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Original Paper

NATURAL CORAL COLONIZATION OF A MARINA SEAWALL IN SINGAPORE

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ABSTRACT

Marinas require extensive modification of a natural coast. The resulting modified habitat is known to support changed biological communities but the ability of tropical marinas to function as a surrogate habitat for scleractinian corals has not been well investigated. An assessment of scleractinian corals naturally colonising a nine-year-old marina seawall in Singapore indicated 26 genera from 13 families, of which Pectinia and Turbinaria were the most dominant. Most colonies measured 10 – 25 cm in diameter. Reefs of adjacent islands provided the larval source while the marina's environmental conditions favored larval recruitment and growth. Specific larval settlement preferences as well as sediment rejection capabilities of the two most common genera could have contributed to their dominance. The study showed that the seawall of a marina can support scleractinian coral communities and with relevant management, can significantly enhance marine biodiversity.

Key words: Scleractinian diversity; seawall; Singapore; tropical marina

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INTRODUCTION

Singapore's coastline has been heavily modified by expanding infrastructure development necessitated by the demands from multiple sectors (Chou, 2006). The increasing popularity of sea-sport and marine-based recreation is evident from the development of new marinas that replace the natural coast with a highly modified one. Such conversions obliterate the original ecology, but the resulting modified habitat can continue to support marine biodiversity (McDonnell and Pickett, 1990). The proliferation of modified marine habitats is accompanied by growing interest in their influence on biodiversity (Connell and Glasby, 1999; Bacchiocchi and Airoldi, 2003; Chapman and Bulleri, 2003; Davis *et al*., 2002).

Human-engineered marine structures are known to function as new substrates for larval settlement, unlike in the terrestrial environment (Sutherland and Karlson, 1977; Butler, 1991; Glasby and Connell, 1999;). Several studies have also demonstrated that biological assemblages on artificial marine structures and nearby natural habitats can be different (e.g. Chou and Lim, 1986; Glasby, 1999; Bulleri and Chapman, 2004; Perkol-Finkel and Benayahu, 2004). Modified marine habitats can indeed serve as novel coastal habitats (Perkol-Finkel *et al*., 2006) but how effective they are as surrogate habitats for the original marine biological diversity remains to be fully documented (Glasby and Connell, 1999). Studies on modified marine habitats were mostly based on fouling epibiota in temperate waters (Connell and Glasby, 1999; Glasby, 1999; Connell, 2000; Holloway and Connell, 2002; Chapman and Bulleri, 2003) but the increase of coastal urbanization, especially in the tropics, underscores the need to understand the contribution of modified marine habitats to marine biodiversity.

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Marinas provide ample opportunity for understanding the role of modified habitats as they have a variety of artificial structures to facilitate recreational boating (Bulleri and Chapman, 2004). Southeast Asia had over 30 marinas at the turn of the century (Goh *et al*., 2000) and new ones continue to be built. Marinas are designed to shelter moored boats against strong waves and currents (Iannuzzi *et al*., 1996). They result in the creation of a semi-enclosed system where hydrodynamic and other coastal environmental processes are altered due to the reduction of wave action and flushing (Hinwood, 1998).

The reduced tidal flow is compounded further by boat maintenance activities that result in pollutant leaching and possible eutrophication (Allen *et al*., 1992; McAllister *et al*., 1996). Depressed water quality and sediment accumulation at the bottom alter benthic biological community structure and habitat complexity (Turner *et al*., 1997). Despite the detrimental effect of marinas on water quality and biodiversity, they warrant study as specialized ecological habitats as more are being developed (Holloway and Connell, 2002) at the expense of natural habitats. They are known to attract and support specific assemblages of marine organisms (Connell and Glasby, 1999; Davis *et al*., 2002; Bacchiocchi and Airoldi, 2003; Detheir *et al*., 2003). The general lack of biological assessments relating to artificial structures in marinas also necessitates further investigation (Bulleri and Chapman, 2004).

Singapore has seven marinas, of which one of the newest is ONE^{o}15 Marina at Sentosa Island, south of the Singapore mainland. Previous investigations of other marinas included marine biodiversity assessments and bioremediation experiments at Raffles Marina (Chou *et al*., 2004), as well as water quality studies at Punggol Marina (Goh *et al*., 2000). ONE^{o}15 Marina was constructed in 1991 over an area that previously supported a fringing reef. This investigation was initiated to examine the natural colonization of scleractinian corals on the interior seawall of the marina and to assess the effectiveness of the seawall as an artificial habitat for coral growth.

MATERIALS AND METHODS

ONE^{o}15 Marina (1°14.753'N, 103°50.490'E) **(Fig. 1)** is situated in an area that was reclaimed from 1991 to 1993. Its development was completed in 1998. Installation of pontoons and pilings began in 2005, making it fully operational. The marina is also capable of berthing up to 270 boats, including 13 mega yachts. The perimeter of the marina is lined by a granite rock seawall sloping down to a sandy-silt bottom, compared to other marinas in Singapore, which have vertical concrete walls down to a sandy-silt bottom.

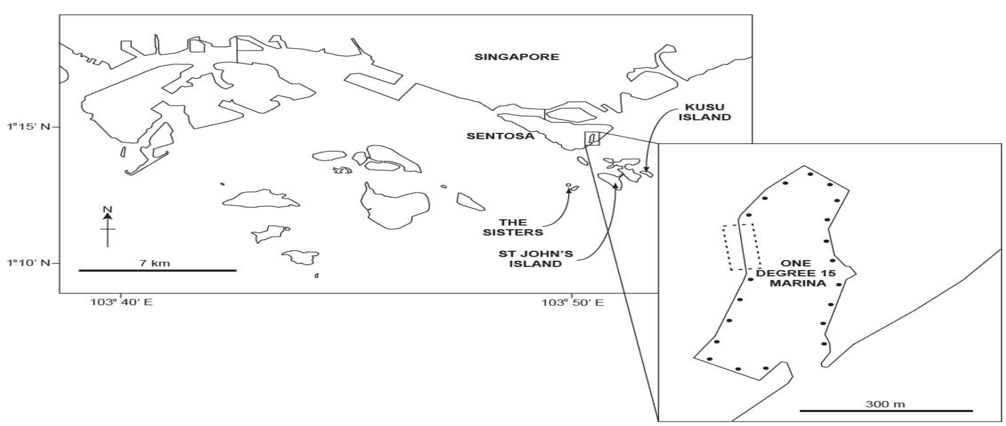

Fig. 1 Map of Singapore and the southern islands. (Inset: Sampling sites within ONE^{o}15 Marina. Each black dot represents one transect. The area within the dotted lines was excluded because it consisted of a sandy bottom and had no coral growth.)

A scleractinian coral diversity assessment was conducted from September 2006 to February 2007. Preliminary surveys revealed the presence of corals only on the granite rock seawall but not the sand-silt bottom. Twenty belt transects (25 m in length; 50 m

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apart) were established starting from the bottom of the seawall (~3m). Meandering swim searches were made along each transect while slowly ascending until all coral colonies were recorded. The colonies within each 25-m belt were counted and identified to genus. The maximum diameter of all colonies was measured and categorized into four size classes ($x \leq 5$ cm, 5 cm $< x \leq 10$ cm, 10 cm $< x \leq 25$ cm, 25 cm $< x \leq 50$ cm).

RESULTS AND DISCUSSION

RESULTS

Twenty-six genera belonging to 13 families were observed on the granite rock seawall of the marina (**Table 1**).

Table 1. *Scleractinian diversity in ONE°15 Marina.*

Family	Genus
Acroporidae	*Astreopora*, *Montipora*
Agariciidae	*Pavona*
Dendrophyllidae	*Turbinaria*
Faviidae	*Cyphastrea*, *Favia*, *Favites*, *Goniastrea*, *Leptastrea*, *Oulastrea*, *Platygyra*
Fungiidae	*Fungia*, *Lithophyllon*, *Podabacia*
Merulinidae	*Hydnophora*, *Merulina*
Mussidae	*Symphyllia*
Oculinidae	*Galaxea*
Pectiniidae	*Oxypora*, *Pectinia*
Pocilloporidae	*Pocillopora*
Poritidae	*Goniopora*, *Porites*
Siderastreidae	*Psammocora*, *Pseudosiderastrea*
Trachyphylliidae	*Trachyphyllia*

In all, 563 coral colonies were counted. The two most common genera were *Pectinia* and *Turbinaria*, with the former accounting for one-third of all the colonies (**Fig. 2**). Colonies of most genera were in the size range of 10 – 25 cm diameter, and none exceeded 50 cm.

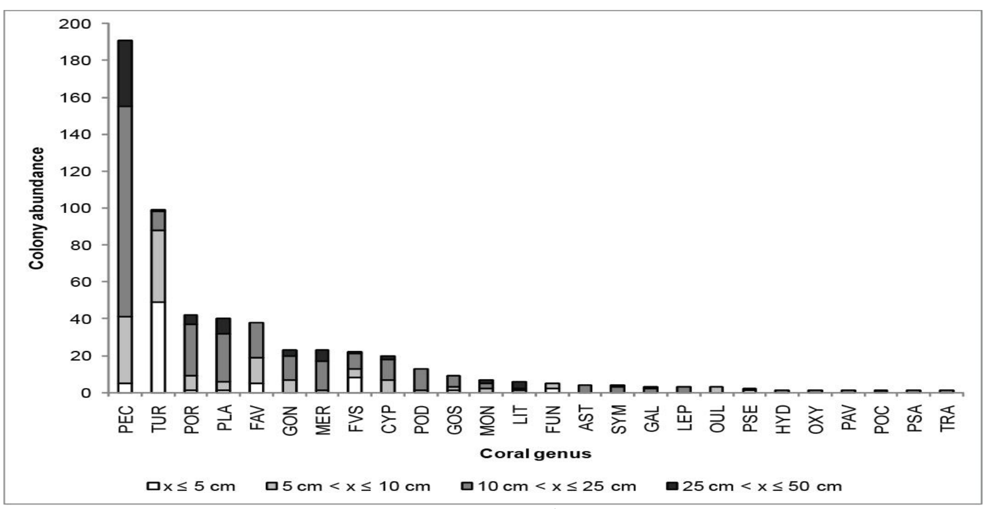

Fig. 2. Size class distribution of scleractinians in ONE°15 Marina. (AST, *Astreopora*; CYP, *Cyphastrea*; FAV, *Favia*; FVS, *Favites*; FUN, *Fungia*; GAL, *Galaxea*; GOS, *Goniastrea*; GON, *Goniopora*; HYD, *Hydnophora*; LEP, *Leptastrea*; LIT, *Lithophyllon*; MER, *Merulina*; MON, *Montipora*; OUL, *Oulastrea*; OXY, *Oxypora*; PAV, *Pavona*; PEC, *Pectinia*; PLA, *Platygyra*; POC, *Pocillopora*; POD, *Podabacia*; POR, *Porites*; PSA, *Psammocora*; PSE, *Pseudosiderastrea*; SYM, *Symphyllia*; TRA, *Trachyphyllia*; TUR, *Turbinaria*.)

DISCUSSION

No marine biodiversity surveys were carried out at Sentosa before land reclamation and the subsequent destruction of the reefs at the eastern shore in 1991. However, reef monitoring data exist for nearby islands (Kusu, St John's and Sisters) at similar depths. The natural colonization by 26 scleractinian genera in the marina represents almost half the total number of genera (56) known for Singapore reefs (Huang *et al*., 2009). This indicates that the marina's environment favored the natural colonization of scleractinian corals and suggests that modified habitats like marinas are able to support naturally occurring biota.

The marina's proximity to many offshore islands and reefs could have supported the re-establishment of scleractinian corals in the marina. Most of the main island's southwestern coast and many of the southern offshore islands are fringed by coral reefs (Chou and Tun, 2005). Mass coral spawning events occur in Singapore reefs (Guest *et al*., 2002), and the marina likely benefits from the influx of coral larvae transported by tidal currents. Genera that are common in the marina (*Pectinia*, *Turbinaria*, *Porites*, *Platygyra*, *Favia*) are also frequently encountered on the reefs of the southern islands (Chou, 1988). This further supports the role of the southern islands' coral reefs as a larval source.

Apart from larval supply, water exchange is another important factor that could account for the presence of coral colonies in the marina. Although the marina is able to support a diversity of genera commonly observed on Singapore reefs, coral cover on the seawall remained sparse, with an average distance of 1 m between colonies in most of the locations where they occurred. The sparse cover is attributed to calmer waters in the sheltered conditions. This modifies the hydrodynamic flow in the marina, which promotes sediment settlement (Allen *et al*., 1992). Sediment accumulation adversely affects coral larvae settlement and effectively reduces the surface area that can be colonized (Babcock and Davies, 1991; Gilmour, 1999). Successfully settled larvae are subjected to high post-settlement mortality due to sediment smothering and light attenuation (Fabricius and Wolanski, 2000).

Coral larvae do not settle randomly (Harrison and Wallace, 1990) but exhibit settlement preferences that influence the distribution of adult colonies (Lewis, 1974; Morse *et al*., 1988; Carlon and Olson, 1993; Baird and Hughes, 2000). The larvae of the two most common genera, *Pectinia* and *Turbinaria* could possess settlement preferences that allowed them to colonize the marina, favoring their dominance. Additionally, the responses of *Pectinia* and *Turbinaria* colonies to high sedimentation could also contribute to their dominance of this modified habitat. Both have sediment rejection capabilities ranging from the use of active (ciliary transport, tissue expansion and mucus production) to passive means (skeletal morphology that directs sediment away) (Stafford-Smith and Ormond, 1992).

Size range data provided an indication of the growth rates of the scleractinian community in this modified habitat. The earliest possible settlement of coral larvae would be in 1998 when construction of the seawall was completed, a nine-year span before the survey in 2007. It is unclear whether coral growth is affected by the sheltered environment of the marina, but growth rates for the more common genera can be estimated. Assuming that *Pectinia*, the most dominant genus colonized the marina soon after its construction was completed in 1998, and from the present size of 10 – 50 cm diameter of most colonies, the average growth rate of this genus is approximately 1 – 5 cm/yr. Most *Turbinaria* colonies measured 10 cm or less, indicating a growth rate of about 1 cm/yr. Similar annual growth rates of ~2.5 cm for *Pectinia* sp. on the natural reefs of Singapore have been reported (Lane, 1991), while *T. mesenterina* and *T. peltata* grew 1.14 cm/yr and 1.20 cm/yr respectively in a reef restoration effort in India (Mathews and Patterson Edward, 2005). The growth rates of *Pectinia* and *Turbinaria* in ONE^{o}15 Marina are comparable to those in natural habitats, suggesting that the environmental conditions in the marina are favorable to scleractinian growth, at least for the dominant genera.

CONCLUSION

The current investigation showed that an appreciable diversity of scleractinians has naturally colonized the marina over nine years

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in the absence of any active restoration effort. The observations indicate that modified habitats with suitable conditions can support the natural recruitment and development of scleractinians and contribute to biodiversity maintenance. The presence of scleractinians indicates the suitability of the water quality and circulation patterns within the marina, paving the way for active coral restoration to be considered.

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TABLES

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Trachyphylliidae	*Trachyphyllia*

FIGURES

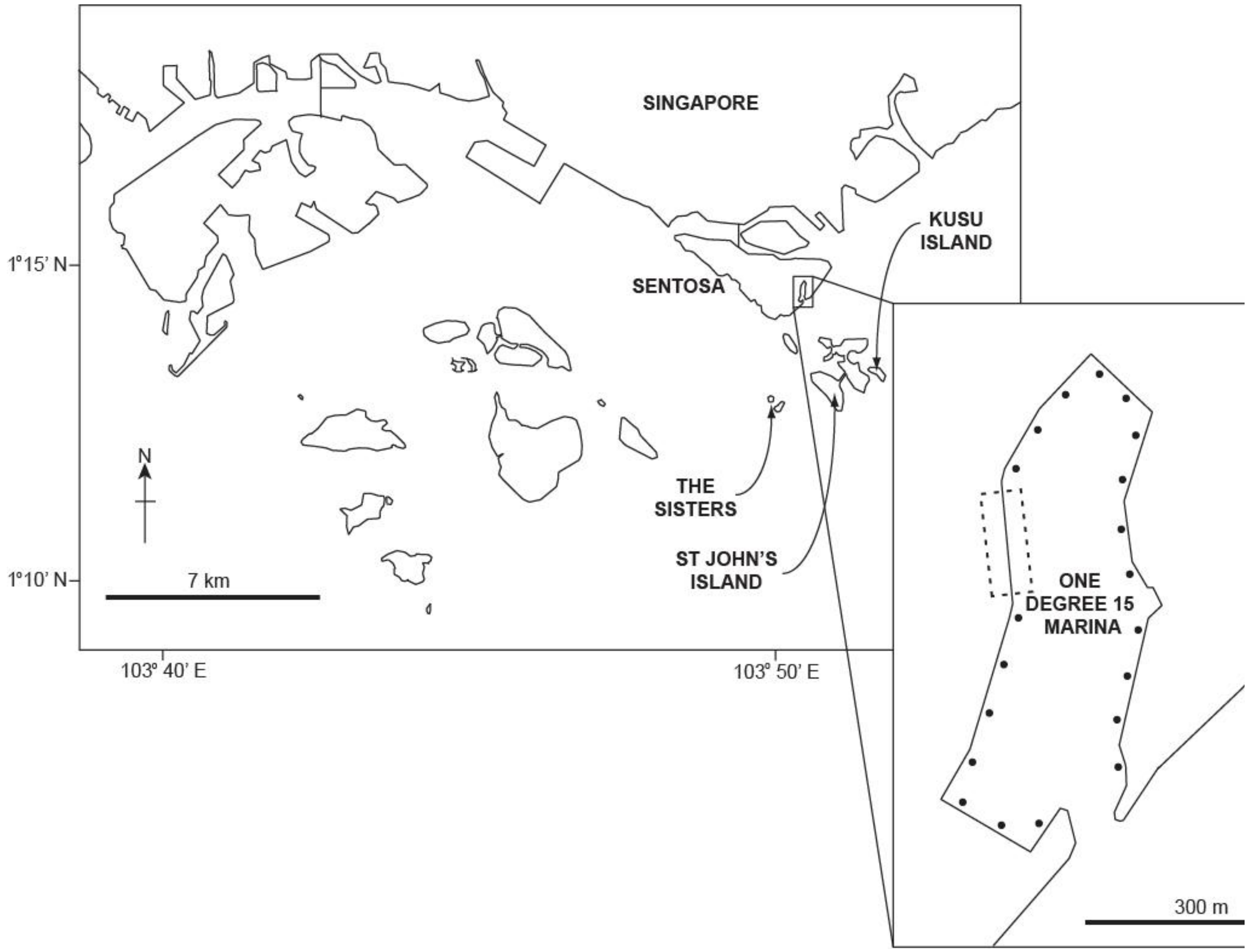

Figure 1. Map of Singapore and the southern islands. (Inset: Sampling sites within ONE^{o}15 Marina. Each black dot represents one transect. The area within the dotted lines was excluded because it consisted of a sandy bottom and had no coral growth.)

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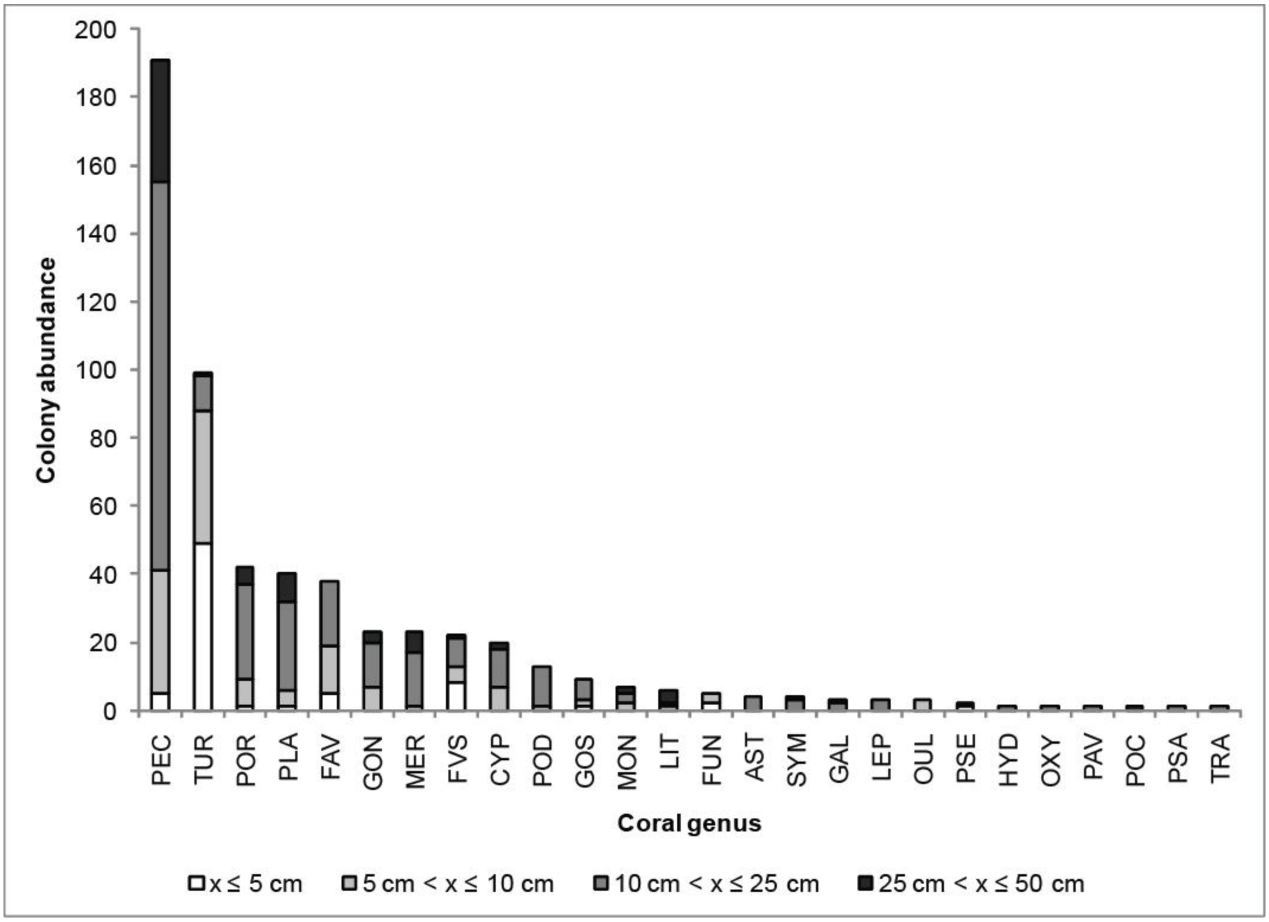

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