CHAPTER 26

Reef Restoration in Singapore

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The loss of more than half of Singapore's coral reef habitats to land reclamation and exposure of the remaining reefs to chronic sedimentation necessitate active restoration interventions. Singapore's reef restoration activities stretch back to the late 1980s. Two initiatives dealt with artificial reefs involving large and heavy structures that required barges and cranes to transport and deploy. The majority dealt with restoration techniques that could be handled by scuba-diving researchers. The earlier artificial reef project in 1989 deployed structures made from tyre pyramids and hollow concrete frames. The project was carried out by the National University of Singapore and supported under the ASEAN-USAID Coastal Resources Management Project. The scale of this artificial reef was dwarfed by the more recent artificial reef project (Singapore's largest artificial reef structures) in 2018 where 10-metre-tall purpose-built concrete and fibreglass structures were placed at Sisters' Islands Marine Park (See Chapter 14). This project was a collaboration between JTC Corporation (JTC) and National Parks Board (NParks).

The large majority of reef restoration projects dealt with coral translocation and strategies to enhance survival and growth of corals, and where structures were involved, they were small and portable. Collectively, the research has revealed much information valuable to the advancement of reef restoration in Singapore's marine environment. This would not have been possible without the funding support from and/or collaboration with various agencies, such as Keppel Group, Housing and Development Board, JTC, Maritime and Port Authority, National Environment Agency, NParks, National Research Foundation (Marine Science Research and Development Programme), Sentosa Development Corporation, Singapore Maritime Institute, Singapore Tourism Board, Wildlife Reserves Singapore Conservation Fund, and the European Union.

Reef restoration efforts employing techniques that overcome sedimentation challenges have indicated their viability (Ng *et al*., 2016a; Chou *et al*., 2018). These range from the provision of sloping solid substrata (Low *et al*., 2006) or horizontal mesh surfaces that prevent sediment accumulation (Ng & Chou, 2014). This will complement the observed natural coral colonisation of seawalls (Chou *et al*., 2010; Ng *et al*., 2012) and other human-made structures such as jetty pilings (Chou & Lim, 1986; Ong & Tan, 2012) lining the urban coast.

In-situ coral nurseries have a significant role in reef restoration efforts in a sediment-stressed environment. Studies on two scleractinian species, *Pachyseris speciosa* and *Pocillopora acuta* (Poquita-Du *et al*., 2017) indicated that fragments raised in nurseries for five months before being transplanted to the reef substrate, grew significantly faster by three to five times compared to those that were transplanted directly without a nursery phase (Afiq-Rosli *et al*., 2017). The faster growth of transplants in nurseries augmented their size and continued to manifest after final transplantation to the reef, enabling them to perform better than directly transplanted fragments.

Nurseries can also be used to nurture 'corals of opportunity' (COPs), which are naturally fragmented corals lying free on the reef floor or coral juveniles that have recruited on loose rubble. COPs raised in nurseries at Pulau Semakau (Chou *et al*., 2009) and nubbins (small fragments) raised in nurseries at St John's and Lazarus Islands (Bongiorni *et al*., 2011) showed that improved survivorship and growth rate can be achieved in Singapore's sediment-impacted waters. These studies highlight the feasibility of establishing coral nurseries in other locations to preserve scleractinian genotypes from reefs that will be directly affected by coastal development.

The coral nurseries themselves served as microhabitats to enhance biodiversity despite the sedimentation, attracting a large variety of species such as fishes (Taira *et al*., 2016) and reef-associated invertebrates (Wee *et al*., 2019). These nurseries also provided opportunities for recruitment, settlement, and development of reef fauna. They enhance ecosystem functioning in degraded as well as non-reefal sites while nurturing coral fragments for transplantation (Chou *et al*., 2018).

It is important to consider preserving the locality's genetic diversity when transplanting corals from a source reef about to be exposed to development impact. Investigations of four coral species from such a reef showed that 33% to 40% of colonies can represent 80% of genetic diversity and more than 50% of colonies represent more than 90% of genetic diversity (Afiq-Rosli *et al*., 2019). Hence, not all colonies need to be relocated when resources are constrained. Colonies of hermaphroditic species can be collected from over a smaller area, while gonochoric species can be collected over a larger spatial area, the latter having greater genetic variability over larger distances.

Biodiversity on artificial substrates developed through natural colonisation can be enhanced by active transplantation particularly in the intertidal zone. Natural colonisation showed the viability of hard structures such as seawalls as habitats for biological communities (Ng *et al.*, 2015) and active transplantation can further enhance the structure's ecological value. Fragments of five species of scleractinian corals, three species of soft corals and three species of sponges reared in *ex-situ* nurseries prior to transplantation exhibited variable survivorship and growth. The scleractinian coral *Porites lobata*, soft coral *Lobophytum* sp., and sponge *Lendenfeldia chondrodes* had high survivorship, rapid growth and extended mean survival times two years after transplantation. Coral species with massive or encrusting growth forms were best at establishing and developing on seawalls and observed to provide shelter and food for reef fish and gastropods.

Active restoration can help to increase the intertidal biodiversity of seawalls but must take into account that not all species can survive conditions at seawalls, particularly those with an early developing pioneering but competitive community. Similarly, not all species do well when transplanted to subtidal seawalls. Of six species investigated, *Hydnophora rigida*, *Podabacia crustacea*, *Echinopora lamellosa* and *Platygyra sinensis* had sustained growth and survival rates exceeding 90% after six months (Toh *et al.*, 2017). The study also showed how involvement of volunteers could lower the labour cost of the transplantation effort. In a recent transplantation project from 2013 to 2019, 904 coral fragments were transplanted to cover 150 square metres of degraded reef and create 272 square metres of 'new' reefs (Chou *et al.*, 2016). The 'new' reefs are non-reefal areas on which coral transplantation was attempted to determine if reef communities could be generated.

Many restoration initiatives are supported by short-term projects over durations that do not allow for long-term assessment. Sessile lifeform diversity developed from natural recruitment on fibreglass reef enhancement units (Ng *et al.*, 2016b) increased significantly over a span of 10 years with hard corals and coralline algae contributing most to the temporal dissimilarity. The reef units augmented ecosystem functioning with 119 sessile and mobile taxa utilising them for food and shelter. It must be emphasised that long-term monitoring is essential for assessing the effectiveness of reef restoration efforts (Chou *et al.*, 2016).

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