Taiwania **66**(3): 337–344, **2021**
DOI: 10.6165/tai.2021.66.337

Fish communities in urban ponds of southern Taiwan: Assessment for conservation potentials

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(Manuscript received 12 July 2021; Accepted 6 August 2021; Online published 13 August 2021)

ABSTRACT: The objectives of this study are two folded: (1) to record fish composition, and (2) to assess the conservation potentials for native fishes in the urban ponds of southern Taiwan. We selected 18 urban ponds in Kaohsiung and Pingtung areas as the sampling sites. Sampling work lasted from October 2019 to March 2020, and four landscape features and 16 environmental variables were measured. Fish sampling was conducted by 10 cast nets per pond, and oral surveys and harvest checking with anglers were performed, ensuring our collections covered the majority of fish composition in each pond. With the exception of one pond where no fish was collected, 20 fish species, including 15 exotic species and five native ones, were recorded from 1,189 individuals in 17 ponds. Both common and near-threatened native species were found, indicating that the urban ponds were able to conserve and support the populations of native and threatened fishes. The first five years after establishing the urban ponds are the critical period for native fishes to be sustained based on a negative correlation between the established ages of ponds and number of native fishes. By integrating a negative correlation between existence ages of ponds and number of native fishes as well as both positive correlations between NO_3-N concentration with total fish species and exotic fish species, we hypothesize that increasing nutrient concentration as the pond aged, possibly the consequence of domestic sewage and excretion of exotic fishes, may enhance the surviving prospects of exotic fishes in the urban ponds of southern Taiwan.

KEY WORDS: Conservation potentials, exotic fish, fish community, native fish, southern Taiwan, urban ponds.

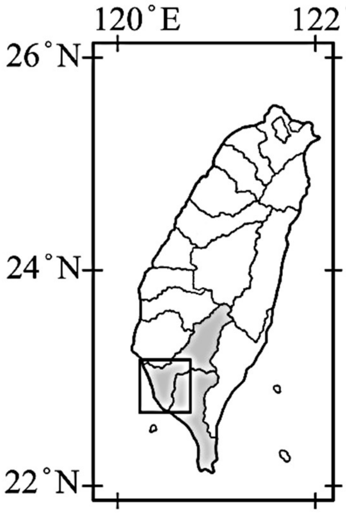
INTRODUCTION

Urbanization has been predicted to be the greatest threat to the loss of biodiversity in the 21st century (Sala *et al.,* 2000). Many studies have centered on assessing the diverse response of terrestrial taxa and habitats to urbanization, but few explored the impacts of urbanization on freshwater organisms and habitats, especially on small lentic systems (Hill *et al*., 2017).

In the late 19th to early 20th centuries, estimated 50-70% ponds were lost worldwide due to urbanization and intensification of agriculture (Wood *et al*., 2003). Similar situation also occurred in Taiwan, with nearly 10,000 agricultural ponds found in Taoyuan County in the past, of which only 3,800 ponds remained, and 84.6% of the pond's surface areas had vanished (Fang *et al*., 2009; Fang *et al*., 2016).

Owing to the decline of natural ponds, artificial and urban ponds are gradually increasing. In Europe, recommendations to build more artificial and urban ponds to conserve aquatic biodiversity are growing (Hassall, 2014), Similarly, in Kaohsiung City, Taiwan, 19 urban wetlands and stormwater ponds have been built since 2001 (Water Resources Bureau 2020). Hassall (2014) indicated that fish diversity is scarcely investigated in the urban ponds, so he proposed that more researches should be applied because fishes are key driver of ecosystems functioning.

More attention has recently been paid to the conservation of freshwater biodiversity and invasion of exotic fishes in urban ponds (Hill *et al*., 2017). After reviewing 279 publications for promoting biodiversity in urban ponds, Oertli and Parris (2019) concluded that urban ponds could support threatened native species of mammals, odonata, amphibians, and reptiles, but fish was not mentioned. With limited information available in Asia, results of studies on ethnic fish composition in urban ponds of Taiwan and other countries have been varied. Kwik *et al*., (2013) noted that 24 fishes, mainly Cichlidae, collected from three urban stormwater ponds were all exotic species in Singapore. In 2003, both native and non-native fishes, specifically eight native species and nine exotic species, were listed in the Lotus Pond, Kaohsiung City, Taiwan (Liang and Chen, 2003). According to a survey conducted from 2012 to 2020, Huang *et al*., (2020) stated that a mixture of exotic and native fishes was observed in the Longluan Lake of Kenting National Park of southern Taiwan. Based on these documentations in Taiwan, we hypothesized that urban ponds in southern Taiwan can support native fishes.



Sites	Codes
1. Dian Bao River Detention Pond A	DBSPA
2. Dian Bao River Detention Pond B	DBSPB
3. Qianfengzi Detention Pond	CFGP
4. Ecological Pond, National University of Kaohsiung	UKEP
5. East Lake, National University of Kaohsiung	UKEL
6. Shilongxi Detention Pond	SLSP
7. Neiweipi Cultural Park	LWPW
8. Banping Lake	BPLW
9. Jhouzai Wetland	GOGW
10. Chaishan Park Detention Pond	CSEP
11. Central Park	CPDP
12. BaoAn Wetland	BSWP
13. Niaosong Wetland	LSWL
14. Baoye Detention Pond	BYEP
15. Shanzaidingku Detention Pond	STGP
16. Fongshan Canal	FSGP
17. Old Iron Bridge Wetland	GTCW
18. Liudui Hakka Cultural Park	LDPP

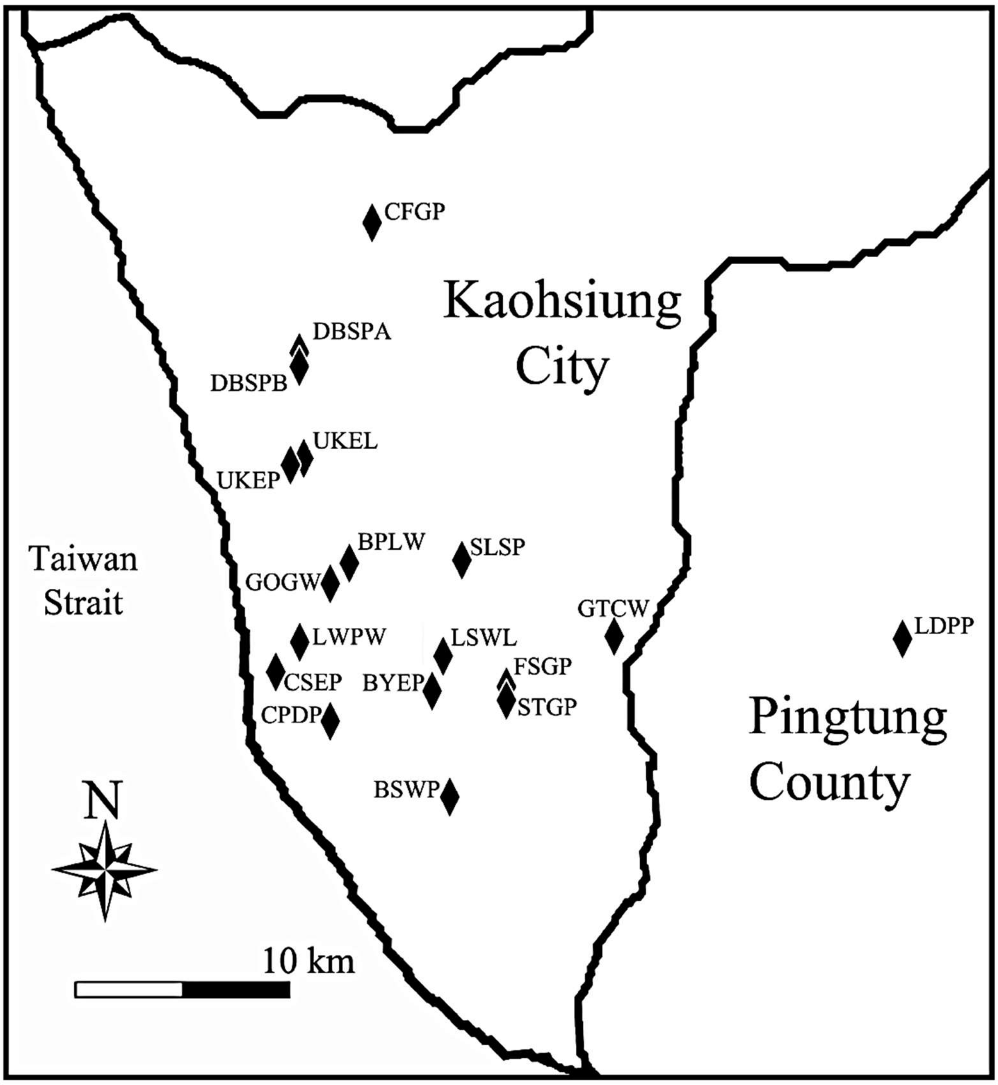


Fig. 1. Locations, full names, and abbreviation codes of 18 sampled urban ponds.

Table 1. Background and Landscape factors of 18 sampled urban ponds in Kaohsiung and Pingtung areas.

Sites	Code	Established Ages (Years)	Shore Perimeter (m)	Surface Area (m^2)	Estimated Human Population within 1 Km^2 radius
1. Dian Bao River Detention Pond A	DBSPA	8	933	28,274	6,709
2. Dian Bao River Detention Pond B	DBSPB	6	798	30,087	4,686
3. Qianfengzi Detention Pond	CFGP	7	1384	115,128	2,446
4. Ecological Pond, National University of Kaohsiung	UKEP	17	266	2,861	8,345
5. East Lake, National University of Kaohsiung	UKEL	17	366	4,760	8,345
6. Shilongxi Detention Pond	SLSP	7	792	18,209	7,492
7. Neiweipi Cultural Park	LWPW	20	1190	27,096	52,450
8. Banping Lake	BPLW	14	857	12,213	23,071
9. Jhouzai Wetland	GOGW	17	671	21,915	35,668
10. Chaishan Park Detention Pond	CSEP	3	711	5,982	18,524
11. Central Park	CPDP	13	437	6,294	47,235
12. BaoAn Wetland	BSWP	7	548	4,340	20,738
13. Niaosong Wetland	LSWL	20	495	10,724	16,654
14. Baoye Detention Pond	BYEP	8	200	1,716	79,439
15. Shanzaidingku Detention Pond	STGP	7	677	16,220	25,933
16. Fongshan Canal	FSGP	3	592	11,663	17,500
17. Old Iron Bridge Wetland	GTCW	18	504	10,850	4,427
17. Liudui Hakka Cultural Park	LDPP	3	390	8,241	947

Thus, the objectives of this study are two-folded: (1) to record fish compositions; and (2) to assess the conservation potentials for native fish in the lentic habitats of urban environments of southern Taiwan.

MATERIALS AND METHODS

Pond background and landscape factors

We selected 18 urban ponds in southern Taiwan to collect fish samples, including 17 in Kaohsiung City and one in Pingtung County (Fig. 1). All selected ponds were not connected, and all of them were converted from terrestrial domains to lentic habitats except the NiaoSong Wetland, previously a detention pond of Taiwan Water Corporation.

Four landscape factors, including established ages, shore perimeter, surface area, and estimated human population within a radius of one kilometer of each pond, were calculated for each pond (Table 1). These factors were calculated by the ortho-rectified photos from Aerial Survey Office (ASO) of Taiwan with the spatial resolution of 1 m. In terms of human population estimations surrounding each pond, we set the center at each sampling pond and 100 m buffer zones to cover the aquatic region; and a radius of 1,000 m was created outside of the buffer zone for measurement.

Fish sampling and environmental measurements

The fish sampling period took place in the dry season from October 2019 to March 2020 (Central Weather Bureau, 2021). During the sampling period, the worst drought in 56 years occurred within the island (Central Weather Bureau, 2021). Fish samples were collected by cast nets (radius: 240 cm, mesh size: 2 cm). Compared to the rainy season, fish samplings were easier to operate, and more species and individuals were expected to be recorded during the period of lower water level in dry season. Fish collection in each pond was carried out by 10 cast nettings on the open water region along the pond perimeter for 180 minutes. Individual cast netting was made 5 to 25 m apart to avoid the regions with dense aquatic vegetation. In the beginning, fish traps were designed and placed in the sampled ponds to supplement fish collections, but these traps were frequently removed or lost by unknown reasons, making the sampling method invalid. Instead, oral surveys with anglers and checking their harvests were both in place to verify that our collections included the majority of fishes and to supplement the sampling record from cast netting.

Table 2. The ranges and means (± SE) of environmental measurements in 18 sampled urban ponds from October 2019 to March 2020.

Environmental Measurement (unit)	Mean ± SE	Range
Sampled Depth (cm)	31.96±11.98	11.07–40.05
Water Temperature(℃)	26.70±1.52	24.74–30.69
Conductivity (mS/cm)	0.94±0.77	0.30–3.57
Turbidity (TDS)	0.60±0.50	0.19–2.31
Dissolved Oxygen (mg/L)	4.69±2.13	1.09–8.83
pH	8.21±0.67	7.15–9.33
COD (mg/L)	48.50±29.98	11–140
BOD (mg/L)	7.89±9.74	2.15–39.10
Suspended Solids (mg/L)	36.93±27.68	7.75–110
Chlorophyll a (ug/L or mg/m^3)	5.30±6.17	0.44–21.86
Turbidity (NTU)	33.13±19.49	2.24–86.72
NH_3-N (mg/L)	1.34±2.68	0.03–11.00
NO_2--N (mg/L)	0.09±0.26	0.00–1.13
NO_3--N (mg/L)	0.28±0.53	0.01–2.08
Hardness (mg/L as $CaCO_3$)	358.56±76.19	146–486
Total Phosphate (mg/L)	0.54±0.38	0.24–1.53

Table 3. Occurrence frequency and total individuals of 20 recorded fish species in 18 urban ponds

Family	Scientific Name	Na(native) / Ex(exotic)	Occurrence Frequency	Occurrence Frequency (%)	Total Individuals	Total Individuals (%)
Ambassidae	*Parambassis siamensis*	Ex	1	5.6	4	0.3
Centrarchidae	*Micropterus salmoides*	Ex	1	5.6	1	0.1
Channidae	*Channa maculata*	Na	0	0.0	0	0.0
	Channa micropeltes	Ex	0	0.0	0	0.0
	Channa striata	Ex	2	11.1	2	0.2
Cichlidae	*Amphilophus citrinellus*	Ex	13	72.2	186	15.6
	Cichla ocellaris	Ex	1	5.6	6	0.5
	Cichlasoma managuense	Ex	3	16.6	9	0.8
	Oreochromis sp.	Ex	17	94.4	824	69.3
Cyprinidae	*Carassius auratus* (cultured)(Shubunkin)	Ex	1	5.6	2	0.2
	Carassius auratus	Na	8	44.4	33	2.8
	Carassius cuvieri	Ex	6	33.3	22	1.9
	Chanodichthys erythropterus	Na	4	22.2	4	0.3
	Culter alburnus	Ex	1	5.6	14	1.2
	Cyprinus carpio carpio	Na	3	16.6	5	0.4
	Cyprinus rubrofuscus	Ex	3	16.6	3	0.3
	Hemiculter leucisculus	Na	3	16.6	8	0.7
	Hypsibarbus pierrei	Ex	5	27.7	13	1.1
Loricariidae	*Pterygoplichthys pardalis*	Ex	5	27.7	12	1.0
Osphronemidae	*Trichogaster trichopterus*	Ex	7	38.8	41	3.4

A total of 16 environmental measurements were done in each pond (Table 2). Before the net casting, 10 water depths were recorded with a wooden graduated scale in the wading region. Five water quality variables, including water temperature (ºC), pH, conductivity (mS/cm), total dissolved solids (mg/L), and dissolved oxygen (mg/L), were measured on site with a Horiba U-20 meter for each pond. For each pond, two water samples were collected with 1 L water bottles, and 10 water quality measurements were conducted in the laboratory, including COD (mg/L), BOD (mg/L), suspended solid (mg/L), chlorophyll a (ug/L), turbidity (NTU), NH_3-N (mg/L), NO_2-N (mg/L), NO_3-N (mg/L), hardness (mg/L), and total phosphate (mg/L).

Data analysis

Collected fishes were identified to species, and each species was divided into ethnic groups of native or exotic species based on Chen *et al*., (2010). The total number of fish species was recorded for each pond, with occurrence frequency for each species. Total individuals and proportional individuals by species as well as by native and exotic species were calculated.

Spearman's rank-order correlation was performed to assess the associations between total fish species and individuals with four landscape factors and 16 environmental variables. The correlations between total species, total individuals, and proportional individuals of native and exotic fish species with four landscape factors and 16 environmental measurements were also executed by Spearman's rank-order correlation.

RESULTS

Landscape factors

The established ages of sampled ponds range from three to 20 years, with an average of 10.8 years (Table 1). The average pond area is 18,698 m^2, varying from 1,716 to 115,128 m^2. The average shore perimeter of selected ponds is 656.2 m, ranging from 200 to 1,384 m. The human population within 1 km^2 of sampled ponds is 946 to 79,438 persons, with an average of 21, 144 individuals.

Environmental measurements

The mean depth of the sampled locations ranged from 11.1 to 40.1 cm, with an average of 32.0 cm (Table 2). The water quality measurements of 18 urban ponds varied. Six degrees of difference in water temperature was present among ponds over the sampling period. The conductivity and total dissolved solids were highly variable, and similar condition was observed in suspended solids, chlorophyll a, and turbidity. The pH indicated low alkalinity with low to adequate dissolved oxygen in these ponds. The COD ranged from 11 to 140 mg/L, and the BOD from 2.1 to 39.1 mg/L. Despite high values of nitrate-nitrogen and PO_4 in a few ponds, most showed lower than 2 mg/L in nutrient concentration during the dry season.

Fish species and individuals

A total of 1,189 fishes, including 50 native fishes and 1,139 exotic fishes, of 20 species belonged to seven families, were found in 17 of the 18 sampled urban ponds (Tables 3 and 4). Among the 20 species, five native and

Table 4. Recorded total fish species in 18 sampled urban ponds. Total and proportional numbers and individuals of native and exotic fish species are also listed. The abbreviation codes of ponds are listed in Table 1.

Code	Total Species	Species (%)		Total Individuals	Individuals (%)	
		Native	Exotic		Native	Exotic
DBSPA	3	1 (33.3)	2 (66.7)	11	3 (27.3)	8 (72.7)
DBSPB	3	2 (66.7)	1 (33.3)	7	2 (28.6)	5 (71.4)
CFGP	5	1 (20.0)	4 (80.0)	42	12 (28.6)	30 (71.4)
UKEP	6	1 (16.7)	5 (83.3)	158	1 (0.6)	157 (99.4)
UKEL	0	0	0	0	0	0
SLSP	5	2 (40.0)	3 (60.0)	11	2 (18.2)	9 (81.8)
LWPW	5	1 (20.0)	4 (80.0)	69	2 (2.9)	67 (97.1)
BPLW	6	0 (0.0)	6 (100.0)	42	0 (0.0)	42 (100.0)
GOGW	6	1 (16.7)	5 (83.3)	50	12 (24.0)	38 (76.0)
CSEP	3	0 (0.0)	3 (100.0)	82	0 (0.0)	82 (100.0)
CPDP	2	0 (0.0)	2 (100.0)	4	0 (0.0)	4 (100.0)
BSWP	9	2 (22.2)	7 (77.8)	281	3 (1.1)	278 (98.9)
LSWL	3	0 (0.0)	3 (100.0)	9	0 (0.0)	9 (100.0)
BYEP	5	0 (0.0)	5 (100.0)	69	0 (0.0)	69 (100.0)
STGP	6	1 (16.7)	5 (83.3)	26	1 (3.8)	25 (96.2)
FSGP	8	3 (37.5)	5 (62.5)	57	3 (5.3)	54 (94.7)
GTCW	2	0 (0.0)	2 (100.0)	79	0 (0.0)	79 (100.0)
LDPP	7	3 (42.9)	4 (57.1)	192	9 (4.7)	183 (95.3)
Total				1189	50 (4.2)	1139 (95.8)
Mean ± SE	4.7±2.3	1.0±1.0 (18.5±19.4)	3.6±1.8 (76.0±26.7)	66.1±74.8	2.7±3.9 (8.1±11.3)	63.2±74.1 (86.4±24.3)

15 exotic species were found. Of the 20 species, 18 were collected in the ponds, and two were based on the survey of the anglers (native *Channa maculate* and exotic *Channa micropeltes*).

Collected species in each pond ranged from 0 to 9, with an average of 4.7 ± 2.3 species/pond (Table 4). The average number of collected exotic fishes (3.6 ± 1.8 species/pond; 76.0 ± 26.7%) is 3.6 times by number and over 4 times greater by proportion than native fishes (1.0 ± 1.0 species/pond; 18.5 ± 19.4%).

Total collected fish individuals from each pond ranged from 0 to 281, averaging 66.1 ± 74.8 individuals/pond (Table 4). The abundance of native species (2.7 ± 3.9 individuals/pond; 8.1 ± 11.3%) is 23.4 times lower by number and 10 times lower by proportion than exotic fishes (63.2 ± 74.1 individuals/pond; 86.4 ± 24%).

Occurrence frequency

Of the five native fishes, the most common species was *Carassius auratus*, appearing in eight urban ponds (Table 3). The other three collected native fishes, *Hemiculter leucisculus*, *Chanodichthys erythropterus*, and *Cyprinus carpio carpio*, were found, respectively, in 5, 4, and 3 ponds. Based on angler harvest, a native fish, *Channa maculata*, was identified in Niaosong Wetland. Among the five native fishes, only *C. auratus* exceeded 30 individuals, while fewer than 20 individuals were collected for the other four species.

Among the 15 exotic fishes, *Oreochromis* sp. was the most common one occurring in 17 (94.4%) urban ponds, with 824 (69.3%) individuals captured (Tables 3 & 4). *Amphilophus citrinellus* appeared as the second most widely distributed species, in 13 (72.2%) ponds, with 186 (15.6%) individuals sampled. The sampled individuals of the other 13 exotic species comprised fewer than 50 individuals. *Trichogaster trichopterus*, *Carassius cuvieri*, *Pterygoplichthys pardalis*, and *Hypsibarbus pierrei* appeared in 7, 6, 5, and 5 ponds, respectively. *Channa micropeltes* was recorded by one angler, and only found in the Niaosong Wetland, while the other eight exotic fishes were collected in three or fewer ponds each.

Correlation with landscape factors and environmental measurements

Significant negative correlation is present between the established years of urban ponds and native fish species (Spearman's ρ= -0.57, $p < 0.05$; Fig 2). The number of total fish species (Spearman's ρ= -0.76, $p < 0.01$) and exotic fish species (Spearman's ρ= -0.70, $p = 0.01$) are significantly and positively correlated with NO_3-N concentration in the urban ponds.

DISCUSSION

Water quality

According to the *Waterbody Classification and Water Quality Criteria of Surface Water* (WCWQSW) for Taiwan, one to five levels of water quality groups for surface waterbodies were used, and their suitable usages were sequentially assigned, such as swimming, aquaculture, industry, irrigation, and environmental protection (Law & Regulation Database, 2020). In the WCWQSW, eight of 16 water quality measurements, including pH, conductivity, dissolved oxygen, BOD, suspended solids, NH_3-N, NO_3-N, and total phosphate, were adopted in this study, and the criteria of five levels are separately stated. We selected the water quality criteria of the 5th level, the lowest criteria for ecological conservation, in order to determine the current environmental status of urban ponds during the dry season in Taiwan.

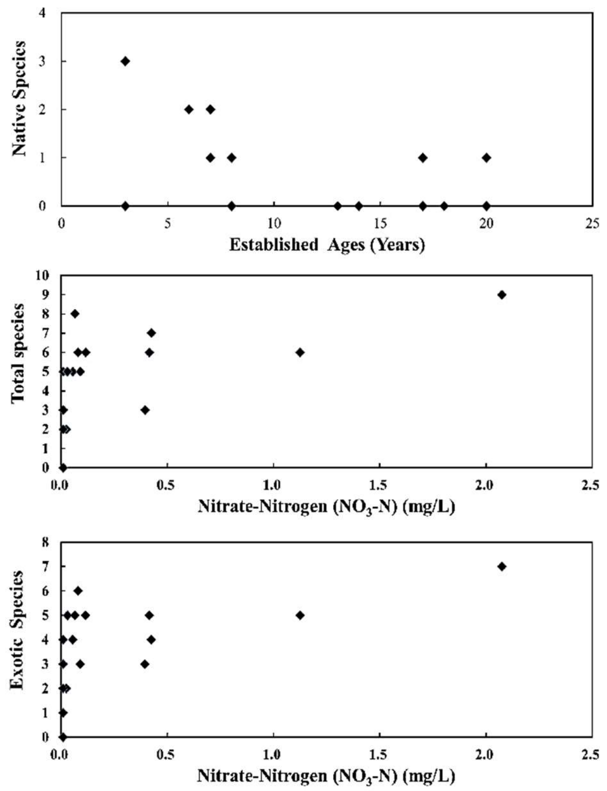


Fig. 2. Correlations between the number of native species and established ages (top), between the number of total species and nitrate-nitrogen concentration (middle), and between the number of exotic species and nitrate-nitrogen concentration (bottom) in the 18 sampled urban ponds.

Weak to medium alkalinity was commonly shown, based on mean and range of pH value. Despite NO_3-N concentration and mean values of dissolved oxygen and suspended solids matching the 5^{th} level criteria, the other four measurements, including conductivity, BOD, NH_3-N, and total phosphate, displayed greater values than the minimum criteria for ecological conservation (the 5^{th} level criteria: dissolved oxygen 2 mg/L, BOD 4 mg/L, suspended solids 100 mg/L, conductivity 0.75 mS/cm, pH 6.0-9.0, NO_3-N 10 mg/L, NH_3-N less than 0.3 mg/L, total phosphate 0.05 mg/L) (Law & Regulation Database, 2020). Despite the low frequency of our water quality sampling, it was conducted during an extreme drought and should reflect the water quality of these urban ponds under extreme environmental conditions. These observations imply that the current environmental status of the urban ponds in the dry season of southern Taiwan may not be suitable for minimum ecological conservation, with low to medium alkalinity, high conductivity, and high nutrient concentrations.

Research suggested that water quality in urban ponds may gradually impair over times due to several unique causes (Hobbie *et al.*, 2017). In comparison with agricultural lands, eutrophication in urban ponds caused by high nutrient loads of nitrogen and phosphorus may have unique pathways, such as sewage and septic tanks overflows (James *et al.*, 2005), runoffs from roads (Daniel *et al.*, 1982), construction sites (Baker *et al.*, 2007), building and impervious paved surface (Zhao *et al.*, 2007), recreational areas like golf courses (Kunimatsu *et al.*, 1999), baiting (Arlinghaus and Mehner, 2005), and feeding for domestic organisms or urban wildlife (Turner and Ruhl, 2007). Due to high human activities and consumptions, several studies also remarked that urban waters commonly received road runoffs with high in trace metals, such as copper, lead, and zinc (Al *et al.*, 2017), and domestic sewage with micropollutants (Verlicchi *et al.*, 2012), like pharmaceuticals, personal care products, household use chemicals, and their metabolites. In order to improve the water quality in urban ponds of Taiwan, better scientific understandings and practical approaches are required to mitigate the environmental pressures from anthropogenic activities and pollutants.

Conservation for native fishes

Conservation potentials for common and near-threatened native fish in urban ponds still existed. In this study, *C. maculata*, listed as ‘‘near-threatened’’ in the *Red Data Book of Freshwater Fishes in Taiwan* by Chen *et al.* (2012), was recorded by one angler from the NiaoSong Wetland. Moreover, four common native fish species listed by Chen *et al.* (2012), including *C. auratus, C. erythropterus, Cyprinus caprio caprio*, and *H. leucisculus*, were also collected. These findings suggested that the ethnic composition of fish communities in the urban ponds of southern Taiwan are different from stormwater ponds in Singapore, whose composition included 24 species of exotic fish only (Kwik *et al.*, 2013). Nevertheless, the risk is high for fish communities in urban ponds of southern Taiwan, which might be fully occupied by exotic fish in the near future if practical measurements are not in place soon. To restore urban waters for conserving and promoting freshwater biodiversity, several actions are required, such as reducing nutrient loads and anthropogenic pollutants, eradicating or controlling aquatic invasive species, stabilizing water storage and reducing extreme discharge events, as well as maintaining and restoring habitat structure (Oertli and Parris 2019, Teurlinck *et al.*, 2019). Preserving soil revetment and bottom in the urban ponds is also suggested for habitat conservation of those native fishes that often burrow into soft sediments or occupy crevices and small spaces in the banks of ponds, such as *Monopterus albus* and *Clarias fuscus* (Lin, 2007).

Both native *Carassius auratus* and cultured *Carassius auratus,* commonly called Shubunkin, were collected in this study. Shubunkins are frequently sold as live foods for aquatic predatory animals in the pet stores of Taiwan. Compared to the larger body size (commonly greater than 10 cm) and darker brown or blue body color of native

Carassius auratus, the shubunkin is distinguishable with a smaller body size (generally smaller than 8 cm) and body overlapping patched of red, white, blue, grey and black colors normally extending to the tip of fins.

Among the exotic species, *Culter alburnus* was listed as an indigenous invasive species because its original distribution range was in mid-Taiwan and many anglers purposely introduced it island-wide (Lin 2007). Chiu *et al*. (2012) reported *C. alburnus* preyed on *Candidia barbat*a, a native fish, and produced an unbalanced age structure of *C. barbata* with fewer younger generation and greater elderly ones in a tributary of Feitsui Reservoir. Even though 14-individuals were collected in one pond, special attention should be paid to *C. alburnus.*

Two exotic fishes, *Oreochromis* sp. *and Micropterus Salmoides*, recorded in this study, appear in the IUCN/SSC 100 of the World's Worst Invasive Alien Species (GLOBAL INVASIVE SPECIES DATABASE, 2021). We listed *Oreochromis* sp. because intensive interbreeding among *Oreochromis mossambicus*, *Oreochromis niloticus*, and *Tilapia Zillii* existed in the field, and it was not easy to morphologically classify their descendants (Chou and Kao, 2017). Currently, *Oreochromis* sp. is hard to eradicate due to its' ubiquitously distribution within the island. By contrast, removing effort should be focused on *M. salmoides,* because only one sample was collected in this study.

Some concerns are raised from our experiences on fish samplings in the lentic habitats of metropolitan area. In general, cast netting was more effective in collecting mid-water fish than benthic species (Lin and Liang, 1996). However, our benthic fishing traps were frequently removed or lost for unknown reasons, thus alternative approaches would be required to supplement the sampling records from cast netting. In this study, exotic mosquito fish *Gambusia affinis* and guppy *Poecillia reticulata*, two ubiquitously distributed species with small body size, were not recorded, which may be due to the selection of a larger mesh size (2 cm) of cast net (Shao 2021). Further investigations on an optimal selection and combination of fishing gears to conduct fish collections in urban ponds will be imperative.

Correlations with landscape and environmental measurements

Based on a significant negative Spearman's correlation, it is suggested that the number of native fish species decreases as the established ages of urban ponds increase. It is found that native and exotic fishes are able to coexist when urban ponds are first constructed, and then the number of native species seemingly declines five years after the ponds were built. Additionally, the number of total fish species and exotic fish species are positively correlated with the concentration of nitrate-nitrogen in the urban ponds. These results suggest that the exotic fish greatly benefited from the increase of nutrient concentration, specifically nitrate-nitrogen concentration, in the urban ponds.

According to the correlations among fish communities, landscape factors, and environmental measurements of urban ponds, a hypothesis is forged to reveal the temporal associations among the established ages, nutrient concentration, and fish community characteristics in the small lentic habitats of the metropolis. As urban ponds extend their lifespans, exotic fishes would be purposefully or unintentionally introduced due to its proximity to residential areas (Kolar and Lodge, 2001). The nutrient concentration, especially nitrate-nitrogen, of urban ponds may concurrently increase with increasing age, resulting from the inputs of domestic sewage or the excretion of exotic fishes as their population greatly grows, like armored catfish *Pterygoplichthys disjunctivus* in the Volusia Blue Spring of Florida, USA (Rubio *et al*., 2016). In this study, the sampled individuals of *Oreochromis* sp. comprised over 80% of the collections, and its fecal waste may conceivably contribute to the escalated nutrient concentration in the urban ponds. Although the increase of such nutrient concentration, especially the nitrate-nitrogen, in the urban ponds would promote the total number of fish species, it is more likely to contribute to the survival of exotic fishes than to the persistence of native species. Test of this hypothesis may reveal the mechanisms underlying the successful establishment of exotic fish in the lentic ecosystems of metropolitan landscapes over times.

CONCLUSIONS

Based on the results of this study, urban ponds are able to provide suitable habitats for conserving near-threatened native fishes and for supporting the populations of common native fishes. In this study, we also postulated that the temporal enhancement of nutrient concentration over years, possibly generated from domestic sewage or exotic fish's excretion, may create a suitable environment for promoting the invasion and persistence of exotic fishes in the small lentic ecosystems of a metropolis. For the persistence of native fishes in the urban ponds of southern Taiwan, the first five years after the establishment of those ponds are critical. Moreover, the implementation of proper management strategies within this period is crucial to restrict the population expansion and dispersal of exotic fish.

ACKNOWLEDGMENTS

This study was supported by the Ministry of Science and Technology of Taiwan via a research grant (MOST 108-2621-B-017-001-MY3) to Shih-hsiung Liang. We are highly grateful to anonymous reviewers for their helpful comments on the manuscript.

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