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Enhancing the biodiversity of coastal defence structures: transplantation of nursery-reared reef biota onto intertidal seawalls

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ABSTRACT

Natural coastlines around the world are increasingly being modified and replaced by breakwaters, revetments and seawalls. Although such infrastructure is primarily intended to protect existing and new shorelines from erosion, such coastal defence structures can also serve as viable habitats for biological communities. In this study, the feasibility of transplanting reef biota to the intertidal zone of seawalls was explored. Fragments of hard corals (*Porites lobata, Pocillopora damicornis, Hydnophora rigida, Diploastrea heliopora, Goniastrea minuta*), soft corals (Cladiella sp., *Lobophytum* sp., *Sinularia* sp.) and sponges (*Rhabdastrella globostellata, Spongia ceylonensis, Lendenfeldia chondrodes*) were collected and reared in an *ex situ* mariculture facility. They were then transferred and affixed to intertidal surfaces of a seawall located on a small island off Changi, Singapore. Survivorship was significantly different between *G. minuta* and *D. heliopora* fragments transplanted on the seawall for 13 months (90% vs 10%; $\chi^2 = 42.29$, $p < 0.001$). For the remaining nine species transplanted for 24 months, survivorship was significantly different among the hard corals ($\chi^2 = 19.59$), soft corals ($\chi^2 = 41.94$) and sponges ($\chi^2 = 50.97$) (all $p < 0.001$). Among the nine species, transplants of the soft coral *Lobophytum*, the sponge *L. chondrodes* and the hard coral *P. lobata* fared the best, registering high overall survivorship (87.5%, 68.1%, and 47.4%, respectively), long mean survival times (21.6 months, 17.8 months, and 12.3 months, respectively), and fast growth (50-fold, 23-fold and 10-fold increases in size, respectively) 24 months post-transplantation. In contrast, *Pocillopora damicornis*, *H. rigida* and *R. globostellata* were unable to establish on the seawall, with all transplants of the former two species perishing within two months, and those of the latter species succumbing 18 months after transplantation. Overall, species with massive and encrusting growth forms were most successful at establishing on the seawall, and were even observed to function as food and shelter for reef fish and gastropods. These results indicate that the transplantation of nursery-reared reef biota is a viable strategy that enhances the ecological value of seawalls.

1. Introduction

Extensive modifications to shorelines around the world have been carried out to cater to a multitude of human needs required by some 2.5 billion people living within 100 km from the sea (Burke et al., 2011). Increasing numbers of commercial, recreational and residential infrastructure such as floating docks, jetties, marinas and seafront housing are constructed in near-shore areas, along with the erection of seawalls and breakwaters to protect these properties from wave impact as well as coastal erosion (French, 2002; Bulleri and Chapman 2010). Interestingly, the introduction of these coastal defence structures has created habitats for fish (Pondella et al., 2002; Cenci et al., 2011), corals (Wen et al., 2007; Viyakarn et al., 2009), and molluscs (Chapman 2006; Moreira et al., 2007), among other biotic assemblages (see Bulleri et al., 2005; Burt et al., 2011; Green et al., 2012).

While such infrastructure may promote the recruitment of certain species, natural coastal habitats face severe threat of loss from land engineering of such scales (Alongi 2002; Burke et al., 2011; Grech et al., 2012). The original biota as well as those from adjacent areas are affected by concomitant changes in hydrodynamics and water quality (Davis et al., 1982; Jonsson et al., 2006; Martins et al., 2009). As existing coastal defence structures are unlikely to be removed, their value as biological habitats could be increased instead via 'ecological engineering' (Chapman and Underwood 2011). Various strategies which have been developed

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for restoring and rehabilitating impacted mangroves (Lewis, 2005) and coral reefs (Edwards, 2010) could be adapted for use on seawalls and revetments to improve their ecological value.

Singapore's coasts are heavily utilised, and intensive land development since the 1960s has reduced its coral reef area by over 60%, replacing much of the original coasts with recreational facilities and coastal defence structures (Hilton and Manning 1995; Chou 2006). Seawalls are the dominant form of coastal protection, typically comprising large granite boulders fitted together to form an inclined wall. To date, they line over 63% of the country's coastline (Lai et al., 2015), and are known to harbour intertidal communities of molluscs, crustaceans and algae (Chim and Tan 2009; Lee et al., 2009a,b; Lee and Sin 2009). Apart from granite seawalls within marinas (Chou et al., 2010; Tan et al., 2012), scleractinian coral assemblages have also colonised the seaward-facing seawalls of the southern offshore islands (Ng et al., 2012). Other reef organisms such as soft corals and sponges have been observed on seawalls in Singapore, but little has been studied about their establishment on such structures. These observations suggest that seawalls can function as a stable substratum for the recruitment of reef-building organisms. While proper management of the marine environment is vital to assist the recovery of reef organisms, natural recolonisation of reef biota may not be able to keep pace with the scale of anthropogenic stressors. There is a need to adapt active restoration methods to enhance the establishment of biodiversity on coastal defence infrastructure.

Common in reef rehabilitation endeavours is a two-step 'gardening' concept, with the first step entailing the establishment of nurseries to allow hard coral propagules to grow in a sheltered environment, and the second step involving transplantation of the coral material to the target recipient sites (Epstein et al., 2003; Rinkevich 2005). In this two-year study, we adapted these techniques to accelerate the establishment of sessile reef biota on a recently constructed seawall on an offshore island northeast of Singapore, and in so doing, bypassed impediments to larval settlement as well as high juvenile mortality rates caused by wide environmental fluctuations on seawalls. Small fragments of hard corals, soft corals and sponges were reared in an *ex situ* mariculture facility and field testing was carried out to determine the suitability of various species for transplanting at 0–0.4m above chart datum (CD), a tidal zone that is the upper limit for coral growth on seawalls in Singapore (Ng et al., 2012). The principal objective was to examine the feasibility of transplantation as a tool for habitat rehabilitation on intertidal seawalls so as to enhance the overall ecological value of these man-made structures.

2. Material and methods

A granite seawall on a small island located off Changi in the northeast corner of mainland Singapore was selected as the study site. The seawall faced the southwest and comprised large granite boulders fitted together to form a cement-grouted upper intertidal section and a lower intertidal ungrouted zone. It terminates at a depth of 25 m below chart datum (CD) and is angled at 33° from the horizontal. At the time of the study, heavy vessel traffic in the waters just off the seawall created strong ship wake on occasion, while marine debris such as plastics and wood were often seen lodged within the ungrouted sections. Naturally recruited colonies of hard corals (*Oulastrea crispata*, *Pocillopora damicornis*, *Porites* sp., *Turbinaria* sp., *Goniopora* sp.), soft corals (*Dendronepthya* sp.), sponges (*Haliclona* sp., *Halichondria* sp.) and sea fans were observed on the wall at +0.1 m CD, while zoanthids, molluscs and algae occupied zones up to +0.7 m CD in the lower intertidal zone.

A total of 11 types of sponges and coral were studied. These comprised three species of sponges (*Rhabdastrella globostellata*, *Spongia ceylonensis*, *Lendenfeldia chondrodes*), three species of soft coral (*Cladiella* sp., *Lobophytum* sp., *Sinularia* sp.) and five species of hard corals (*Porites lobata*, *Pocillopora damicornis*, *Hydnophora rigida*, *Diploastrea heliopora*, *Goniastrea minuta*). These species were selected for their abundance in Singapore's marine environment, ease of culture in mariculture tanks, as well as their ability to withstand short periods of emersion (Goh et al., 2009; Huang et al., 2009; Lim et al., 2012). This was to ensure that the organisms were native biota which could establish themselves securely on the lower intertidal region of the seawalls–a zone which was exposed for some two hours of spring low tides for up to three consecutive days each month. At least six different colonies of each species were collected from various reefs in the Singapore Strait and transported immediately to a mariculture facility at the Tropical Marine Science Institute on St John's Island, which functioned as an *ex situ* nursery. The sponges and soft corals were housed in indoor tanks (average temperature of 29.0 °C, salinity of 30 ppt, and light intensity of 24.9 μmol m^{-2} s^{-1}) while the hard corals were placed in shaded outdoor tanks (average temperature of 29.5 °C, salinity of 30 ppt, and light intensity of 375 μmol m^{-2} s^{-1}) for a one-month acclimation period.

Circular cement tiles (diameter 5 cm, thickness 0.5 cm) made from equal parts of sand, cement and water served as platforms for the attachment of soft coral and sponge fragments so as to facilitate the transplantation of these soft-bodied animals onto the granite seawall. These tiles were pre-conditioned for a month by leaving them in a tank that was supplied with flow-through filtered seawater. Only animals which were visibly healthy (no bleaching or tissue loss) were fragmented after the acclimation period. The sponges were excised in filtered seawater with a sharp blade, ensuring each fragment had at least one surface with an intact pinacoderm. Using coarse string, each fragment was tied gently onto a tile with the pinacoderm making contact with one surface of the cement tile. Likewise, the soft corals were fragmented with a blade in filtered seawater and their cut surfaces were gently placed onto the cement tiles to encourage self-attachment. This method was adopted as adhesives such as cyanoacrylate glue easily killed the sponge and soft coral tissues upon contact, hampering self-attachment. In comparison, coarse string held the fragments snugly in contact with the surface of the tile and facilitated the growth of live tissue directly onto the cement substratum. The hard corals were fragmented with a hammer and chisel, but were not attached to any cement tiles. Gentle aeration and circulation were provided to allow these fragments to recover in their holding tanks. After three months, healthy fragments of hard corals, together with sponges and soft coral fragments which had securely self-attached to the cement tiles and which were at least 3 cm in diameter were selected for transplantation onto the seawall.

2.1. Transplantation

Adapting the methods by Gomez et al. (2010), epibiota on large granite boulders at +0.1–+0.3 m CD on the seawall were scrubbed off thoroughly using a steel brush prior to the application of marine epoxy (Fosroc Nitomortar UA) in a ratio of 2.5 parts base putty to one part hardener. A first group comprising hard corals (38 *Porites lobata*, 36 *Pocillopora damicornis*, and 18 *Hydnophora rigida* fragments), soft corals (30 *Cladiella*, 40 *Lobophytum*, and 31 *Sinularia* fragments), and sponges (44 *Rhabdastrella globostellata*, 49 *Spongia ceylonensis*, and 47 *Lendenfeldia chondrodes* fragments) were transplanted in May 2010 over a period of three days during the spring low tides. In April 2011, a second group of another 30 hard coral fragments each of *Diploastrea heliopora* and *Goniastrea minuta* were transplanted at the same tidal height on adjacent granite boulders. The exposed surfaces of five to ten boulders were used per species. The transplants were spaced 15 cm apart from