RAFFLES BULLETIN OF ZOOLOGY Supplement No. **32**: 85–94
Date of publication: 30 December 2015
http://zoobank.org/urn:lsid:zoobank.org:pub:28B921A9-5C59-46D8-83DF-2A3483BDF1EF

Assemblages and diversity of fishes in Singapore's marinas

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Abstract. Singapore's coastal environment has been extensively transformed by numerous development projects since the 1960s. However, fish diversity remains relatively high despite the extent of anthropogenic modifications to these environments. The diversity and abundance of fishes supported by recreational marinas in Singapore was examined in this study. Custom-made fish traps were deployed at ONE°15 Marina Club (OMC), Marina at Keppel Bay (MKB) and Raffles Marina (RM). A total of 49 species from 31 families were documented. The average number of fishes caught and the Margalef Diversity index were highest in RM while MKB had the highest evenness and Shannon index. Raffles Marina harbored many estuarine species such as *Arius oetik* and *Etroplus suratensis*, while reef-associated species such as chaetodontids and pomacentrids inhabited MKB and OMC. Our findings supplemented ichthyological surveys carried out from 2004 to 2014, which when combined, generated an updated list of over 105 species from 48 families inhabiting recreational marinas in Singapore. The results indicate that marinas in Singapore can support and sustain diverse fish assemblages, and can potentially play important roles for marine conservation in human-modified coastal areas.

Key words. fish diversity, marinas, refugia, modified coastal habitats, Singapore

INTRODUCTION

Coastal areas in Singapore have been extensively transformed over the past six decades. Land reclamation along coastlines significantly modified the country's coastal profile. Consequently Singapore's land area increased from 581.5 km^2 in the 1960s to over 710 km^2 at present (Tun, 2012) with more than 60% of its coastline consisting of seawalls (Lai et al., 2015). As one of the world's busiest ports, over 80% of its waters are designated for shipping activities while the remaining are used for military training, aquaculture and small-scale fisheries, and recreational activities (Chou, 2008). The magnitude and frequency of such resource use cause continued and constant pressure on the physical and biological processes of Singapore's coastal ecosystems. Today, its natural coastal habitats are only 10–54% of those in the 1950s (Yee et al., 2010; Tun, 2012; Yaakub et al., 2014).

Degradation to Singapore's natural coastal habitats resulted in a decrease in abundance but little or no decline in species richness of marine fishes (Chou, 2006). More than 150 fish species from at least 50 families had been recorded from inshore waters up to a depth of 18.5 m in the 1970s (Tham, 1973). In recent years, appreciable biodiversity existed even for heavily impacted localities, as observed from surveys of fish communities in various human-modified marine environments. These ranged from an estuarine strait with heavy sea traffic and intensive land development (Hajisamae & Chou, 2003; Ng et al., 2015), estuarine areas prior to conversion into freshwater reservoirs (Tan et al., 2010; Ng & Tan, 2013), reclaimed sandy shores and reforested mangroves (Jaafar et al., 2004b), recreational beaches (Kwik et al., 2010; Kwik, 2012), and an enclosed waterway in a luxury seafront residential enclave (Chen, 2008). Despite having undergone intense modification and anthropogenic influence, these studies indicate that the inshore habitats of Singapore functioned as nursery grounds for a wide range of juvenile fish species. The importance of coastal assessment and monitoring is evident; these enhance our understanding of the effects of coastal modification on Singapore's inshore fish biodiversity, and improve coastal management practices. This is especially pertinent with the increase in yachting activities and the establishment of facilities such as jetties, coves and marinas to cater to the increasing popularity of seafront living and marine recreational activities (Leonardo, 2008; Chou et al., 2014). In a bid to become a premier marine leisure hotspot, there exist seven marinas for the berthing of pleasure crafts, built over reclaimed land on its northeastern, southern and western coastlines of Singapore (Chou et al., 2010).

The initial stages of marina construction involve the reclamation of natural shorelines or dredging, thus transforming a heterogeneous seabed into one with homogenous silt substrate (Iannuzzi et al., 1996). To attenuate strong wave action, structures are installed in the form of seawalls, pontoons and pilings to create sheltered conditions

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ISSN 2345-7600 (electronic) | ISSN 0217-2445 (print)

for the berthing of smaller recreational and commercial vessels (Hinwood, 1998). Hydrodynamic processes are altered and compounded by boating activities, inevitably resulting in the accumulation of sediment, wastes, nutrients and pollutants within the semi-enclosed environment of marinas. While pontoon and piling surfaces within marinas are increasingly studied as novel habitats for colonisation of epibiotic communities (e.g., Glasby, 1999; Bulleri & Chapman, 2004; Chou et al., 2010), literature sources for fish assemblages are scarce, especially for marinas within the equatorial zone.

Studies on marinas in Singapore have focused on water quality assessments (Goh et al., 2000; Ng et al., 2012), soft bottom benthic communities (Jaafar et al., 2004a), and epibiotic communities colonising the surfaces of berthing pontoons and seawalls (e.g., Jaafar et al., 2004a; Chou et al., 2010; Tan et al., 2012; Lam & Todd, 2013). Using gill, lift, and scoop nets, as well as fish traps, Jaafar et al. (2004a) surveyed the nektonic community at Raffles Marina and reported the presence of 63 species of fishes spanning different trophic levels and niches. The dearth of information on other marinas necessitates a thorough investigation into the role of marinas as a habitat for coastal fishes. The current study aims to document the ichthyofaunal diversity in Singapore's recreational marinas. First, data from published and grey literature was consolidated to produce a species checklist. Fish surveys using traps were then conducted within three marinas to add to the checklist, and spatial variations of fish assemblages inhabiting Singapore's marinas were investigated. Results from this study provide insights into possible factors that drive differences in fish assemblages among the marinas in Singapore.

MATERIAL AND METHODS

Fish sampling was carried out at three marinas on the western and southern coasts of Singapore (Fig. 1). The first, Marina at Keppel Bay (MKB) (1°15'54.67"N, 103°48'46.04"E) is on Keppel Island, south of mainland Singapore. This marina was built in 2007 and spans an approximate area of 7.3 ha. Vertical seawalls bound the north and south of the marina, and openings at the west and east, facilitate tidal exchanges. Vessel traffic is restricted to the west entrance. The second, ONE°15 Marina Club (OMC) (1°14'42.67"N, 103°50'27.49"E) was built over reclaimed land on the east of Sentosa Island and became fully operational in 2005. The marina spans 11.3 ha and its entrance faces the Singapore Strait. The third, Raffles Marina (RM) (1°20'35.57"N, 103°38'3.52"E), was opened in 1994. It is located just south of the bridge connecting Malaysia to Singapore (i.e., Second Link) and is approximately 3.7 ha in size. Vertical concrete seawalls enclose most of the marina except for a single opening facing the west Johor Strait to allow vessel entry and exit.

Surveys were conducted from September to November 2013 in OMC and MKB, and from December 2013 to January 2014 at RM. To document fish assemblages, we deployed unbaited fish traps (known locally as '*bubus*') employing a catch-and-release method within these three marinas. The traps were custom-made from galvanised steel wire and measured 1 m × 0.6 m × 0.3 m with a mesh size of 4 cm and a 20 cm wide entrance. In spite of the apparent species selectivity of the traps, such a sampling method was the most viable option for sites where large-scale conventional sampling (e.g., visual surveys using SCUBA or trawl nets) could not be carried out. Using fish traps such as these were especially suitable for areas with poor visibility (e.g., < 1 m), frequent boat traffic, and limited accessibility. Using a stratified random method, 32 trap deployment sites were each selected at MKB and OMC, and 18 sites were selected at RM. At each deployment site, a set of four traps was placed on the seafloor for three to four days. Upon retrieval of the traps, the fishes were photographed and immediately released, based on a protocol approved by the Institutional Animal Care and Use Committee (protocol number 2013-06310) of the National University of Singapore.

Species richness (*S*), Margalef diversity, Shannon's diversity (H') and Pielou's evenness (J') indices were calculated for the fish assemblages at each study site. The average numbers of fishes caught for each of the three marinas was fourth-root transformed and compared using a one-way analysis of variance (ANOVA) in R 2.14.2 followed by Tukey HSD post-hoc tests. For comparisons of fish communities among marinas, the data was square-root transformed and analysed using the Bray-Curtis similarity index, with the assemblage patterns visualised using non-metric multi-dimensional scaling (nMDS) plots. Differences in fish assemblages were tested with ANOSIM, while dissimilarity percentages of permutations between each site were calculated using SIMPER. All community analyses were carried out using PRIMER software package (v6.1.16; Clark & Gorley, 2006).

Information from surveys specifically carried out in Singapore marinas was consolidated into a checklist from peer-reviewed as well as grey literature (2004 to present), including the current study. All taxa were categorised based on their associated and preferred habitats, with information obtained from Fishbase (Froese & Pauly, 2014). Species names were updated following Kottelat (2013), and fishes that could not be identified to species were not included in the checklist.

RESULTS

We obtained a total of 1160 fishes comprising 49 species from 31 families (Table 1; see Appendix). Seven species were found in all study sites: *Chelmon rostratus*, *Parachaetodon ocellatus*, *Gerres oyena*, *Diagramma pictum*, *Choerodon oligacanthus*, *Monacanthus chinensis* and *Siganus javus*. Several species were unique to only one study site: *Lophiocharon trisignatus*, *Arius oetik*, *Etroplus suratensis*, *Lates calcarifer*, *Lutjanus johnii*, *Ostracion nasus*, *Johnius belangerii* and *Siganus guttatus* were only found at RM; *Cheilodipterus singapurensis*, *Abalistes stellatus*, *Lutjanus russelli*, *Pempheris oualensis*, *Abudefduf bengalensis*, *Dischistodus prosopotaenia*, *Pomacentrus littoralis* and *Scarus ghobban* were only found at OMC; and *Upeneus tragula*, *Nemipterus furcosus*, *Pentapodus setosus*, *Scolopsis*

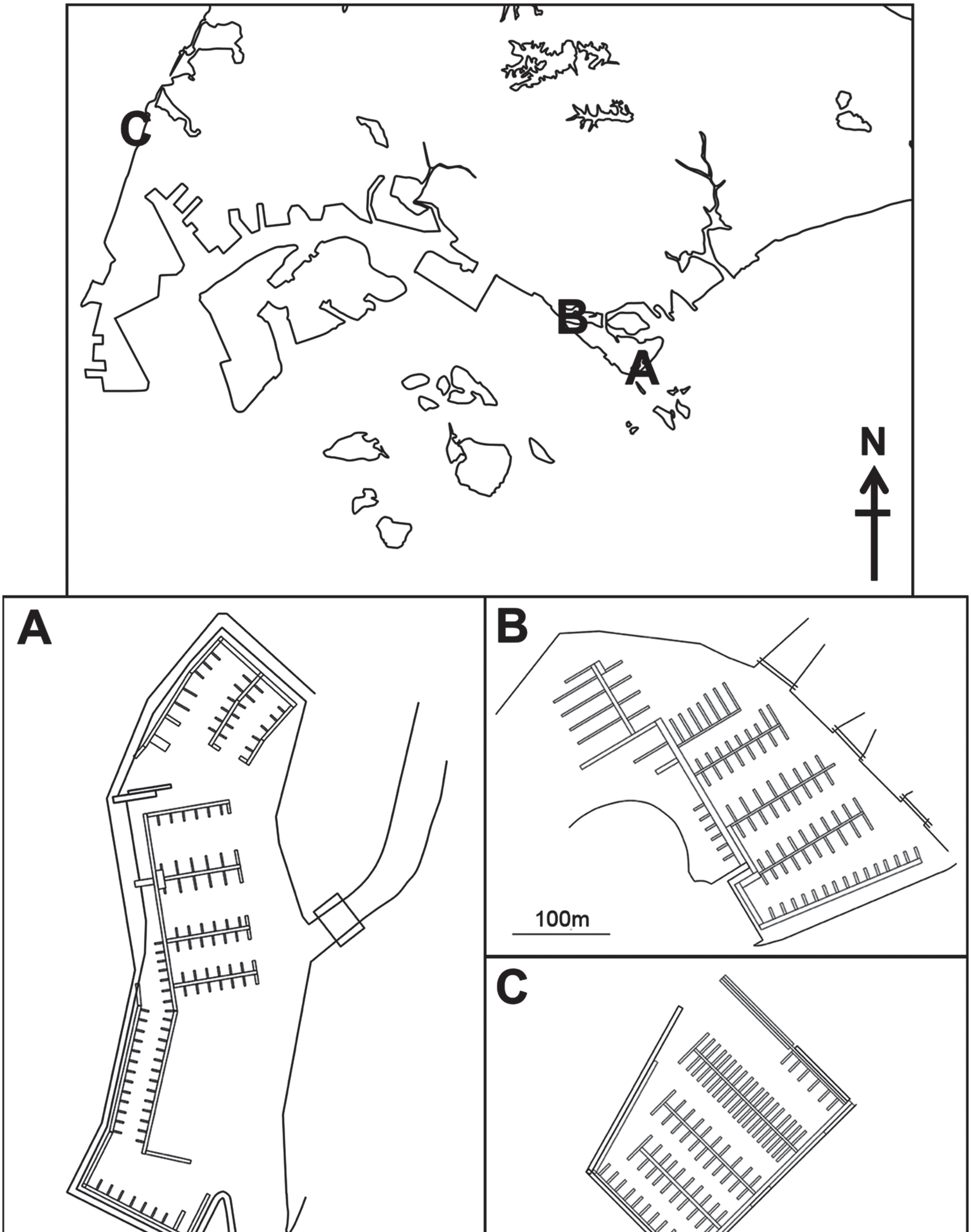

Fig. 1. Location of study sites: A, ONE°15 Marina Club; B, Marina at Keppel Bay; C, Raffles Marina.

Table 1. Average number of fishes caught per trap set, number of species (*S*), number of families (F), Margalef diversity index (D), Shannon's diversity index (H') and Pielou's evenness Index (J') of fishes in ONE°15 Marina Club (OMC), Marina at Keppel Bay (MKB), Raffles Marina (RM).

Site	Average Catch (± s.e.)	S	F	D	H'	J'
OMC	11.2 ± 6.7	29	18	8.15	1.99	0.59
MKB	9.4 ± 8.9	26	16	7.21	2.37	0.73
RM	28.4 ± 10.0	26	19	8.65	1.63	0.50

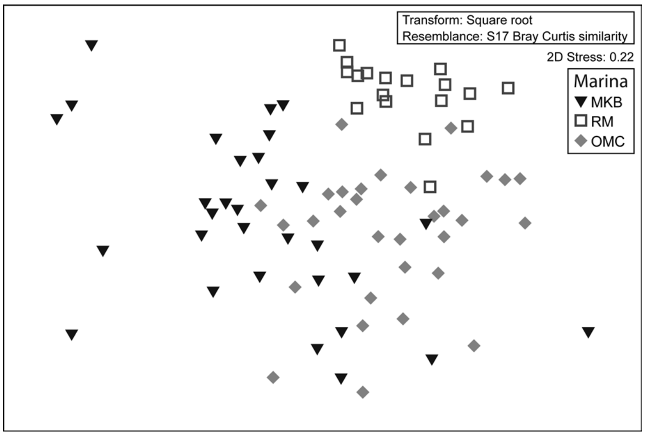

Fig. 2. Non-metric multidimensional scaling plot of fish assemblage by catch at ONE°15 Marina Club (OMC), Marina at Keppel Bay (MKB) and Raffles Marina (RM). ANOSIM Global R = 0.384, p < 0.001.

taeniopterus, *Cymbacephalus nematophthalmus* and *Synanceia horrida* were only found at MKB.

Fish assemblages between marinas. The average number of fishes caught per trap set was significantly different between the marinas (ANOVA: $F_{2,78} = 28.00$, $P < 0.001$). Tukey HSD revealed that the mean catch was obtained in RM (28.44 ± 2.36) was significantly higher than OMC (11.16 ± 1.19) and MKB (9.44 ± 1.58; all mean ± S.E.). While MKB registered the highest Shannon Wiener diversity index (H') and evenness index (J'), RM had the highest Margalef Diversity index, indicating higher species richness per unit effort at the latter site.

Fish assemblages between the marinas were distinct despite sharing common taxa (Fig. 2, 3; ANOSIM Global R = 0.384; $p < 0.001$). The fish assemblage in RM overlapped but was distinct from OMC and MKB (R = 0.481 and 0.493 respectively, p < 0.001), while those in OMC and MKB were barely separable (R = 0.259; p < 0.001). The assemblage in

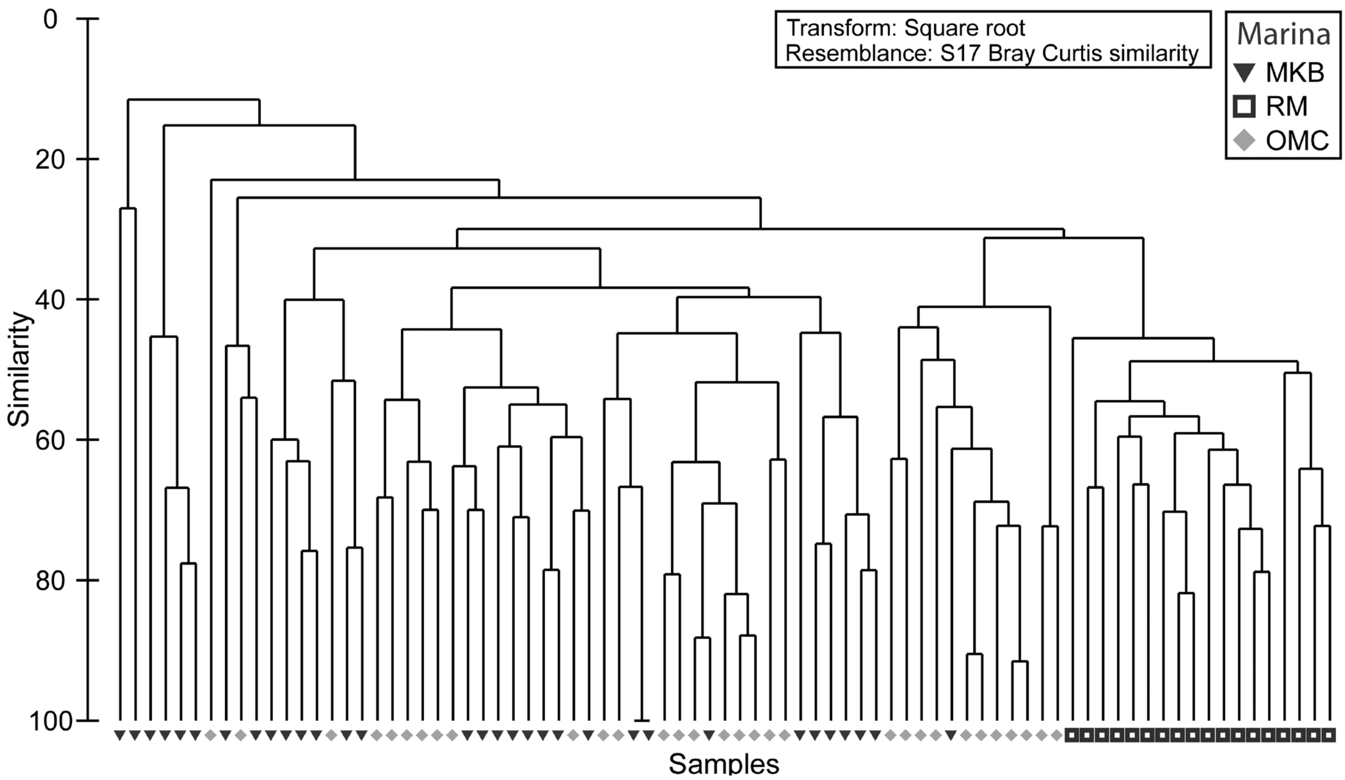

Fig 3. Dendogram for hierarchical clustering of all sampling sites at ONE°15 Marina Club (OMC), Marina at Keppel Bay (MKB) and Raffles Marina (RM), using group-average linking of Bray-Curtis similarities.

Table 2. Average catch (AC) and percentage abundance (%) of species that contributed most to dissimilarities in fish caught at ONE°15 Marina Club (OMC), Marina at Keppel Bay (MKB) and Raffles Marina (RM).

Species	OMC		MKB		RM	
	AC	%	AC	%	AC	%
Monacanthus chinensis	6.1	54.8	2.3	24.2	17.7	62.8
Parachaetodon ocellatus	0.2	1.7	1.6	17.2	0.7	2.4
Etroplus suratensis	–	–	–	–	1.8	6.3
Arius oetik	–	–	–	–	0.9	3.3
Chelmon rostratus	1.2	10.4	0.4	4.3	0.1	0.2
Siganus javus	0.4	3.5	1.7	17.5	1.7	5.9
Choerodon oligacanthus	0.4	3.2	0.8	8.9	0.4	1.6

RM had the highest similarity (53.9%), followed by OMC (40.9%) and MKB (32.1%). Assemblages between marinas were highly dissimilar (67.9–77.6% dissimilarity), primarily due to differences in the abundances of commonly trapped species such as *M. chinensis*, *P. ocellatus*, *E. suratensis*, *A. oetik*, *Ch. rostratus*, *S. javus* and *C. oligacanthus* (Table 2). *Monacanthus chinensis* accounted for 50.1% of total catch and was the dominant species in all three marinas. In RM and OMC, *M. chinensis* comprised 62.8% and 54.8% of all the fishes caught respectively, while in MKB this species comprised 24.2% of total catch. *Parachaetodon ocellatus*, *S. javus* and *C. oligacanthus* were proportionally higher in MKB. *Chelmon rostratus* was most abundant in OMC (1.2 fish caught per set of traps), and least common in RM (0.4 fish caught per set of traps).

Fish checklist. Based on published and grey literature of research carried out in and after 2004, and also including results of the current study, 105 species from 48 families of fishes were recorded from marinas in Singapore (see Appendix I). Fishes found in the three marinas in 2014 were analysed for habitat associations. Fishes associated with an estuarine environment made up 62.5%, 53.9% and 42.9% of those caught in RM, MKB and OMC respectively. Fishes associated with reef habitats made up 92.9%, 76.9% and 70.8% in OMC, MKB, and RM respectively.

DISCUSSION

The floating pontoons, pilings and seawalls which host encrusting and sedentary organisms in the three marinas functioned as artificial reefs and fish aggregating areas (Rilov & Benayahu, 1998; Rilov & Benayahu, 2000; Fabi et al., 2004). The pontoons create overhangs that encourage the presence of shade-preferring fishes, such as *Pempheris oualensis* (Fishelson et al., 1971), while the pilings and seawalls extend throughout the water column, and are able to accommodate species from the water surface to the seabed (Fabi et al., 2004). They attract fishes commonly associated with artificial structures (Hair & Bell, 1992; Connell, 2001), such as *M. chinensis*, which was the most abundant species in all marinas. The presence of schooling and generalist species such as *S. javus*, *E. suratensis*, *Scatophagus argus*, and *M. chinensis* at these marinas suggest that these areas could provide both food sources and shelter for smaller fishes.

While fish communities in modified environments can differ from that of the original or adjacent marine habitats (e.g., Wen et al., 2010), the surrounding environment influences the fish community in the new habitats. Two of these marinas, MKB and OMC are located near to coral reef habitats found south of the mainland. Their proximity to this habitat type facilitated the natural colonisation of up to 26 scleractinian coral genera on the berthing pontoons and seawalls, and created an environment conducive for the development of reef biota at both these marinas (Chou et al., 2010; Lam & Todd, 2013). Consequently, fishes recorded in OMC and MKB are reef-associated, such as, *Choerodon schoenleinii* (Lieske & Myers, 2001), *Choerodon anchorago* (Allen & Erdmann, 2012), *C. oligacanthus* (Mohsin & Ambak, 1996), and various species of pomacentrids. This supports our observation of obligate corallivores such as *C. octofasciatus* (Allen et al., 2003; Cole et al., 2008) occurring only in MKB and OMC, and the higher abundance of other reef-associated chaetodontids, *Ch. rostratus* and *P. ocellatus*, in MKB and OMC.

On the other hand, Raffles Marina is located along the western Johor Strait and adjacent to mangrove and seagrass habitats. No scleractinian corals were observed growing on the pontoons and seawalls (Jaafar et al., 2004a). Fishes present at RM are those adapted to estuarine and turbid waters with fine silt soft-bottomed substrate, such as *O. nasus* (Allen & Erdmann, 2012). The marina also supports generalist species such as *E. suratensis*, a non-native cichlid adapted to brackish waters with a wide diet range and opportunistic feeding modes (Ng & Tan, 2010). Interestingly, the average catch at RM was more than two times that at MKB and OMC. This is in line with studies that documented higher fish biomass or density in reefs adjacent to mangroves and seagrass beds, as compared to those sited far from these nursery habitats (Mumby et al., 2004; Dorenbosch et al., 2005). The combination of calmer waters and a higher density of artificial structures in RM, which is smaller and more compact than MKB and OMC, could also lead to higher catch abundance. The intense use of fish traps at Raffles Marina led to the capture of 12 species previously undocumented by Jaafar et al. (2004a).

Surveys of fish assemblages inhabiting human-modified inshore waters of Singapore have been ongoing for almost two decades. However, with the land area projected to increase to 766 km^2 by the year 2030 (MND, 2013), it is even more pertinent to understand which species can persist in these environments in order to enhance marine conservation and facilitate coastal management strategies. This study demonstrates that many fish species are utilising the marinas and that marinas can potentially assume a supportive role as refugia and breeding areas for fish communities. By minimising pollution and ensuring conditions viable for the re-colonisation of extant biota, marinas are in a unique position to lead and implement marine conservation efforts. With direct access to the sea, marinas are no longer mere users of this resource, but are presented with the opportunity to be a responsible partner in protecting and sustaining it (Chou, 1998).

ACKNOWLEDGEMENTS

We are grateful to members of the Reef Ecology Laboratory, NUS, for their tireless enthusiasm and assistance with field work. Low Inn Zheng and Toh Tai Chong were instrumental to the completion of the study. We thank Kelvin Lim and Tan Heok Hui for assistance in fish identification, and the staff of Raffles Marina, ONE°15 Marina Club and Marina at Keppel Bay for all help rendered in the course of this study. This study was supported by the National Parks Board (grant number R-154-000-557-490).

LITERATURE CITED

Allen GR, Steene R, Humann P & Deloach N (2003) Reef Fish Identification – Tropical Pacific. New World Publications, Jacksonville, United States, 457 pp.

Allen GR & Erdmann MV (2012) Reef fishes of the East Indies. University of Hawaii Press, Perth, Australia, 1292 pp.

Bulleri F & Chapman MG (2004) Intertidal assemblages on artificial and natural habitats in marinas on the north-west coast of Italy. Marine Biology, 145(2): 381–391.

Chen D (2008) The effects of pontoons construction on the fish community in Sentosa Cove. Unpublished Thesis, National University of Singapore, Singapore, 25 pp.

Chou LM (1998) Marinas and marine conservation. Marinas 5 Conference, September 1998, Singapore.

Chou LM (2006) Marine habitats in one of the world's busiest harbours. In: Wolanski E (ed.) The Environment in Asia Pacific Harbours. Springer, Netherlands. Pp. 377–391.

Chou LM (2008) Nature and sustainability of the marine environment. In: Wong TC, Yuen B & Goldblum C (eds.) Spatial planning for a sustainable Singapore. Springer Science+Business Media, Philadelphia, PA. Pp. 169−182.

Chou LM, Ng CSL, Chan SMJ & Seow LA (2010) Natural coral colonization of a marina seawall in Singapore. Journal of Coastal Development, 14(1): 11–17.

Chou LM, Toh KB & Ng CSL (2014) What lies beneath – Biodiversity in Raffles Marina. Nautique Mar/Apr 2014: 12–13.

Clark KR & Gorley RN (2006) PRIMER v6: User Manual. Plymouth Marine Laboratory, Plymouth, United Kingdom. 192 pp.

Cole AJ, Pratchett MS & Jones GP (2008) Diversity and functional importance of coral-feeding fishes on tropical coral reefs. Fish and Fisheries, 9: 1–22.

Connell SD (2001) Predatory fish do not always affect the early development of epibiotic assemblages. Journal of Experimental Marine Biology and Ecology, 260(1): 1–12.

Dorenbosch M, Grol MGG, Christianen MJA, Nagelkerken I & van der Velde G (2005) Indo-Pacific seagrass beds and mangroves contribute to fish density and diversity on adjacent coral reefs. Marine Ecology Progress Series, 30: 63–76

Fabi G, Grati F, Puletti M & Scarcella G (2004) Effects on fish community induced by installation of two gas platforms in the Adriatic Sea. Marine Ecology Progress Series, 273: 187–197.

Fishelson L, Popper D & Gunderman N (1971) Diurnal cyclic behaviour of *Pempheris oualensis* Cuv. & Val. (Pempheridae, Teleostei). Journal of Natural History, 5(5): 503–506.

Froese R & Pauly D (2014) FishBase version 06/2014. www.fishbase.org (Accessed 17 August 2014).

Glasby TM (1999) Differences between subtidal epibiota on pier pilings and rocky reefs at marinas in Sydney, Australia. Estuarine, Coastal and Shelf Science, 48(2): 281–290.

Goh B, Nayar S & Chou LM (2000) The waters in our marinas: does green really mean clean? Marinas 6 Conference, Singapore, 10 pp.

Hair CA & Bell JD (1992) Effects of enhancing pontoons on abundance of fish: initial experiments in estuaries. Bulletin of Marine Science, 51(1): 30–36.

Hajisamae S & Chou LM (2003) Do shallow water habitats of an impacted coastal strait serve as nursery grounds for fish? Estuarine, Coastal and Shelf Science, 56: 281–290.

Hinwood J (1998) Marina water quality and sedimentation. Marinas 5 Conference, Singapore. 4 pp.

Iannuzzi TJ, Weinstein MP, Sellner KG & Barrett JC (1996) Habitat disturbance and marina development: An assessment of ecological effects. I. Changes in primary production due to dredging and marina construction. Estuaries, 19(2): 257–271.

Jaafar Z, Chou LM & Yatiman Y (2004a) Marine ecology of Raffles Marina and a pilot study on bio-remediators to improve its water quality. In: Phang, SM, Chong VC, Ho SC, Noraieni HM and Ooi JLS (eds.) Marine Science into the New Millenium. Malaysia University of Malaya Maritime Research Centre, Kuala Lumpur. Pp. 649–666.

Jaafar Z, Hajisamae S, Chou, LM & Yatiman Y (2004b) Community structure of coastal fishes in relation to heavily impacted human modified habitats. Hydrobiologia, 511(1–3): 113–123.

Kottelat M (2013) The fishes of the inland waters of southeast Asia: a catalogue and core bibiography of the fishes known to occur in freshwaters, mangroves and estuaries. The Raffles Bulletin of Zoology, Supplement 27: 1–663.

Kwik JT (2012) Controlled culling of venomous marine fishes along Sentosa Island beaches: a case study of public safety management in the marine environment of Singapore. The Raffles Bulletin of Zoology, 25: 93–99.

Kwik JT, Chen ZP, Sin TM & Ng PKL (2010) Diel variations and diversity of fish communities along the unreclaimed shallow coastal habitats of Changi Point Beach, Singapore. Raffles Bulletin of Zoology, 58(1): 125–135.

Lai S, Loke L H, Hilton MJ, Bouma, TJ & Todd, P.A (2015). The effects of urbanisation on coastal habitats and the potential for ecological engineering: A Singapore case study. Ocean & Coastal Management, 103, 78–85.

Lam KM & Todd PA (2013) Spatial differences in subtidal epibiotic community structure in Marina at Keppel Bay, Singapore. Nature in Singapore, 6: 197–206.

Leonardo PA (2008) Sail the seas of Southeast Asia – Yachts, clubs and marinas in the latest hot destination. http://www.nbcnews.com/id/24581068/ns/travel-destination_travel/t/sail-seas-southeast-asia/ (Accessed 18 July 2014).

Lieske E & Myers R (2001) Collins Pocket Guide: Coral Reef Fishes – Indo-Pacific and Carribbean. Harper Collins Publishers, London, United Kingdom, 400 pp.

Ministry of National Development (2013) A high quality living environment for all Singaporeans – Land use plan to support Singapore's future population. http://www.mnd.gov.sg/LandUsePlan/e-book/index.html (Accessed 15 July 2014).

Mohsin AKM & Ambak MA 1996. Marine fishes and fisheries of Malaysia and neighbouring countries. University of Pertanian Malaysia Press, Serdang, Malaysia, 744 pp.

Mumby PJ, Edwards AJ, Arias-Gonzalez JE, Lindeman KC, Blackwell PG, Gall A, Gorczynska MI, Harborne AR, Pescod CL, Renken H, Wabnitz CCC & Llewellyn G (2004) Mangroves enhance the biomass of coral reef fish

Ng CSL, Ong LJ & Chou LM (2012) *Lyngbya majuscula* blooms in an enclosed marine environment. EnvironmentAsia, 5(2): 93–98.

Ng HH, Tan HH, Lim KPP, Ludt WB & Chakrabarty P (2015) Fishes of the Eastern Johor Strait. Raffles Bulletin of Zoology, Supplement 31: 303–337.

Ng PX & Tan HH (2013) Fish diversity before and after construction of the Punggol and Serangoon reservoirs, Singapore. Nature in Singapore, 6: 19–24.

Ng TH & Tan HH (2010) The introduction, origin and life-history attributes of the non-native cichlid *Etroplus suratensis* in the coastal waters of Singapore. Journal of Fish Biology, 76(9): 2238–2260.

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.

Rilov G & Benayahu Y (2000) Fish assemblage on natural versus vertical artificial reefs: the rehabilitation perspective. Marine Biology, 136(5): 931–942.

Tan HH, Low ME & Lim KPK (2010) Fishes of the Marina Basin, Singapore, before the erection of the Marina Barrage. Raffles Bulletin of Zoology, 58(1): 137–144.

Tan YZ, Ng CSL & Chou LM (2012) Natural colonisation of a marina seawall by scleractinian corals along Singapore's east coast. Nature in Singapore, 5: 177–183.

Tham AK (1973) Sea fish. In: Chuang SH (ed.) Animal life and Nature in Singapore. Singapore University Press, Singapore. Pp. 202–226.

Tun KPP (2012) Optimisation of Reef Survey Methods and Application of Reef Metrics and Biocriteria for the Monitoring of Sediment-impacted Reefs. Unpublished PhD Thesis. National University of Singapore, 179 pp.

Wen CC, Pratchett MS, Shao KT, Kan KP & Chan BKK (2010) Effects of habitat modification on coastal fish assemblages. Journal of Fish Biology, 77(7): 1674–1687.

Yaakub SM, McKenzie LJ, Erftemeijer PL, Bouma T & Todd PA (2014) Courage under fire: Seagrass persistence adjacent to a highly urbanised city-state. Marine Pollution Bulletin, 83(2): 417–424.

Yee ATK, Ang WF, Teo S, Liew SC & Tan HTW (2010) The present extent of mangrove forests in Singapore. Nature in Singapore, 3: 139–145.

APPENDIX

Appendix 1. Occurrence of fish species of fish species in marinas of Singapore resulting from the current study, as well as grey and published literature from research carried out in and after 2004. Abbreviations used: SC, Sentosa Cove (source: Chen 2008); MKB, Marina at Keppel Bay (source: current study); OMC, ONE°15 Marina Club (source: current study); RM, Raffles Marina (source: Jaafar et al 2004b, denoted with *; current study, denoted with °). + denotes cartilaginous fish. The symbol '×' denotes presence of species in location specified.

Family	Species	Preferred Habitat	Occurrence			
			SC	MKB	OMC	RM
Ambassidae	*Ambassis kopsii* *	Estuary	×			×
	Ambassis vachellii *	Estuary	×			×
Antennariidae	*Lophiocharon trisignatus* * °	Reef				×
Apogonidae	*Apogon amboinensis* *	Estuary	×			×
	Ostorhinchus cyanosoma	Reef	×			
	Apogon hyalosoma *	Estuary; river	×			×
	Ostorhinchus margaritophorus *	Reef				×
	Pristicon trimaculatus	Reef	×			
	Cheilodipterus quinquelineatus	Reef	×			
	Cheilodipterus singapurensis	Reef; seagrass			×	
	Sphaeramia orbicularis *	Reef				×
Ariidae	*Arius oetik* °	Estuary				×
	Arius venosus *	Estuary				×
	Atherina valenciennei *	Estuary				×
Balistidae	*Abalistes stellatus*	Estuary; soft bottom			×	
Batrachoididae	*Batrachomoeus trispinosus*	Reef; estuary; soft bottom		×		
Belonidae	*Strongylura strongylura* *	Mangroves				×
Blenniidae	*Omobranchus ferox* *	Lakes; estuary				×
	Omobranchus zebra *	Estuary				×
Carangidae	*Caranx ignobilis* *	Reef				×
	Scomberoides commersonnianus	Reef; mangroves	×			
Centriscidae	*Aeoliscus strigatus* *	Reef				×
Chaetodontidae	*Chaetodon octofasciatus*	Reef		×	×	
	Chelmon rostratus * °	Rocky shore; reef; estuary	×	×	×	×
	Coradion chrysozonus *	Reef				×
	Parachaetodon ocellatus * °	Reef; soft bottom; seagrass		×	×	×
Cichlidae	*Etroplus suratensis* * °	River; estuary				×
Dasyatidae	*Taeniura lymma* + °	Reef				×
Diodontidae	*Diodon liturosus* *	Reef; estuary				×
Eleotridae	*Butis butis* *	Estuary; river				×
	Butis koilomatodon *	River; estuary				×
Ephippidae	*Platax teira* *	Reef				×
Gerreidae	*Gerres oyena* °	Estuary; reef	×	×	×	×
Gobiidae	*Acentrogobius caninus*	Estuary	×			
	Cryptocentrus cinctus	Sandy bottom	×			
	Drombus triangularis	Mangroves; river	×			
	Exyrias belissimus	Reef; soft bottom	×			
	Exyrias puntang	Estuary; soft bottom	×			
	Istigobius ornatus	Estuary; rocky; reef	×			
	Yongeichthys nebulosus	Estuary; river; reef; soft bottom	×			

Family	Species	Preferred Habitat	Occurrence			
			SC	**MKB**	**OMC**	**RM**
Haemulidae	*Diagramma pictum* [o]	Estuary; reef; soft bottom		×	×	×
	Plectorhinchus chaetodontoides *	Reef				×
Labridae	*Choerodon schoenleinii*	Reef	×	×	×	
	Choerodon anchorago *	Reef; seagrass	×	×	×	×
	Choerodon oligacanthus [o]	Reef		×	×	×
	Halichoeres bicolor	Reef; seagrass; soft bottom	×			
	Halichoeres nigrescens	Rocky shore	×			
Latidae	*Lates calcarifer* * [o]	Estuary; river				×
	Psammoperca waigiensis [o]	Rocky shore; reef; estuary			×	×
Lethrinidae	*Lethrinus lentjan*	Reef; estuary; seagrass; sandy bottom		×	×	
Lobotidae	*Lobotes surinamensis* *	Estuary				×
Lutjanidae	*Lutjanus carponotatus*	Reef		×	×	
	Lutjanus johnii * [o]	Reef; estuary	×			×
	Lutjanus russellii	Rocky shore; reef; estuary		×		
Monacanthidae	*Acreichthys tomentosus* * [o]	Reef; seagrass	×			×
	Anacanthus barbatus *	Reef; estuary				×
	Chaetodermis penicilligerus *	Reef				×
	Monacanthus chinensis * [o]	Estuary; reef; soft bottom	×	×	×	×
	Paramonacanthus choirocephalus *	Reef; soft bottom				×
	Pseudomonacanthus macrurus [o]	Reef; estuary		×	×	×
Monodactylidae	*Monodactylus argenteus* *	Reef; estuary	×			×
Mugilidae	*Ellochelon vaigiensis*	Estuary; reef	×			
Mullidae	*Upeneus tragula*	Estuary; reef		×		
Nemipteridae	*Nemipterus furcosus*	Soft bottom; estuary		×		
	Nemipterus peronii *	Soft bottom				×
	Pentapodus setosus	Soft bottom		×		
	Scolopsis taenioptera	Soft bottom		×		
	Scolopsis vosmeri *	Soft bottom				×
Ostraciidae	*Ostracion nasus* * [o]	Rocky; soft bottom				×
Pempheridae	*Pempheris oualensis*	Reef			×	
Platycephalidae	*Cymbacephalus nematophthalmus* *	Rocky shore; mangroves		×		×
Plotosidae	*Paraplotosus albilabris* [o]	Reef			×	×
	Plotosus canius [o]	Estuary				×
	Plotosus lineatus * [o]	Reef; estuary			×	×
Pomacanthidae	*Pomacanthus annularis* *	Reef				×
Pomacentridae	*Abudefduf bengalensis* *	Reef	×		×	×
	Dischistodus fasciatus	Reef; seagrass	×			
	Dischistodus prosopotaenia	Reef			×	
	Pomacentrus alexanderae	Reef	×			
	Pomacentrus cuneatus	Reef	×			
	Pomacentrus littoralis	Reef			×	
	Pomacentrus tripunctatus *	Reef	×			×
Pseudochromidae	*Congrogadus subducens* *	Reef				×
Scaridae	*Scarus ghobban*	Reef			×	
Scatophagidae	*Scatophagus argus* * [o]	Estuary	×			×
Sciaenidae	*Johnius belangerii* [o]	Estuary				×

Family	Species	Preferred Habitat	Occurrence			
			SC	MKB	OMC	RM
Serranidae	*Cephalopholis boenak* *	Reef				×
	Diploprion bifasciatum *	Reef		×	×	×
	Epinephelus coioides º	Reef; estuary		×	×	×
Siganidae	*Siganus canaliculatus* *	Reef; estuary; rocky shore		×	×	×
	Siganus javus º	Rocky shore; reef	×	×	×	×
	Siganus guttatus * º	Reef; estuary	×			×
Sillaginidae	*Sillago sihama* *	Sandy shore; estuary				×
Synanceiidae	*Synanceia horrida* *	Reef; estuary	×	×		×
Syngnathidae	*Hippichthys cyanospilus* *	Estuary				×
	Hippichthys penicillus *	Estuary				×
	Hippocampus comes	Reef		×	×	
	Hippocampus kuda *	Estuary; reef; seagrass				×
Terapontidae	*Pelates quadrilineatus* *	Estuary				×
	Eutherapon theraps *	Estuary				×
Tetraodontidae	*Arothron immaculatus*	Estuary; seagrass		×	×	
	Arothron reticularis *	Reef; estuary				×
	Dichotomyctere nigroviridis *	Estuary; river				×
Toxotidae	*Toxotes jaculatrix* *	Estuary; river	×			×
Zenarchopteridae	*Zenarchopterus buffonis* *	Estuary; river				×