relief, the artificial reef structures provide new space suitable for such corals displaced from other development sites. Close to 2,000 coral colonies from various locations have since been transplanted to the structures. NParks and coral reef researchers identified different coral genera to be translocated. The introduction of these transplanted coral colonies will enhance the overall marine biodiversity of the Sisters' Islands Marine Park.

Biodiversity development is currently being monitored through a few research projects. These are formulated to establish the natural colonisation patterns of the structures by fish and benthic species, and growth and survival of transplanted corals. The results of these investigations will influence modifications in the design of new structures to further increase their effectiveness.

High-relief artificial reefs can provide numerous ecosystem services. Mimicking natural reef slopes, they are effective for enhancing marine biodiversity, especially of the open sea. They therefore have the potential of expanding Singapore's reef ecosystem. This approach is valuable as reef restoration can only improve the health of existing reefs without much possibility of areal expansion. It is also useful in Singapore's limited but heavily utilised sea space. The eight units of the high relief artificial reef structures provide 1,000 square metres of space for the development of corals and reef-associated biota. Apart from enhancing marine biodiversity, these structures can be placed in configurations to absorb wave energy and, therefore, provide a coastal defence service.

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References

Chou LM (2021) Enhancing marine biodiversity with artificial structures. Sustainable Engineering Technologies and Architectures. AIP Publishing LLC, pp. 5.1–5.22.

DHI (2016) Environmental Impact Study: Artificial Reef Development in Singapore Phase 2.

Ng CS, Toh TC & Chou LM (2016) Coral restoration in Singapore's sediment-challenged sea. Regional Studies in Marine Science, 8(3): 422–429.

Ng CS, Toh TC & Chou LM (2017) Artificial reefs as a reef restoration strategy in sediment-impacted environments: Insights from long-term monitoring. Aquatic Conservation: Marine and Freshwater Ecosystems, 27(5): 976–985.

White AT, Chou LM, De Silva MWRN & Guarin FY (1990) Artificial reefs for marine habitat enhancement in Southeast Asia. ICLARM Education Series 11. International Centre for Living Aquatic Resources Management, Manila, Philippines, 45 pp.