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Research Article

Urban stormwater ponds in Singapore: potential pathways for spread of alien freshwater fishes

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Abstract

Urban stormwater ponds in Singapore are interspaced among the industrial and residential areas of this highly urbanized country and represent potentially harsh artificial habitats in which freshwater fish communities might be limited to low numbers of just a few hardy species. A recent first-time survey of three large urban ponds in Singapore, however, revealed that the fish communities in these ponds are greater in density and species richness than expected, with a combined richness of 24 species and fish densities ranging from 0.26 to 306.04 fish Ha^{-1}. These fish communities consisted of only alien species, with the dominant species being *Amphilophus citrinellus*. The connectivity of urban stormwater ponds to other freshwater systems in Singapore, including protected catchments with natural stream and swamp habitats that are refuges for native species, could make these habitats hotspots and beachheads for the invasion or spread of alien freshwater fish. This is a cause for concern and raises the need for more stringent regulatory controls of fish releases into these ponds.

Key words: fish diversity; non-native species; artificial ponds; urbanised country

Introduction

The relative importance of natural or man-made ponds has only recently been recognized in many countries (Cereghino et al. 2008). In most countries, such relatively smaller ponds can greatly outnumber larger water bodies (Oertli et al. 2005). Studies on man-made ponds have so far focused primarily on water quality in urban ponds (Shaw et al. 1997; Durant et al. 2004) or on non-native fish species or phytoplankton in peri-urban ponds in temperate countries (Copp et al. 2005; Peretyatko et al. 2007; Peretyatko et al. 2009; De Backer et al. 2010).

The fish communities of urban ponds specifically have received little attention, with only some published studies targeting certain species such as carp or goldfish (Copp et al. 2010; Tarkan et al. 2010). In Singapore, there are limited undeveloped habitats in this urbanized country, with many artificially constructed urban ponds (e.g. retention ponds, aquaculture ponds, landscape or golf course ponds, abandoned granite quarry ponds) inter-spaced throughout the country. An important function of many of the larger urban ponds is to provide stormwater containment or sedimentation areas for drainages around the country (Yeo et al. 2010). A pilot study on urban ponds by the authors indicated that due to their interconnectivity and shared water sources, the physico-chemical nature of these ponds appears relatively similar (unpublished data). Moreover, construction and concretization of these ponds have resulted in similar artificial and harsh environmental conditions (e.g. high turbidity) which would lead us to expect a low abundance or diversity of fish in such habitats.

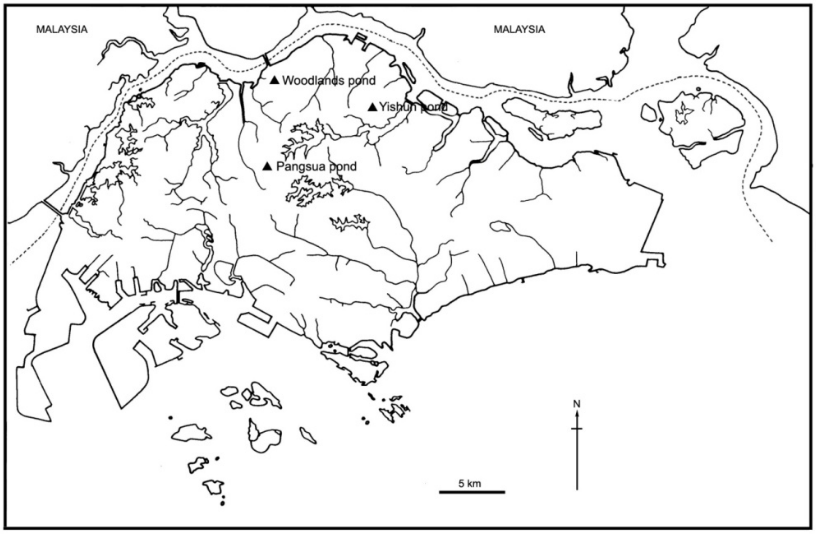

Figure 1. Map of the three urban ponds surveyed in Singapore.

Lentic biodiversity research in Singapore has mostly focused on the larger reservoirs within Singapore (Ng and Tan 2010), with almost no research on the numerous urban ponds (in excess of 60 ponds, pers. obs.) scattered throughout the country, especially with regards to their fish communities. One possible reason for such paucity in urban pond research locally might be the general inaccessibility of these ponds, which are usually found within restricted areas and their jurisdictions, to either private clubs or government bodies (Wee and Corlett 1986). Recently, due to potential urban developments, an opportunity arose to study the fish communities in three of the larger urban ponds. This preliminary assessment of the fish diversity of these ponds could provide a foundation for further and more detailed studies into the many other urban ponds found here to determine their importance and roles as alternative habitats for freshwater fish communities in Singapore.

Methods

Between October and December 2012, three urban ponds in Singapore, Pang Sua pond (1°22′54″ N, 103°45′57″ E), Woodlands pond (1°26′24″ N, 103°46′24″ E) and Yishun pond (1°25′64″ N, 103°50′43″ E) (WGS 84 coordinate system) were sampled monthly (Figure 1). During each sampling occasion (consisting of two days), polyfibre cast nets (4m drop × 12m circumference × 2cm mesh) and traditional metal fish traps (60cm × 40cm × 30cm × 2cm mesh) were used to collect fish samples. On the first day of each sampling occasion, six traps were deployed evenly along the banks of each of the ponds. In addition, 12 cast nettings over two hours were performed around the perimeter of the pond. During the second sampling day, all traps deployed on the previous day were collected after 24 hours. To reduce the chance of recaptures, fish were contained until all net casting or trap collecting for that sampling event were complete. Choice of these methods was based on the extremely soft substrate and large amount of debris in these ponds, which made larger seine nets difficult to deploy. Cumulative species richness plots indicated that all species were captured by the second sampling occasion. All fish caught were identified; enumerated and total lengths (mm TL) measured using a measuring board. With the exception of voucher specimens, all other fish were released back into their respective ponds. The relative abundance of each species caught using cast nets and traps were calculated based on,

$$Relative\ abundance = \frac{Abundance\ of\ species_i}{Total\ abundance\ of\ species} \times 100$$

As sampling effort was similar for all three ponds, comparisons based on fish density were

Table 1. Fish densities of 24 non-native freshwater fish caught at Pang Sua, Woodlands and Yishun ponds between October and December 2012 using cast nets and traps (values in parenthesis indicate area of ponds in Hectares). Shannon Diversity Indices (H') are also indicated for each pond.

Family	Species	Pang Sua (2.4 Ha)	Woodlands (3.0 Ha)	Yishun (3.81 Ha)
Ambassidae	*Parambassis siamensis*	2.08	0.67	-
Cichlidae	*Acarichthys heckelii*	-	11.67	-
	Amphilophus citrinellus	172.50	108.67	306.04
	Amphilophus × *Paratheraps*	-	-	0.26
	Cichla orinocensis	-	1.33	-
	Cichlasoma hybrid	-	-	11.81
	Cichlasoma urophthalmus	-	-	1.31
	Etroplus suratensis	-	-	0.26
	Geophagus altifrons	-	4.67	0.52
	Oreochromis mossambicus	18.75	1.67	4.99
	Oreochromis niloticus	-	-	7.61
	Parachromis managuensis	0.83	-	2.10
	Paratheraps synspilum	3.75	-	1.84
	Tilapia buttikoferi	1.67	-	0.79
Clariidae	*Clarias gariepinus*	0.42	0.33	0.52
Cyprinidae	*Cyprinus carpio*	0.42	-	-
	Dawkinsia filamentosus	-	0.67	-
	Toxobramis houdemeri	-	-	96.06
Eleotridae	*Oxyeleotris marmorata*	0.42	1.00	0.26
Gobiidae	*Pseudogobiopsis oligactis*	-	0.33	-
Lepisosteidae	*Atractosteus spatula*	-	-	0.26
Loricariidae	*Pterygoplichthys disjunctivus*	-	0.67	-
	Pterygoplichthys pardaris	0.42	-	-
Osteoglossidae	*Scleropages formosus*	0.42	-	-
	Shannon Index H'	0.60	0.74	0.91

performed and calculated based on,

$$Fish\ density = \frac{Number\ of\ fish\ caught\ for\ species_i}{Total\ area\ of\ pond\ sampled\ (Ha)}$$

Fish voucher specimens were euthanized using MS-222 in solution and fixed in formalin for one week, before transfer into 75% ethanol for storage and deposition in the Raffles Museum of Biodiversity Research. The total length (TL) of the fish was measured, from tip of upper jaw to tail fin tip. For each pond, diversity was calculated using the Shannon Index,

$$H' = -\sum_{i=1}^{R} p_i \log p_i$$

As data was not normally distributed, a non-parametric one-way Kruskal Wallis analysis of variance tests was performed to compare fish lengths of similar species between the three sites using Statistica 8.0 (StatSoft 2007).

Results

A total of 2,535 fishes comprising 24 non-native species from nine families were captured using both cast nets and traps at the three urban ponds (Table 1). Of the nine families, representatives of cichlids, clariids, cyprinids and eleotrids were found in all three ponds. The same species found in all the three ponds included the Midas cichlid, *Amphilophus citrinellus*, the Mozambique tilapia, *Oreochromis mossambicus* (Peters, 1852), the marbled goby, *Oxyeleotris marmorata* (Bleeker, 1852), and the African sharptooth catfish, *Clarias gariepinus* (Burchell, 1822). Fish density was highest for *A. citrinellus* amongst all species caught across all ponds. Density comparisons of species that were found in all three ponds indicated that highest density of *A. citrinellus* was found at Yishun pond (306.04 fish Ha^{-1}), with slightly lower densities at both Pang Sua and Woodlands

Table 2. Relative abundance (%) and size of 11 fish species caught at Pang Sua Pond between October and December 2012 using cast nets and traps (where TL = total length in mm; s.d.= standard deviation).

Family	Species	n	Relative abundance (%)	Size range (mm)	Mean T.L. (sd)
Cichlidae	*Amphilophus citrinellus*	414	85.5	11–266	122.5 (35.2)
Cichlidae	*Oreochromis mossambicus*	45	9.3	100–304	243 (43.1)
Cichlidae	*Paratheraps synspilus*	9	1.9	61–184	94.3 (38.5)
Parambassidae	*Parambassis siamensis*	5	1.0	50–60	53 (4.5)
Cichlidae	*Tilapia buttifoferi*	4	0.8	94–141	119.8 (19.4)
Cichlidae	*Parachromis managuensis*	2	0.4	184–251	217.5 (47.4)
Clariidae	*Clarias gariepinus*	1	0.2	200	200
Cyprinidae	*Cyprinus carpio*	1	0.2	275	275
Eleotridae	*Oxyeleotris marmorata*	1	0.2	201	201
Loricariidae	*Pterygoplichthys pardalis*	1	0.2	460	460
Osteoglossidae	*Scleropages formosus*	1	0.2	365	365

ponds (172.5 Ha^{-1} and 106.67 Ha^{-1} respectively) (Table 1). This pattern also occurred for the carnivorous *C. gariepinus*, with highest densities recorded at Yishun pond (52.63 fish Ha^{-1}), and lower densities at Pang Sua (41.67 fish Ha^{-1}) and Woodlands (33.33 fish Ha^{-1}) ponds (Table 1). Interestingly, higher densities of *O. mossambicus* were caught at the smaller Pang Sua pond (18.75 fish Ha^{-1}) compared to the larger Yishun (4.99 fish Ha-1) and Woodlands (1.67 fish Ha^{-1}) ponds. Similarly, higher densities of *O. marmorata* were found in the smaller Woodlands (1.0 fish Ha^{-1}) and Pang Sua ponds (0.42 fish Ha^{-1}) compared to Yishun pond (0.26 fish Ha^{-1}) (Table 1). The Shannon Index for each pond was relatively low (H'< 1.0, see Table 1) supporting observations on the numerical dominance of *A. citrinellus* for all ponds.

Within each of the ponds, cichlids were the dominant family consisting of 45.5% of the fish community at both Pang Sua and Woodlands, and 66.6% at Yishun pond (Tables 2, 3 and 4). The most abundant species caught was *A. citrinellus* with relative abundances of more than 70% in all three ponds, which included juveniles to adults for this cichlid species (Tables 2, 3 and 4). A Kruskal Wallis test indicated that there was a significant difference in the average length of *A. citrinellus* from all the ponds ($H_{2,1906}$ = 257.13, $P<0.05$), with the largest *A. citrinellus* found at Woodlands, followed by Yishun and Pang Sua ponds, respectively. Analysis of *O. mossambicus* (the second most commonly found species in all three ponds) found that *O. mossambicus* were largest at Woodlands pond as compared to the smaller specimens caught at Yishun and Pang Sua pond ($H_{2,69}$ = 14.18, $P<0.05$). Overall, the largest fish species caught at both Pang Sua and Woodlands pond was the vermiculated sailfin catfish, *Pterygoplichthys disjunctivus* (Weber, 1991), while the *C. gariepinus* was the largest fish species caught at Yishun pond (Tables 2, 3 and 4). *A. citrinellus* were the smallest fish caught at all three ponds (Tables 2, 3 and 4).

Discussion

The results from this study showed that species richness within the three urban ponds appears relatively low with low diversity indices in all ponds. This was reflected in low species richness and evenness in the three urban ponds. However, overall fish density was higher in the larger urban ponds ranging from 2.52 to 10.54 fish m^{-2} in the smaller to larger ponds respectively. Such fish densities were surprising considering the artificial nature and harsher environmental conditions (e.g. higher turbidity and warmer water temperatures compared to other lentic habitats in Singapore) that have been previously recorded in all three ponds. The results also appear to show that the fish community consisted of introduced species with the dominant species including two feral species (*Amphilophus citrinellus* and *Oreochromis mossambicus*) with established breeding populations (i.e. presence of breeding pits and size classes ranging from juveniles to egg brooding

Table 3. Relative abundance (%) and size of 11 fish species caught at Woodlands Pond between October and December 2012 using cast nets and traps (where TL = total length in mm; s.d.= standard deviation).

Family	Species	n	Relative abundance (%)	Size range (mm)	Mean T.L. (s.d.)
Cichlidae	*Amphilophus citrinellus*	326	82.5	10–190	153.6 (17)
Cichlidae	*Acarichthys heckelii*	35	8.9	55–145	119.4 (17.8)
Cichlidae	*Geophagus altifrons*	14	3.5	54–127	93.9 (24)
Cichlidae	*Oreochromis mossambicus*	5	1.3	304–399	354.2 (41.7)
Cichlidae	*Cichla orinocensis*	4	1.0	270–301	284.3 (13.1)
Eleotridae	*Oxyeleotris marmorata*	3	0.8	255–340	288 (45.6)
Cyprinidae	*Dawkinsia filamentosus*	2	0.5	105–116	110.5 (7.8)
Parambassidae	*Parambassis siamensis*	2	0.5	35–127	81 (65.1)
Loricariidae	*Pterygoplichthys disjunctivus*	2	0.5	423–447	435 (17)
Clariidae	*Clarias gariepinus*	1	0.3	390	390
Gobiidae	*Pseudogobiopsis oligactis*	1	0.3	42	42

Table 4. Relative abundance (%) and size of 15 fish species caught at Yishun Pond between October and December 2012 using cast nets and traps (where TL = total length in mm; s.d.= standard deviation).

Family	Species	n	Relative abundance (%)	Size range (mm)	Mean T.L. (sd)
Cichlidae	*Amphilophus citrinellus*	1166	70.4	16–236	140.9 (26.3)
Cyprinidae	*Toxabramis houdemeri*	366	22.1	95–194	114.6 (8.9)
Cichlidae	*Cichlasoma* hybrid	45	2.7	87–248	169.1 (30.4)
Cichlidae	*Oreochromis niloticus*	29	1.8	180–375	288.6 (43.8)
Cichlidae	*Oreochromis mossambicus*	19	1.1	186–351	270.4 (49.9)
Cichlidae	*Parachromis managuensis*	8	0.5	70–266	161.4 (87.7)
Cichlidae	*Paratheraps synspilum*	7	0.4	126–217	168.7 (30.8)
Cichlidae	*Cichlasoma urophthalmus*	5	0.3	121–168	146.6 (17.5)
Cichlidae	*Tilapia buttikoferi*	3	0.2	120–278	182.3 (84.1)
Clariidae	*Clarias gariepinus*	2	0.1	606–613	609.5 (4.9)
Cichlidae	*Geophagus altifrons*	2	0.1	218–238	228 (14.1)
Cichlidae	*Amphilophus* × *Paratheraps*	1	0.1	203	203
Lepisosteidae	*Atractosteus spatula*	1	0.1	515	515
Cichlidae	*Etroplus suratensis*	1	0.1	73	73
Eleotridae	*Oxyeleotris marmorata*	1	0.1	143	143

adults). It also appeared that larger sized fish for these dominant species were found in the larger urban ponds, this might be attributed to more resources (i.e. food and habitat) available in the larger ponds. A comparison with the non-native fishes found in the reservoirs of Singapore (Ng and Tan 2010) indicated that the majority of species were the same (21 of the 24 caught in urban ponds), with three species unique to the urban ponds, namely the blood parrot cichlid (a hybrid of *Amphilophus* and *Paratheraps*), the black spot barb, *Dawkinsia filamentosus* (Valenciennes, 1844), and Chinese cyprinid, *Toxabramis houdemeri* (Pellegrin 1932) (Lim and Kwik 2012).

While there are regulations and restrictions with regards to accessing these urban ponds, easy but illegal access is possible due to many ponds not having physical barriers and being located within residential areas. This is likely to increase the potential for intentional fish introductions into such habitats by members of the public—a major pathway for introduction of freshwater alien species in Singapore (Ng and Tan 2010; Yeo and Chia 2010). The potential for anthropogenic introduction of even more species (Copp et al. 2005), is also likely to be exacerbated in Singapore with its considerable trade in ornamental and aquarium fish species (Ng et al. 1993). In addition, as many of the waterways within Singapore are linked (Yeo and Lim 2011), urban ponds such as the three currently surveyed could potentially be sources of introductions or further spread of different fish species into the reservoirs where some native fishes are still found (Baker and Lim 2008). This would especially pose a threat for reservoirs in the Central

Catchment Nature Reserve, which are also connected to natural freshwater habitats that serve as refuges for native fish species (Baker and Lim 2008). While the threat of non-native fish spreading from urban ponds might be mitigated by extirpating fish populations in these ponds, this might inadvertently spawn other pest issues which can be of public concern. An example could the emergence of chironomids which can be a nuisance problem (Lin and Quek 2009), which could potentially be limited by insectivorous fish found in these ponds.

The introduction of alien fishes may have direct impacts on native fish including predation, interspecific competition on food and habitat resource, the introduction of diseases and parasites, as well as interfering with the reproduction of native fish (Taylor et al. 1984; Courtenay and Meffe 1989; Arthington 1991; Townsend and McIntosh 1992; Copp et al. 2010). They might also have indirect effects by altering natural habitats, which are essential for maintaining biological processes of native fish (Roberts et al. 1995; Arthington and McKenzie 1997; Baxter et al. 2004). Thus such potential impacts are a cause for concern in Singapore given the large number of introduced fish species, especially with tilapiine fishes such as *O. mossambicus* and *O. niloticus* that are locally abundant, and have been known to have negative impacts on native biodiversity (Canonico et al. 2005). *A. citrinellus,* the dominant species in the surveyed urban ponds, has also established itself in Thailand and Australia (Wilson 2005; Nico et al. 2007), but it is uncertain what impacts this species might have on the native fishes of Singapore if it spreads into reservoirs or natural stream or swamp systems. It is also not clear why this particular species has adapted so successfully to urban pond conditions, though it is possible that such introduced fishes can survive due to their ability to adapt to water conditions to which native fish are more sensitive (Arthington et al. 1990; Moyle and Light 1996; Arthington and McKenzie 1997). Other possible reasons might be attributed to their fast maturation and relatively long life span (Barlow 1983), high level of parental care (Buckley et al. 2010), and their preference for breeding in submerged crevices and rocky embankments (Wootton 1998) which are found along the shores of these urban ponds. As such, it is possible that *A. citrinellus* could potentially survive well in the larger lentic habitats where rocky habitats can also be found. Future comparative studies looking at both inter and intra-specific competition for resources and the reproductive biology of these urban pond fishes might help answer questions on why certain fish species appear to have adapted more successfully than others.

This preliminary study indicates that urban ponds provide a suitable habitat for non-native fish to establish and thrive in. In at least these three urban ponds in Singapore, non-native fish have successfully established themselves, with breeding populations. This should be an impetus for more studies into other urban ponds, which are found throughout this small, urbanized country, and could represent an abundance of potential hotspots or pathways for invasion or spread of non-native fishes in Singapore. This might involve future studies using methods such as otolith microchemistry and stable isotope analysis to look at the trophic relationships and linkages within these ponds. Moreover, this could also have a major impact on current biodiversity and reiterates the importance of some legislative regulatory controls over the release of fishes into the various water bodies in Singapore species.

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