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NATURAL COLONISATION OF A MARINA SEAWALL BY SCLERACTINIAN CORALS ALONG SINGAPORE'S EAST COAST

Y. Z. Tan[1], **C. S. L. Ng**[2*] and **L. M. Chou**[1]
[1]*Department of Biological Sciences, National University of Singapore*
14 Science Drive 4, Singapore 117543, Republic of Singapore
[2]*Tropical Marine Science Institute, National University of Singapore*
18 Kent Ridge Road, Singapore 119227, Republic of Singapore
(*[*]Corresponding author: tmsncsl@nus.edu.sg*)

ABSTRACT. — Highly modified habitats resulting from coastal development could facilitate the re-establishment of biological communities. At the Singapore Armed Forces Yacht Club in Changi, Singapore, the diversity and distribution of scleractinian corals were investigated using belt surveys at two different depths (1–3.5 m and 3.5–6 m) of a seawall. The 1,762 scleractinian colonies recorded are represented by 37 genera from 14 families. The dominant genera, in descending order, were *Pectinia*, *Porites*, *Turbinaria*, *Goniastrea*, and *Leptastrea*. Generic richness, abundance, and evenness were lower in the deeper belts. The majority of the colonies in the marina were juveniles smaller than 10 cm across, indicating that coral recruitment is an active, ongoing process, and that such environments, albeit highly modified, can function to support scleractinian diversity.

KEY WORDS. — Scleractinian diversity, seawall, Singapore, marina

INTRODUCTION

Human-modified areas can become hotspots of biodiversity. High species richness can result from the provision of novel habitats (Gilbert, 1989), the spread of exotic species (Sukopp & Wurzel, 2003), and the attraction of migratory species (Jokimäki & Suhonen, 1998) to these modified areas. For example, novel habitats such as buildings, parks, reservoirs, and other modified biotopes have the capacity to accommodate a variety of species (Adams, 1994), while the higher temperature in cities can promote naturalisation and the spread of exotic plants that originate from warmer areas (Sukopp & Wurzel, 2003).

Modification of marine habitats usually involves the introduction of hard structures into the environment. These hard structures may provide a novel substratum for the establishment of organisms like scleractinian corals. In Thailand, 40–70% coral cover by 67 species of scleractinian corals developed on the breakwaters in the harbours of Sattahip (Viyakarn et al., 2008). In Taiwan, corals were found on several man-made sites. At the breakwaters off Dou-Fu-Chia and Yuan-An where 123 and 107 scleractinian species were recorded, respectively, coral cover ranged from 25–40% with *Acropora* being the most dominant (Wen et al., 2006), while at the inlet of a nuclear plant within Kenting National Park, approximately 0.01 km^2 of scleractinian cover comprising mainly acroporids from 25 species was found (Tang et al., 2009). In Dubai, coral cover was 19% greater in artificial reefs compared to the natural reefs, but in terms of species richness and diversity, the natural reefs were higher (29 vs. 20 species and H' = 2.3 vs. 1.8) (Burt et al., 2009). At Pulau Hantu, Singapore, coral cover on a vertical concrete jetty pile was twice that on the adjacent natural reef slope, with species count on the concrete pile at 27 compared to 12 on the reef slope (Chou & Lim, 1986).

Marinas represent a highly modified environment with the formation of semi-enclosures from artificial structures like seawalls, pilings, and pontoons, resulting in the reduction of environmental processes such as wave energy and water movement (Hinwood, 1998). The semi-enclosed nature of marinas also diminishes tidal exchange, which can lead to the accumulation of pollutants and subsequent impacts on epifaunal assemblages (Lenihan et al., 1990; Turner et al., 1997; Piola et al., 2009). In addition, substrate composition can be changed when muddy intertidal surfaces are scraped by swinging mooring chains to expose larger particles such as gravel and shell fragments, causing the abundance of bird prey species to fall, such as that of the amphipod *Corophium volutator* (Herbert et al., 2009). Through these modifications, marinas are highly specialised habitats that attract and support selected species (Connell & Glasby, 1999). Although scleractinian corals are known to establish in human-modified coastal environments, studies on scleractinian diversity in marinas remain limited.

The majority of Singapore’s natural coasts have been replaced by man-made structures. Despite the loss of natural habitats, marine biodiversity appears resilient against species loss, although species occurrence and abundance may have decreased (Chou, 2006). These impacts will persist as more coastal areas are converted owing to the increasing popularity of marine recreation activities and sea-sports (Hilton & Manning, 1995). The Singapore Armed Forces Yacht Club (SAFYC) at Changi is one of the four marinas along the southern coast of Singapore Island. This study assesses the diversity and size-class distribution of scleractinian corals that were naturally recruited in the SAFYC.

MATERIAL AND METHODS

The SAFYC is located at the southeastern part of Singapore Island at 01°18.56′N, 104°00.55′E (Fig. 1). Fully constructed in 2004, it became operational in 2005 and has a berthing capacity of 56 boats. The marina is surrounded by concrete walls and pillars with one opening for boat access. Underneath the floating pontoons nearest to shore is an approximately 80-m stretch of granite rock seawall sloping down to a sand-silt bottom. The deepest point is 7 m. A preliminary survey showed that hard corals were primarily present on the seawall. No corals were on the sand-silt bottom.

Surveys for this study were conducted from Feb–Mar.2010 at the SAFYC. Belt transect surveys (10 × 2.5 m; 5 m apart) were conducted on the seawall. Four belt transects were situated at the shallow section of the seawall (1–3.5 m depth) and four at the deep section (3.5–6 m depth). Meandering swim searches were performed until all colonies within each belt were recorded and identified to genus. The maximum diameter of each colony was also measured and categorised into one of four size classes ($x < 10$ cm; 10 cm $\le x < 25$ cm; 25 cm $\le x < 50$ cm; $x \ge 50$ cm). Corals on structures other than the seawall were also noted. The scleractinians observed were identified to genus.

The Shannon-Wiener diversity index ($H' = -\sum [p_i \ln \{p_i\}]$) and the Shannon evenness index ($E = H' / \ln [S]$) were used to compare the diversity between the shallow and deep sections of the seawall.

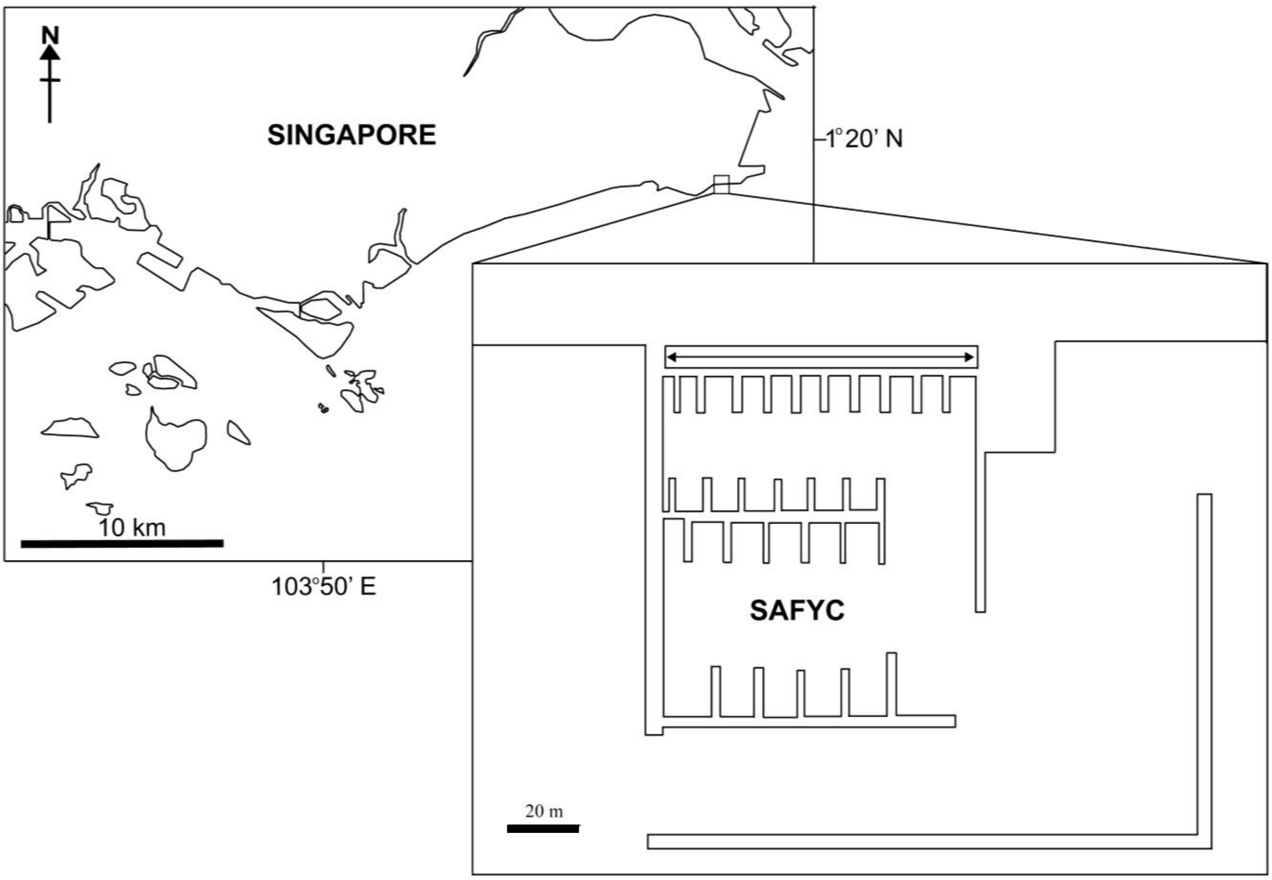

Fig. 1. South-eastern Singapore. Inset: Layout of the Singapore Armed Forces Yacht Club. Surveys were conducted on the seawall closest to shore demarcated by the two-headed arrow.

RESULTS

The 1,762 scleractinian colonies counted on the seawall belonged to 37 genera from 14 families. The shallow section (1–3.5 m) had 1,191 colonies from 35 genera (Fig. 2a). The most dominant was *Porites* (14.4%). Other genera represented by more than 50 colonies were *Favia*, *Fungia*, *Goniastrea*, *Leptastrea*, *Pectinia*, *Podabacia*, and *Turbinaria*. The diversity index was 2.83 and evenness was 0.80. The largest was a *Hydnophora* colony (59 cm) (Fig. 3). At the deep section of the seawall (3.5–6 m), 571 colonies from 32 genera were recorded. The most dominant genus was *Pectinia* (31.2%) (Fig. 2b). Another genus with more than 50 colonies was *Turbinaria*. The diversity index was 2.35 and evenness was 0.69. The largest was a *Porites* colony (56.2 cm) (Fig. 4). A colony of *Scapophyllia* was observed on one of the concrete pillars. This genus was not found on the seawall during the survey.

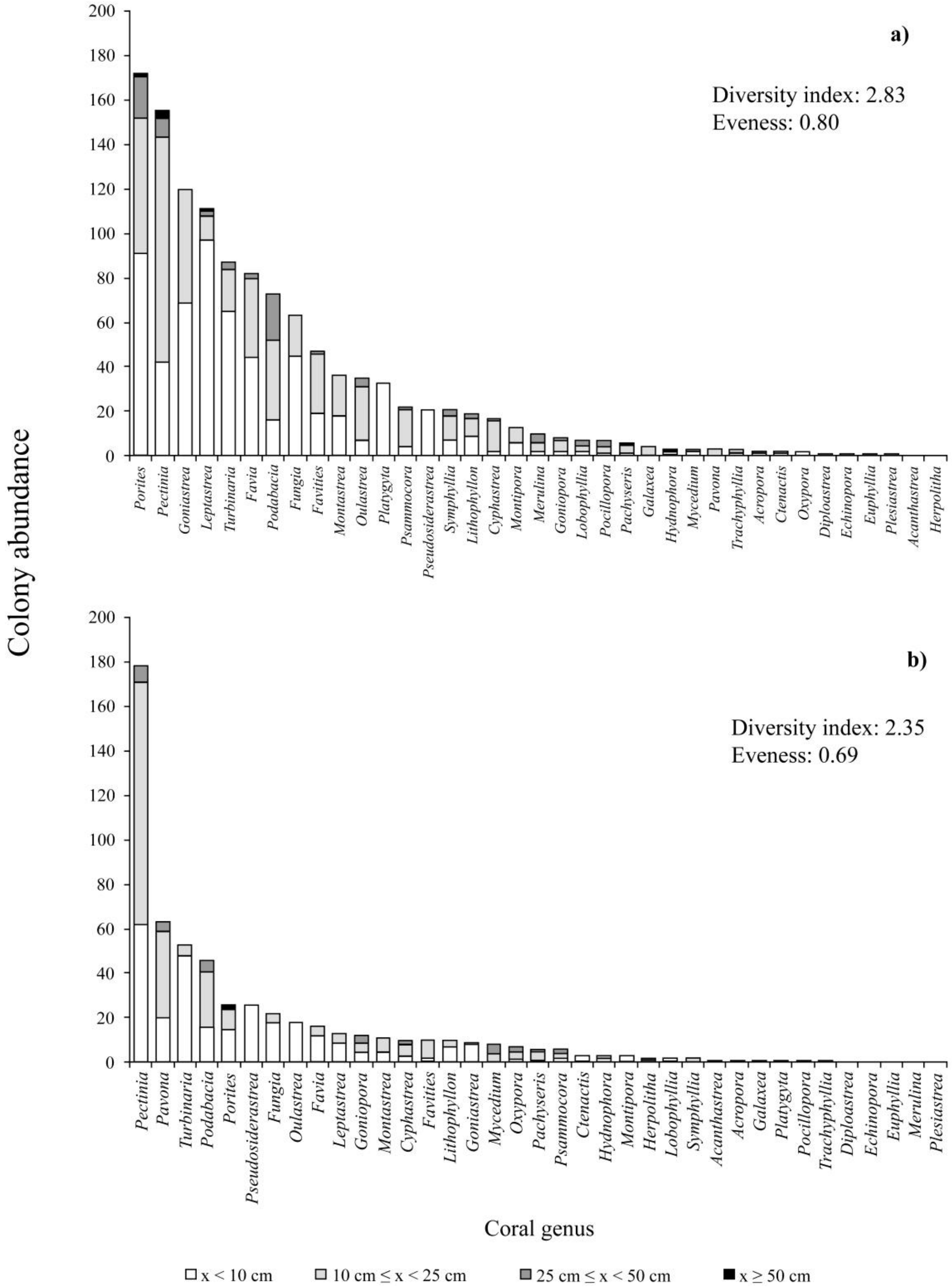

Fig. 2. Size class distribution of scleractinian genera at the (a) shallow section and (b) deep section of the seawall in the Singapore Armed Forces Yacht Club.


Fig. 3. *Hydnophora* colony on the shallow section of the seawall (59 cm across).

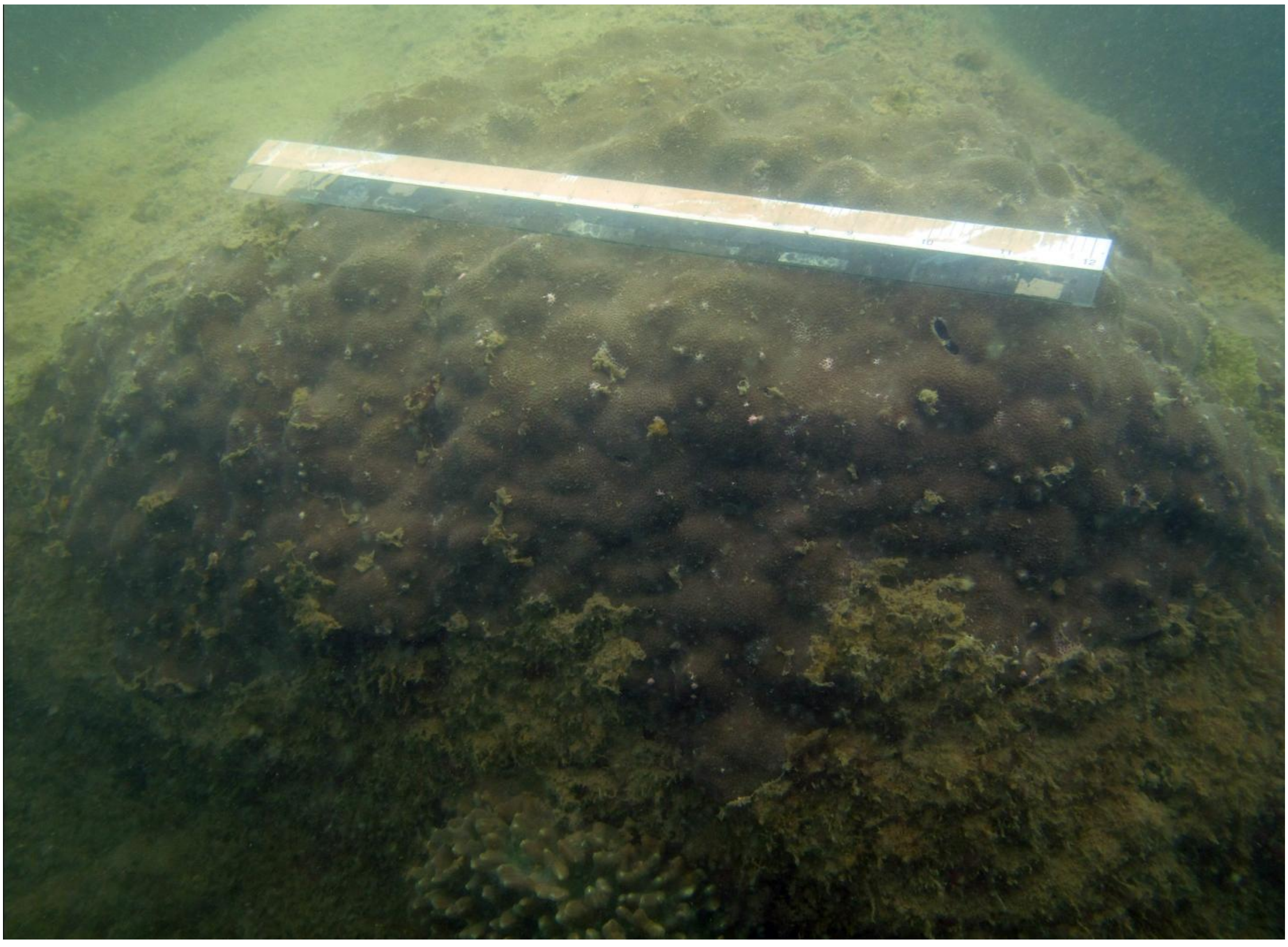
Fig. 4. *Porites* colony on the deep section of the seawall (56.2 cm across).

DISCUSSION

Few surveys concerning the biodiversity of coral communities on seawalls in Singapore have been undertaken. A study at ONE°15 Marina, Sentosa revealed 26 scleractinian species from 563 colonies (Chou et al., 2010). In this study, 37 genera from the 1,762 colonies were found in the SAFYC, which is more than half of the genera (56) recorded in Singapore (Huang et al., 2009). The most dominant genus in the SAFYC is *Pectinia*, which is similar to the case for ONE°15 Marina. This genus is also commonly found in the natural reefs of the Southern Islands of Singapore (Chou, 1988). The dominance of *Pectinia* in Singapore's waters could be attributed to its foliose growth form, which is efficient for calcium deposition under low light conditions (Davies, 1980). Furthermore, its high sediment rejection capability allows *Pectinia* to cope with high sedimentation (Stafford-Smith & Ormond, 1992).

The SAFYC exhibited a higher scleractinian abundance and richness compared to ONE°15 Marina (1189 vs. 563). Three genera, *Fungia*, *Leptastrea*, and *Podabacia*, which were commonly found in the SAFYC, were low in abundance compared to ONE°15 Marina (at the same depth). The differences in the scleractinian communities may be attributed to location and structural differences of both marinas. The SAFYC projects out from the coast while ONE°15 Marina is an embayment. While coral larvae can disperse from the fringing reefs of the main island's southwestern coast and southern offshore islands to establish in these marinas (Chou & Tun, 2005), the dominant east-west tidal streams at the east of Singapore could also have contributed larvae from other source sites to the SAFYC (Chan et al., 2006), possibly resulting in relatively less recruitment at ONE°15. Scleractinian recruitment may also have been reduced at ONE°15 Marina as the granite seawall terminates at a depth of 3 m, unlike at the SAFYC where the hard substrate extends to 7 m deep. Thus, although the surveyed area in ONE°15 Marina was much larger, abundance and richness is greater at the SAFYC.

Corals were observed to be mainly recruited on hard structures like the seawalls, pillars, and pilings in the SAFYC, showing that concrete and granite materials used in constructing these structures do provide suitable substrates for coral recruitment (Fitzhardinge & Bailey-Brock, 1989; Lam, 2003; Creed & De Paula, 2007). However, the distribution of species and abundance differed. Coral abundance, richness, and evenness were noted to be lower in the deep section compared to the shallow section. This result is consistent with other studies based on the distribution of macro-benthos at different depths in artificial reefs (Relini et al., 1994; Kocak & Zamboni, 1998; Moura et al., 2007).

As the study focused on the establishment of scleractinians, water quality was not monitored. The presence of 37 genera of scleractinian corals, however, indicates that the water quality was good enough to support their natural establishment. The majority of the colonies is in the under-10 cm class-size, and the presence of juvenile corals imply that coral recruitment is an active ongoing process in the marina. It is natural for the larger colonies to be fewer as the marina was constructed in 2004 and there has been less than seven years of growth for the earliest recruits. Another reason for the low abundance of large colonies could be because of the different environmental conditions from natural settings resulting in slow growth rates or low survival rates, or even both (Shinn, 1966; Bak & Engel, 1979; Babcock & Mundy, 1996). Coral communities are not known to occur along the southeast coast of the Singapore Island. This could be owed to the lack of suitable hard substrates along that stretch of the shore. It was not until 2004, when a seawall was developed that a niche was made available for coral larvae to settle on.

Scleractinian corals can establish naturally in human-modified marine environments, but our understanding of how modified habitats alter coral diversity remains limited. Although the number of coral genera in the SAFYC is comparable to those in the Southern Islands of Singapore (Chou & Lim, 1986; Goh & Chou, 1992, 1993), this does not suggest that modified habitats such as marinas can replace natural habitats. Understanding the diversity of coral species in modified habitats, however, can facilitate better management and improvement of these areas to ensure the preservation and flourishing of coral communities. Along the southeast coast of Singapore Island, coral larval supply is not the limiting factor to coral establishment, but the absence of suitable hard substrates for effective recruitment is.

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