Coastal Urbanization Impacts on Biodiversity the Case of Marinas in Singapore

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Abstract
Most of Singapore's coastline has been modified by coastal development with variable influences on marine biodiversity. Marinas are typically designed as a semi-enclosed environment with a complex mix of structures that provide ecological niches throughout the water body. Water flow is inevitably reduced with a possible decline of water quality. This investigation was conducted to determine how marinas affect marine biodiversity. The three marinas studied - Marina at Keppel Bay (MKB), One Degree 15 Marina (ODF), Raffles Marina (RM) - all supported rich biodiversity. The combined 71 faunal taxa (two Classes, 10 Orders and 59 Families) from the soft bottom of all three marinas surveyed using the Ekman grab, were dominated by polychaetes (71.4%) and arthropods (16.7%; mainly crustaceans). The total fish species surveyed using customised traps was 49 from 31 Families, ranging from the very common and abundant fan-bellied filefish (*Monacanthus chinensis*) and eeltail catfish (*Plotosus* spp.), to the less commonly seen fishes such as the starry triggerfish (*Abalistes stellatus*) and estuarine stonefish (*Synanceja horrida*). Reef-associated fish species were more abundant at MKB and ODF, while estuarine species dominated at RM. Epibiotic diversity was evident on the artificial structures in all marinas. The submerged sides of berthing pontoons supported up to 107 taxa, dominated by ascidians, macroalgae and sponges. Corals also recruited naturally with 10 and 22 scleractinian genera established on pontoons at MKB and on seawalls at ODF, respectively. In general, fish and soft bottom macrobenthic abundance and diversity were comparable or higher within the marina compared to the adjacent open water. The findings indicate that modified coastal environments such as marinas can support diverse biological communities.

Keywords: coastal, biodiversity, urbanization, marinas, Singapore

Introduction

Extensive coastal development in Singapore since the 1960s has resulted in the modification of many natural shores to cater to various sectoral demands such as port operations and marine recreation, causing interference with natural physical processes and impacts on the original biodiversity (Chou, 2006). The popular demand for seafront living and marine recreation has also resulted in the transformation of natural shores to human-modified ones such as marinas and coves. Marinas – of which Singapore currently has seven – are built to provide sheltered conditions for the berthing of pleasure craft (Chou et al., 2010). These semi-enclosed environments can compound environmental problems due to the resultant alterations in hydrodynamics and reduction in water quality, and lead to the decline of marine life.

However, the newly created environment with its structural complexity can support and sustain new or modified biological communities. For example, coastal infrastructure such as seawalls have been observed to serve as habitat for various species (Martin et al., 2005; Clynick, 2006), while organisms growing on the surfaces of other structures can serve as food for larger animals (Rilov & Benayahu, 1998). Marinas comprise a complex mix of artificial structures such as berthing pontoons, pilings and seawalls, and thus have the potential to function as new habitats for marine organisms. To investigate how marinas in Singapore affect marine biodiversity, surveys were conducted between 2012 and 2015, focusing on the epibiotic, pelagic and macrobenthic communities in Raffles Marina (RM), One Degree 15 Marina (ODF) and Marina at Keppel Bay (MKB). The open waters up to 150m beyond these marinas were also surveyed.

Macrobenthic diversity

The reduced hydrodynamic energy within the marinas result in the accumulation of a thick layer of sediment on the seabed. Macrobenthic organisms inhabiting the soft bottom sediment within the three marinas, as well as the adjacent open waters of RM (i.e., the Straits of Johor) and MKB (i.e., the Straits of Singapore), were surveyed using an Ekman grab. The area outside ODF was not surveyed as the substrate comprised mainly coarse gravel and cobble. The sediment samples were sieved to extract the animals, which were then brought back to the lab for identification under the microscope.

A total of 71 faunal taxa (two Classes, 10 Orders and 59 Families) were recorded within the marinas. Annelids (71.4%) and arthropods (16.7%; mainly crustaceans) comprised the majority of the macrobenthos, followed by molluscs (6.3%), echinoderms (4.0%), and other animals such as fishes, cnidarians, and platyhelminthes (1.7%). There was a higher abundance of macrobenthic organisms within RM and MKB compared to the adjacent open waters. While faunal diversity was higher within MKB (Shannon Wiener index, $H' = 2.41 \pm 0.30$) than the open waters ($H' = 2.00 \pm 0.64$), that within RM ($H' = 1.93 \pm 0.52$) was lower compared to the surrounding waters ($H' = 2.31 \pm 0.29$).

The dominance of opportunistic polychaetes (i.e. those that thrive in polluted environment) from the families Cirratulidae (Rygg, 1985; Reish & Gerlinger, 1997; Ganesh et al., 2014) and Spionidae (Levin et al., 1996; Chandler et al., 1997; Inglis &

Kross, 2000; Neira et al., 2013) and low Shannon Wiener Index in RM were indicative of depressed environmental quality within the marina, but this was likely a consequence of the much reduced flushing in the Johor Straits. The enclosed nature of RM compounded the situation. This was in contrast to MKB and ODF, where the abundance of opportunistic polychates was not as high (RM: 29.58%; MKB: 9.65%; ODF: 6.40%). The presence of openings at both ends of MKB encouraged water exchange between the marina and the fast currents of the Straits of Singapore, thus helping to maintain acceptable water quality.

Epibiotic diversity

The presence of various structures in marinas such as pilings, berthing pontoons and seawalls served as suitable substrate for the recruitment and colonization of sessile epibiotic communities. Pontoons – as floating structures that demarcate berths for vessels in the marinas – are unique as parts of them are permanently submerged close to the water surface. Yet, information on their potential as habitat for epibiotic organisms in Singapore's urbanized coasts is minimal (Lam & Todd, 2013). The epibiotic assemblages on the sides of the berthing pontoons in all three marinas were photographed *in situ* and the images analyzed using the software CPCe (Kohler & Gill, 2006) for the percentage area occupied by each taxa. In spite of the limited area available for colonization, a total of 107 taxa were recorded on the submerged sides of these pontoons. The epibiotic communities on the pontoons were dominated by macroalgae (43.53%), sponges (8.17%) and ascidians (6.03%). A diverse range of other animals were also recorded, including bivalves, alcyonarians, hexacorallians, hydrozoans, bryozoans, annelids, gastropods, arthropods, and echinoderms. MKB and RM, with up to 50cm of their concrete-coated pontoons submerged, harbored higher richness, 87 and 90 respectively. Only 66 taxa were recorded on ODF pontoons, likely due to their small submerged area (10-15cm). Interestingly, reef-building corals from 10 scleractinian genera (seven families) were recorded on the pontoons at MKB. Corals of the genus *Pocillopora* were the most common. The presence of a constant light source, altered hydrodynamic conditions, and larvae that recruit near the water surface resulted in the creation of a habitat rarely found in nature (Connell, 2000; Holloway & Connell, 2002; Perkol-Finkel et al., 2006, 2008), and it was clear that the shallow floating pontoons in the three marinas facilitated the filter-feeding and photosynthetic processes of the epibiotic communities.

Seawalls are another major component in Singapore's marinas, and consist of large granite rocks piled together to form the periphery of each marina. These are substrates which in recent years have been documented to support the natural colonization of hard corals in Singapore's marinas (Chou et al., 2010; Tan et al., 2012). Additional surveys of scleractinians colonizing the seawalls in ODF showed 22 scleractinian genera (out of Singapore's total of 56; Huang et al., 2009) from 12 families with colonies of the genus *Turbinaria* dominating. There was an increase in diversity and evenness compared to the scleractinian communities surveyed in 2007 within the same marina, when the dominant genus was *Pectinia* (Chou et al., 2010). The current study also recorded corals larger than 50cm diameter, which were not observed in the previous survey. The results indicated that seawalls in marinas have the potential to sustain scleractinian biota in spite of impending global threats, such as the mass bleaching due to sea warming in 2010 which severely impacted large tracts of Singapore's coral reefs (Tun et al., 2011).

Pelagic diversity

Although marinas in subtropical areas are known to function as habitats for diverse fish assemblages (e.g. Clynick et al., 2007), surprisingly little is known about those in tropical marinas. Custom-made fish traps were deployed on the seabed in a catch-and-release program to document the fish communities inhabiting all three marinas. To investigate if the presence of marinas affects nearshore fish communities, the open waters adjacent to RM were also surveyed. No sampling was carried out outside ODF and MKB due to navigational safety reasons.

Forty-nine fish species from 31 families were recorded from within all three marinas. MKB and ODF, both situated in the vicinity of coral reefs, harbored reef-associated fish species (e.g. *Chelmon rostratus*, *Parachaetodon ocellatus*), with the former having the highest diversity of all three marinas. RM was sited in an estuarine strait, and thus supported mainly estuarine species (e.g. *Arius oetik*, *Etroplus siratensis*). Fish diversity measured using the Shannon Wiener index was the least within RM, but catch abundance here was the highest among the three marinas.

Diversity (H') and richness (S) were comparable between fish communities within RM (H' = 1.63; S = 26) and the adjacent open waters (H' = 1.80; S = 24), but abundance within the marina was twice that of the latter. These results differ slightly from other studies which reported that fish communities within heavily modified environments were highly dissimilar to the original or adjacent natural habitats (Wen et al., 2010; Clynick, 2006; Guidetti, 2004). More importantly, the current findings highlight the ability of a tropical marina to aggregate or attract diverse fish communities from the relatively featureless open water vicinity.

Conclusion

The results from this study indicate that rather than being entirely harmful to marine biodiversity, marinas can host altered but reasonable levels of biodiversity. Apart from being sheltered havens for vessels, they also create novel habitats and serve as refugia for marine life. To optimize this role of promoting coastal biodiversity, the proper management of marinas must be complemented with sound scientific inputs and regular monitoring. In Singapore where the coastline has been rapidly urbanized, marinas have functional roles in biodiversity maintenance.

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References

Chandler, G. T., Shipp M. R., & Donelan T. L., (1997). Bioaccumulation, growth and larval settlement effects of sediment- associated polynuclear aromatic hydrocarbons on the estuarine polychaete, *Streblospio benedicti* (Webster). *Journal of Experimental Marine Biology and Ecology,* **213:** 95- 110.

Chou, L. M., (2006). Marine Habitats in One of the World's Busiest Harbours. In: E. Wolanksi (ed.), *The Environment in Asia Pacific Harbours*. Netherlands, Springer. Pp. 377-391.

Chou, L.M., Ng C.S.L., Chan S.M.J. & Seow L.A., (2010). Natural coral colonisation of a marina seawall in Singapore. *Journal of Coastal Development*, **14**:11–17.

Clynick, B. G., (2006). Assemblages of fish associated with coastal marinas in north-western Italy. *Journal of the Marine Biological Association of the United Kingdom*, **86**(04): 847–852.

Clynick, B. G., Chapman M. G. & Underwood A. J., (2007). Effects of epibiota on assemblages of fish associated with urban structures. *Marine Ecology Progress Series*, **332**: 201–210.

Connell, S.D., (2000). Floating pontoons create novel habitats for subtidal epibiota. *Journal of Experimental Marine Biology and Ecology*, **247**:183–94.

Ganesh, T., Rakhesh M., Raman A. V., Nanduri S., Moore S. & Rajanna B., (2014). Macrobenthos response to sewage pollution in a tropical inshore area. *Environmental Monitoring and Assessment*, pp 1-14.

Guidetti, P., (2004). Fish assemblages associated with coastal defence structures in south-western Italy (Mediterranean Sea). *Journal of the Marine Biological Association of the UK*, **84**(3): 669–670.

Holloway, M. G., & Connell, S. D., (2002). Why do floating structures create novel habitats for subtidal epibiota? *Marine Ecology Progress Series*, **235**, 43-52.

Huang, D., Tun K.P.P., Chou L.M. and Todd P.A., (2009). An inventory of zooxanthellate scleractinian corals in Singapore, including 33 new records. *The Raffles Bulletin of Zoology*, **22**:69–80.

Inglis, G. J., & Kross J. E., (2000). Evidence for Systematic Changes in the Benthic Fauna of Tropical Estuaries as a Result of Urbanization. *Marine Pollution Bulletin,* **41**: 367-376.

Kohler, K.E. & Gill S.M., (2006). Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers and Geosciences*, **32**(9): 1259-1269.

Lam, L.M. & Todd P.A., (2013). Spatial differences in subtidal epibiotic community structure in Marina at Keppel Bay, Singapore. *Nature in Singapore*, **6**:197–206.

Levin, L., Caswell H., Bridges T., DiBacco C., Cabrera D., & Plaia G., (1996). Demographic responses of estuarine polychaetes to pollutants: life table response experiments. *Ecological Applications,* **61**: 295-1313.

Martin, D., Bertasi, F., Colangelo, M.A., De Vries, M., Frost, M., Hawkins, S.J., Macpherson, E., Moschella, P.S., Satta, M.P., Thompson, R.C. & Ceccherelli, V.U. (2005) Ecological impact of coastal defence structures on sediments and mobile infauna: evaluating and forecasting consequences of unavoidable modifications of native habitats. *Coastal Engineering*, **52**: 1027–1051.

Neira, C., Levin L. A., Mendoza G. & Zirino, A., (2013). Alteration of benthic communities associated with copper contamination linked to boat moorings. *Marine Ecology,* **35:** 46-66.

Perkol-Finkel S., Zilman G., Sella I., Miloh T. & Benayahu Y., (2006). Floating and fixed artificial habitats: Effects of substratum motion on benthic communities in a coral reef environment. *Marine Ecology Progress Series*, **317**:9–20.

Perkol-Finkel S., Zilman G., Sella I., Miloh T. & Benayahu Y., (2008). Floating and fixed artificial habitats: Spatial and temporal patterns of benthic communities in a coral reef environment. *Estuarine, Coastal and Shelf Science*, **77**:491–500.

Reish, D. J., & Gerlinger T. V., (1997). A review of the toxicological studies with polychaetous annelids. *Bulletin of Marine Science,* **60**:584- 607.

Rilov G. & Benayahu Y., (1998). Vertical artificial structures as an alternative habitat for coral reef fishes in disturbed environments. *Marine Environmental Research*, **45**(4): 431–451.

Rygg, B., (1985). Distribution of Species along Pollution- induced Diversity Gradients in Benthic Communities in Norwegian Fjords. *Marine Pollution Bulletin,* **16:** 469- 474.

Tan, Y.Z., Ng C.S.L. & Chou L.M., (2012). Natural colonisation of a marina seawall by scleractinian corals along Singapore's east coast. *Nature in Singapore*, **5**:177–183.

Tun, K., Chou, L. M., Low, J., Yeemin, T., Phongsuwan, N., Setiasih, N., Wilson, J., Amri, A.Y., Adzis, K.A.A., Lane, D., van Bochove, J.–W., Kluskens, B., Long, N.V., Tuan, V.S., & Gomez, E., (2011). The 2010 coral bleaching event in Southeast Asia–A regional overview In Japan Wildlife Research Center (Ed.), *Status of Coral Reefs in East Asian Seas Region: 2010* (pp. 9-27). Tokyo, Japan: Ministry of the Environment, Japan.

Wen, C. C., Pratchett M. S., Shao K. T., Kan K. P. & Chan B. K. K., (2010). Effects of habitat modification on coastal fish assemblages. *Journal of Fish Biology*, **77**(7): 1674–1687.