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Spatio-temporal variability of small fishes related with environmental factors in a typical domestic tap water lake, Eastern China*

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Abstract The knowledge of prey small fish stock, distribution and abundance is necessary to guide stocking of piscivorous fish for the biomanipulation in domestic tap water lakes. This study describes the current status of small fish community in Kuilei Lake (China), and examines the spatial and seasonal variations of the community in relation to key environmental factors. Based on submerged macrophyte cover and water depth, the lake was divided into five major habitats: (1) macrophyte covered shallow habitat of water depth < 2.00 m, (2) uncovered or less-covered shallow habitat (2.00 m–3.50 m), (3) uncovered medium shallow habitat (3.50 m–5.00 m), (4) uncovered medium deep habitat (5.00 m–6.50 m) and (5) uncovered deep habitat (6.50 m–8.50 m). The abundance and composition of small fish were monitored by benthic fyke-net sampling from April 2013 to January 2014. A total of 2881 individuals belonging to 5 families and 21 species were collected. Based on their abundance (accounted for 88.96% of the total) and occurrence (more than 33.33%), *Acheilognathus chankaensis*, *Acheilognathus macropterus*, *Microphysogobio microstomus*, *Pseudorasbora parva* and *Rhinogobius giurinus* were recognized as dominant small fish species. The results of correlation analysis identified that species richness (*Sr*), Shannon-Wiener diversity index (*H'*) and Margalef's richness index (*D*) were significantly negatively correlated with water depth, but positively correlated with biomass of submerged macrophytes.Redundancy analysis (RDA) revealed that the spatial distributions of most small fishes were negatively associated with water depth. The details of these findings are beneficial to understanding the adaptation of the small fishes in degraded environments, and to developing suitable biomanipulation strategies for the management of fish resources and water quality in the lakes along the lower reach of the Changjiang (Yangtze) River basin.

Keyword: small fishes; spatial and temporal variation; community structure; biomanipulation; lake ecosystem restoration

1 INTRODUCTION

The Changjiang (Yangtze) River is used for domestic tap water resource by residents who live in the lower reach of its basin but water pollution of the river has become a serious health risk (Qiu et al., 2014). In order to deal with this risk, the local governments have begun to utilize lakes in its catchment as sources of domestic tap water.

Supplying high quality drinking water is the ultimate aim of ecosystem management of the domestic tap water lakes. Generally, water quality of lakes is correlated with the health of ecosystem. Many fishes impact on the regulatory effects on a

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variety of ecosystem structure and function (Power et al., 1985; Flecker, 1996; Hacker and Gaines, 1997; Hargrave et al., 2006; Hargrave, 2009). These effects are often firmly coupled to the fish species' trophic position in the aquatic food web (Hargrave, 2009). The predecessors of domestic tap water lakes along the lower Changjiang River basin were traditionally used for aquaculture-based fisheries. Due to overfishing and habitats loss, the populations of piscivorous fishes (e.g. *Channa argus*, *Culter alburnus*, *Culter mongolicus* and *Siniperca chautsi*) dramatically declined, and subsequently induced the flourishing of small fish (e.g. *Pseudorasbora par*va, *Acheilognathus macropterus* and *Acheilognathus chankaensis*) (Cao et al., 1991; Zhang et al., 1997; Liu et al., 2005; Mao et al., 2011). Previous studies illustrated that the small fish have an essential role in aquatic ecosystems, representing the main pathway by which energy and nutrients are transported from lower (i.e. plankton, plant detritus) to upper trophic levels (i.e. large fish, water birds) (Cury et al., 2000). In addition, most small fish species are omnivorous and or planktivorous in the Changjiang lakes (Anonymous, Department of Ichthyology, Institute of Hydrobiology, CAS, 1976; Xie et al., 2001, 2005; Zhang, 2005; Ye et al., 2006). Omnivorous fish mainly feed on bottom-dwelling organisms or plant detritus (Xie et al., 2005; Zhang, 2005). Their feeding habits may transport nutrients from the benthic to the pelagic phase, which result in increased nutrient levels and consequent algae bloom impacting quality water (Kloskowski et al., 2011). With a high biomass and density of omnivorous fish, the effect will be more severe (Cline et al., 1994; Miller and Crowl, 2006; Roozen et al., 2007). Moreover, the increasing density of planktivorous fish decreases the biomass of zooplankton, which losses controlling phytoplankton standing stocks because weakened grazing rates give rise to algae bloom (Post and Mcqueen, 1987).

The classical biomanipulation has been applied in eutrophicated lake remediation (Cilinengbu et al., 2012). It is a widely accepted and frequently applied ecotechnology to enhance the environmental quality of standing waters (Mehner et al., 2002). The central goal of classical biomanipulation is to increase the abundance of piscivorous fish community by stocking and catch restrictions to reduce the density of planktivorous fish enhancing large herbivorous zooplankton (predominantly large Daphnia species). This leads to higher grazing pressure on phytoplankton and more transparent water, which in turn allows recovery of submerged vegetation and the associated fauna (Mehner et al., 2004; Ha et al., 2013). In general, different piscivorous fish species have different life-history traits, such as distribution, predatory strategy and prey selectivity (Claessen et al., 2002; Li et al., 2013). As an example, in North America, in some lakes with northern pike, the abundance of spiny-rayed prey fish is more than the soft-rayed prey fish but in other lakes without northern pike the density and biomass of the spiny-rayed and soft-rayed are not significantly different (Robinson and Tonn, 1989). The choice of piscivorous fish species and reasonable stocking abundance are vital roles to achieve the desired goals in eutrophic lake restoration through classical biomanipulation.

Kuilei Lake is a shallow lake originally used for aquaculture-based fisheries that has been transformed into a domestic tap water source. The fish community in Kuilei Lake has a low biomass of piscivorous fish and a high abundance of small fish, which is similar to an aquaculture-based fishery lake, but does not correspond to an ichthyo-fauna of a domestic tap water lake in general (Scharf, 2007). To address this, the classical biomanipulation was considered to regulate fish community and water quality through trophic-cascade effects by stocking piscivorous fish. It is essential to understand the abundance and sturcture of forage fish in Kuilei Lake on the basis of the fact that small fishes are the dominant food items for piscivorous fish, which is crucial for establishing the optimal stocking program of piscivores. In this study, the abundance, community composition, and spatial and temporal variations of small fish community in relation to environmental factors in Kuilei Lake were examined. Such information is expected to be useful for providing guidance for the stocking of piscivorous fish.

2 MATERIAL AND METHOD

2.1 Study area

The study was conducted in Kuilei Lake (31°24′N, 120°51′E), Jiangsu Province, Eastern China (Fig.1). This lake (670 hm^2) is located on the north bank of the lower reach of the Changjiang River and is used as a source of domestic tap water for residents in Kunshan City, that has a population of about 1.65 million. The physico-chemical characteristics of the lake were monitored from April 2013 to January 2014 and are presented in Table 1.

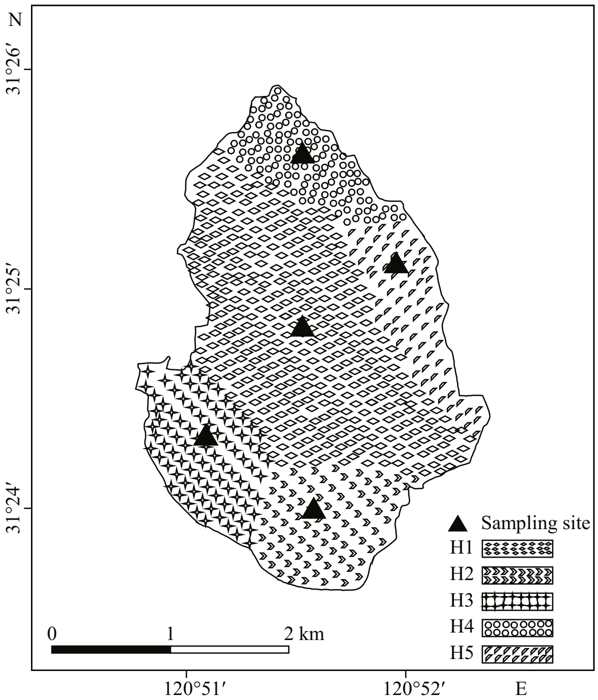

Fig.1 Kuilei Lake, showing the distribution of the five major habitat types H1, H2, H3, H4 and H5, and the location of sampling sites

2.2 Habitat characterization

Habitat characteristics, including water depth, transparency, submerged macrophyte biomass and bottom types, were investigated prior to fish sampling. The maximum water depth was 8.50 m with a mean depth of 2.75 m. The bottom characteristic is soft muddy bottom. The aquatic macrophytes species were dominated by *Ceratophyllum demersum*, *Hydrilla verticillata*, *Najas marina* and *Vallisneria spinulosa*. Based on the water depth and distribution of dominant aquatic macrophytes, the lake was divided into five major habitats (Fig.1). The main characteristics of the five habitats are shown in Table 2.

Table 1 The mean and standard deviation (±SD) of the physico-chemical parameters monitored in Kuilei Lake

Parameter	Mean±SD
Water temperature (°C)	18.84±7.93
Secchi depth (cm)	69.78±13.86
pH	8.25±0.22
Conductivity (μS/cm)	492.52±5.54
Dissolved oxygen (mg/L)	9.97±2.13
Total nitrogen (mg/L)	1.11±0.25
Total phosphorus (mg/L)	0.06±0.05
Chlorophyll *a* (μg/L)	4.79±1.89

2.3 Fish sampling

Small fish were sampled quarterly in April 2013, July 2013, October 2013 and January 2014 using benthic fyke-nets. The net comprised a trunk stem with twenty traps, two end traps and two pockets. The total length of the net was 15 m, including 12 m of trap (0.6 m for each trap), 2 m of end trap (1 m for each trap), and 1 m of end pocket (0.5 m for each one). The framework of each trap was made of iron wire with a width of 0.35 m and a height of 0.62 m. The stretched mesh size was 4 mm. At each sampling site, four nets were deployed separately with a stone sinker at each end. Two ropes with buoys were attached to each end pocket of the net. For each sampling, the nets were deployed between 8:30 and 10:30 hours, and the catches from the end pockets were collected after 24 h. The catches per net in weight were recorded as biomass of catches per unit effort ($CPUE_B$) and the catches per net in number as number of catches per unit effort ($CPUE_N$). The number of samples taken in each habitat in each season is 4 times.

Table 2 Characteristics of each habitat type in Kuilei Lake

Code/habitattype	Longitude and latitude of sampling site	Area (ha)	Range of depth (m)	Mean macrophyte biomass±SD (kg/m^2)	Mean Secchi depth±SD (cm)	Dominant aquatic macrophyte
H1 (covered shallow habitat)	31°24′57.42″N 120°51′34.43″E	270.6	< 2.00	2.82±0.39	71.2±18.40	*Najas marina*, *Vallisneria spinulosa* and *Ceratophyllum demersum*
H2 (uncovered or less-covered shallow habitat)	31°23′52.77″N 120°51′38.21″E	77.1	2.00–3.50	0.40±0.06	61.2±10.70	No submerged macrophyte or only sparse *Vallisneria spinulosa* and *Hydrilla verticillata*
H3 (uncovered medium shallow habitat)	31°24′28.34″N 120°50′57.60″E	94.3	3.50–5.00	0	74.8±17.80	No submerged macrophytes
H4 (uncovered medium deep habitat)	31°25′26.06″N 120°51′29.66″E	127.0	5.00–6.50	0	70.8±12.40	No submerged macrophytes
H5 (uncovered deep habitat)	31°25′9.74″N 120°51′55.56″E	101.0	6.50–8.50	0	71.0±12.50	No submerged macrophytes

2.4 Data collection

All collected small fish were identified to the species level and counted, and individually measured to the nearest 1 mm in total length (TL, mm) and weighed to the nearest 0.01 g. The data of fish abundance ($CPUE_N$ and $CPUE_B$) and *Sr* (total number of species) were collected and computed. Submerged macrophyte composition and biomass were recorded at each sampling site. Dissolved oxygen (mg/L), total nitrogen (mg/L), total phosphorus (mg/L), chlorophyll *a* (μg/L), water temperature (°C), water depth (m), Secchi depth (cm) and pH value were measured at each site during each sampling procedure.

2.5 Data analysis

The following indices and equations were used to evaluate the fish species diversity and the contribution of each fish species (Margalef, 1958; Ludwig and Reynolds, 1988).

(i) Shannon-Wiener diversity index (H')

$$H'=-\sum_{i-1}^{S} p_i \ln p_i, \tag{1}$$

where S is the total number of species and p_i is the proportion of individuals belonging to the i^{th} fish species in the sample.

(ii) Margalef's richness index (D)

$$D=(S-1)/\ln N, \tag{2}$$

where N is the total number of fish samples and S is the total number of species.

The rank-abundance plot was used to display species abundance data, and grouped all the fish species according to their relative abundance (% of total catch) and frequency of occurrence (Magurran, 2004). We then classified the fish species into different trophic groups based on their main food items (Zhang, 2005; Ye et al., 2006), and calculated the proportions of each group in total species number and total catch respectively.

One-way analysis of variance was conducted to determine significant differences among the habitat types in the following community indexes: (1) *Sr*, (2) H', (3) D, and (4) biomass of catches per unit effort ($CPUE_B$). Correlation analysis was used to show the relationship between these indexes and submerged macrophyte biomass and water depth.

Redundancy analysis (RDA) was used to show the relationship between spatial distribution of small fish and habitat conditions (submerged macrophyte biomass, depth, pH, DO and transparency), and to summarize any temporal variations of small fish community in Kuilei Lake. In order to avoid unduly impact on the analysis, the small fish species (abundance ≤13 individuals) were not included in the RDA.

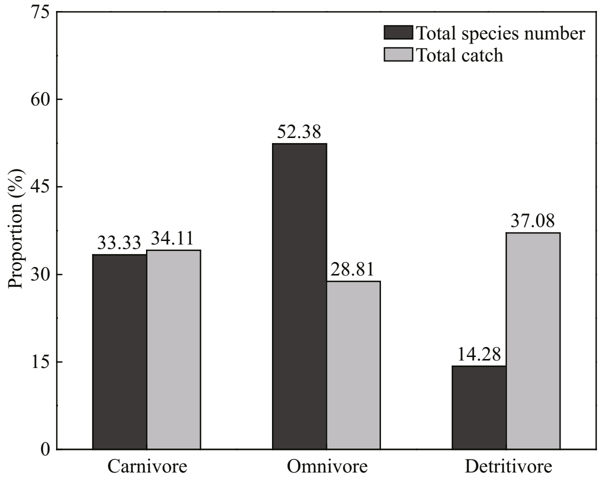

Fig.2 Proportions of the three trophic fish guilds in total species number and total catch in Kuilei Lake

All analyses were performed using R software (Version 3.2.4). The data of fish abundance, submerged macrophyte biomass, water depth, DO and transparency at each sampling site were $\log(x+1)$ transformed to stabilize variances.

3 RESULT

3.1 Species composition

A total of 2 881 individuals, belonging to 5 families, 19 genera, and 21 species, were collected throughout the study. Cyprinidae was the predominant family, accounting for 71.4% of the total. Based on the basis of their age at first maturity less than two years, the 21 species were considered as small fish species (Anonymous, Department of Ichthyology, Institute of Hydrobiology, CAS, 1976) (Table 3). The total of the small fish length ranged from 10 to 220 mm. The maximum sizes recorded of 9 species were smaller than 100 mm, and the others ranged between 100 and 220 mm.

All the small fish species were classified into three trophic guilds based on the ingested food items: detritivore, carnivore and omnivore (Table 4). The total species number of omnivorous guild was highest and accounted for 52.4% (11 species), followed by carnivores (7 species, 33.3%), and detritivores (3 species, 14.3%); the trophic guild with the highest proportion in total catch was the detritivores (37.1% of the total catch), followed by carnivores (34.1%) and omnivores (28.8%) (Fig.2).

Table 3 List of fish species caught in Kuilei Lake from April 2013 to January 2014, with the codes used in the analysis, relative abundance, occurrence frequency, mean TL, and TL range

Family/scientific name	Code	Relative abundance (%)	Occurrence frequency (%)	Mean TL±SD (mm)	TL range (mm)
Cyprinidae					
Toxabramis swinhonis	TSW	0.52	10.00	112±25	52–146
Hemiculter leucisculus	HLE	0.07	3.33	104±58	63–145
Culter dabryi	CDA	2.60	30.00	104±56	35–218
Culter alburnus	**CAL**	**0.79**	**13.33**	**58±23**	**27–120**
Culter mongolicus	**CMO**	**0.75**	**15.00**	**121±73**	**53–237**
Cultrichthys erythropterus	CER	0.83	20.00	131±45	61–212
Paracanthobrama guichenoti	PGU	0.28	10.00	123±60	51–181
Pseudorasbora parva	PPA	7.01	35.00	55±12	24–107
Sarcocheilichthys sinensis	SSI	0.45	3.33	52±16	41–63
Sarcocheilichthys nigripinnis	SNI	2.36	26.67	66±11	25–95
Abbottina rivularis	ARI	0.10	11.67	31±2	30–33
Microphysogobio microstomus	MMI	20.34	73.33	51±8	21–71
Acheilognathus macropterus	AMA	36.83	56.67	65±14	22–133
Acheilognathus chankaensis	ACH	7.12	33.33	55±7	24–82
Paracheilognathus imberbis	PIM	1.53	18.33	43±10	4–68
Rhodeus ocellatus	ROC	0.07	1.67	45±7	40–50
Carassius auratus	CAU	0.73	20.00	68±35	33–215
Bagridae					
Pelteobagrus fulvidraco	PFU	0.28	10.00	143±77	30–220
Eleotridae					
Odontobutis obscura	OOB	0.69	23.33	124±41	31–184
Micropercops swinhonis	MSW	0.35	3.33	30±5	30–45
Gobiidae					
Taenioides cirratus	TCI	0.28	10.00	160±46	84–210
Rhinogobius giurinus	RGI	17.67	65.00	32±9	11–61
Mastacembelidae					
Mastacembelus sinensis	MSI	0.07	5.00	164±38	64–215

The species in bold were large fishes and were excluded from the analysis.

3.2 Abundance and occurrence

Based on the relative abundance and occurrence frequency, small fish species in Kuilei Lake were classified into three groups (Fig.3). *A. macropterus*, *M. microstomus*, *P. parva*, *A. chankaensis* and *R. giurinus* were the dominant species characterized by high relative abundance (exceeding 5% of the total) and high occurrence frequency (ranged from 33.33% to 73.33%). These five species accounted for 88.96% of the total number of small fish collected throughout the sampling period. The other frequently occurring species included *C. dabryi*, *S. nigripinnis*, *P. imberbis*, *C. erythropterus*, *O. obscura*, *C. auratus* and *T. swinhonis*. These seven species showed a moderate relative abundance (ranged from 0.52% to 2.60%) and occurrence frequency (ranged from 10% to 30%). Their abundance accounted for 9.26% of the total. The rare species included *P. fulvidraco*, *A. rivularis*, *H. leucisculus*, *S. sinensis*, *R. ocellatus*, *M. sinensis*, *M. swinhonis*, *P. guichenoti*, and *T. cirratus*. These nine species contributed only 1.77% of the total. In addition, The $CPUE_B$ of benthic fyke-nets in summer is the highest in the four seasons, and the $CPUE_B$ of H1 is higher than the other habitats (H2, H3, H4, H5) except autumn (Fig.4).

3.3 Spatial variation

The *Sr*, *D* and *H'* showed significant differences among the five habitat types (P<0.05) (Table 5). No

Table 4 Main food items and tropic guilds of small fish species in Kuilei Lake

Species	Code	Main food items	Trophic guild
Toxabramis swinhonis	TSW	Insect larvae, micro-crustacean, plant detritus, algae	Omnivore
Hemiculter leucisculus	HLE	Algae, plant detritus, micro-crustaceans, rotifera	Omnivore
Culter dabryi	CDA	Small fish, shrimps	Carnivore
Cultrichthys erythropterus	CER	Small fish, shrimps	Carnivore
Paracanthobrama guichenoti	PGU	Insect larvae, algae, Oligochaeta	Omnivore
Pseudorasbora parva	PPA	Zooplankton, micro-crustaceans, algae, plant detritus	Omnivore
Sarcocheilichthys sinensis	SSI	Algae, plant detritus	Detritivore
Sarcocheilichthys nigripinnis	SNI	Insect larvae, micro-crustaceans, shrimps, zooplankton	Omnivore
Abbottina rivularis	ARI	Plant detritus, Oligochaeta, micro-crustacean	Omnivore
Microphysogobio microstomus	MMI	Algae, plant detritus, micro-crustaceans, insect larvae, zooplankton	Omnivore
Acheilognathus macropterus	AMA	Algae, plant detritus	Detritivore
Acheilognathus chankaensis	ACH	Algae, plant detritus	Detritivore
Paracheilognathus imberbis	PIM	Algae, plant debritus	Omnivore
Rhodeus ocellatus	ROC	Algae, plant detritus, micro-crustaceans, rotifera	Omnivore
Carassius auratus	CAU	Algae, plant detritus, micro-crustaceans, insect larvae	Omnivore
Pelteobagrus fulvidraco	PFU	Plant detritus, insect larvae, small fish, shrimps	Omnivore
Odontobutis obscura	OOB	Small fish, shrimps	Carnivore
Micropercops swinhonis	MSW	Micro-crustacean, insect larvae, gastropod	Carnivore
Taenioides cirratus	TCI	Small fish, shrimps	Carnivore
Rhinogobius giurinus	RGI	Insect larvae, small fish, micro-crustaceans	Carnivore
Mastacembelus sinensis	MSI	Small fish, shrimps	Carnivore

Dietary data are from Anonymous, Department of Ichthyology, Institute of Hydrobiology, CAS, (1976), Xie et al. (2001, 2005) and Zhang (2005).

Table 5 Spatial variation on species diversity of the small fish community (mean±SD) and Pearson's correlation coefficients (*R*) and corresponding *P*-values between *Sr*, *H'*, *D*, CPUE$_B$ and habitat conditions (submerged macrophyte biomass, water depth) were given

Code	Habitat						Submerged macrophyte biomass		Water depth	
	H1	H2	H3	H4	H5	*P*	*R*	*P*	*R*	*P*
Sr	11.25±1.7^a	9.50±2.65^{ab}	7.00±2.94^{ab}	7.00±2.16^{ab}	6.25±2.98^b	0.020	0.573	<0.01	-0.555	0.011
H'	1.63±0.22^a	1.34±0.24^{ab}	1.34±0.24^{ab}	1.28±0.20^b	0.82±0.46^c	<0.01	0.571	<0.01	-0.770	<0.00
D	1.96±0.26^a	1.77±0.60^{ab}	1.40±0.35^{ab}	1.32±0.24^{ab}	1.20±0.48^b	0.029	0.511	0.021	-0.556	0.011
CPUE$_B$	781.77±572.73	300.23±253.29	366.31±460.20	391.40±438.55	373.93±237.71	0.663	0.338	0.145	-0.175	0.462

Data with the same letter are not significantly different, P>0.05.

significant difference was found in the CPUE$_B$. The *D*, *H'*, CPUE$_B$ and *Sr* in H1 were higher than the other habitats where submerged aquatic macrophytes were absent or rare. The aquatic vegetation habitat H1 was dominated by *V. spinulosa*, *C. demersum* and *N. marina*. Results of correlation analysis showed that *Sr*, *H'* and *D* were significantly negatively correlated with water depth but significantly positively correlated with submerged macrophyte biomass. The CPUE$_B$ was not significantly affected by water depth and submerged macrophyte biomass (Table 5).

In order to avoid undue influence on the analysis, the nine rare fish species were not included in the RDA (Braak, 1986; Pennington, 1996). These species had a very low abundance (≤13 individuals), and removing them had no distinct influence on the associations between the other species and habitat condition. The result of RDA model was significant (P<0.01) showing a significant relationship between environmental factors and fish distribution, and the two axes together explained 39.8% of the variability in the fish-habitat relationship (33.2% and 6.6%, respectively) (Fig.5). The RDA identified the association between the 12 small fish species with environmental condition: (1) *A. chankaensis*, *A. macropterus*, *M. microstomus* and *P. imberbis* preferred to high dissolved oxygen habiats; (2) *R. giurinus*, *O. obscura*, *C. erythropterus*, *S. nigprinnis* and *P. parva* preferred to dense submerged macrophytes; (3) The distribution of *C. auratus* was mainly positively influenced by the dissolved oxygen and submerged macrophytes; (4) only *C. dabryi* was associated with deeper areas; (5) *T. swinhonis* was less influenced by the environment variables (Fig.5).

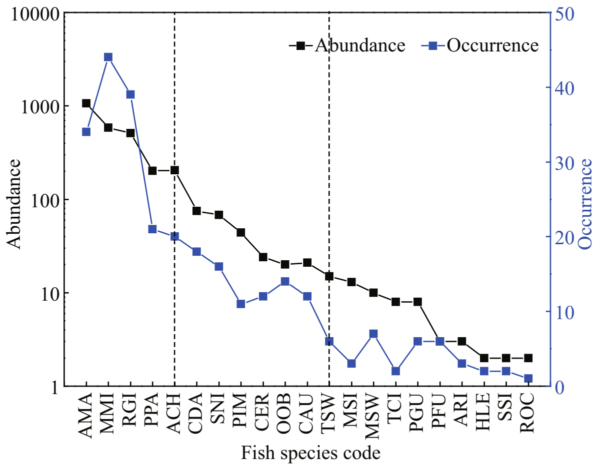

Fig.3 Rank-abundance (total number of individuals sampled) and occurrence (number of the samples in which the species was present) of the small fish species caught in Kuilei Lake throughout the study

Species abundance represented in log scale to avoid undue influence of the most abundant species on the figure and the meaning of codes is the same as in Table 3.

3.4 Seasonal variation

The results of RDA analysis clearly illustrates the separation among the four seasons based on the

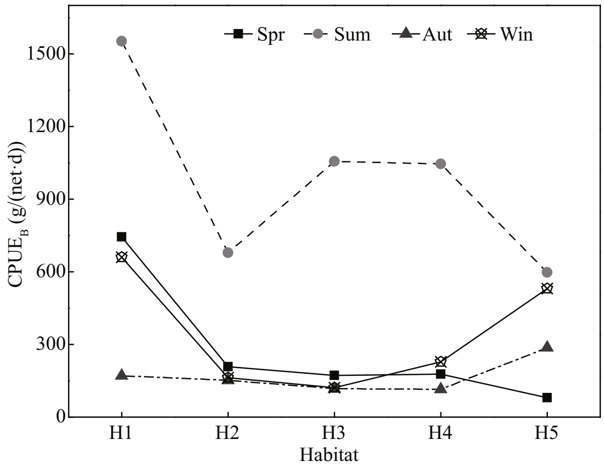

Fig.4 The catch per unit effort (CPUE$_B$) of benthic fyke-net in different habitats and seasons

Spr: Spring; Sum: Summer; Aut: Autumn; Win: Winter.

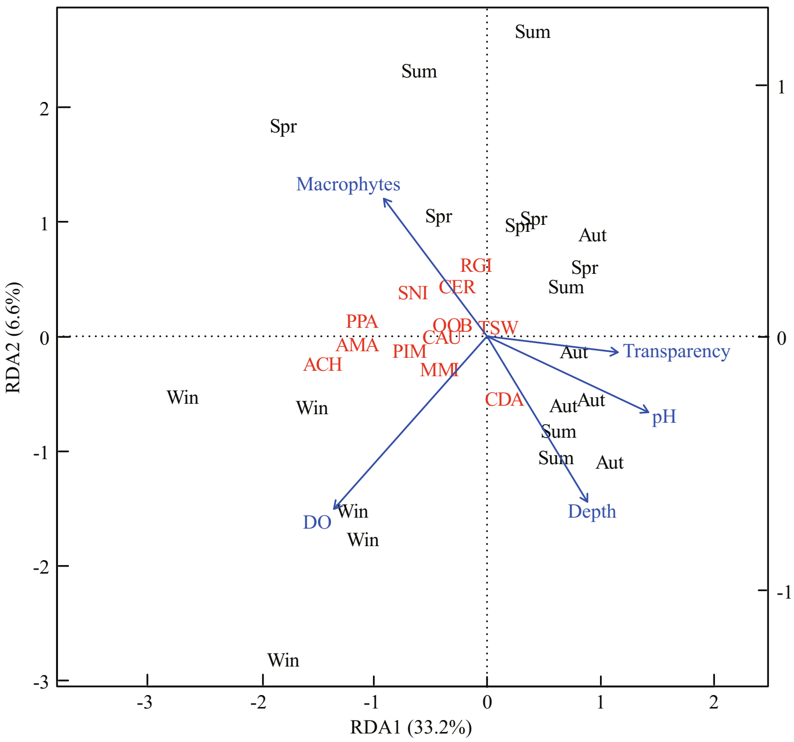

Fig.5 Redundancy analysis (RDA) showing 12 small fish Species distribution in relation to pH, DO, macrophytes, transparency and depth in Kuilei Lake

Spr: Spring; Sum: Summer; Aut: Autumn; Win: Winter.

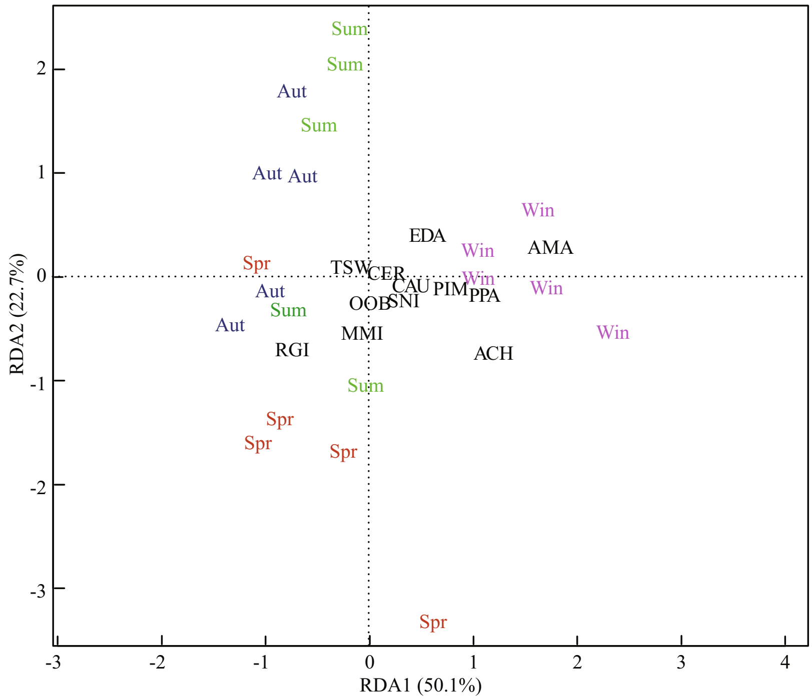

Fig.6 Redundancy analysis (RDA) showing the temporal variation of small fish community in Kuilei Lake

Spr: Spring; Sum: Summer; Aut: Autumn; Win: Winter.

composition of small fish species, in which Spring, Summer and Autumn are close to each other, and winter is a clear differentiation compared with other seasons (Fig.6).

Population size structures of five numerically dominant small fish species were measured in the four seasons. The mean total length of *A. macropterus*, *M. microstomus*, *P. parva*, and *A. chankaensis* were the lowest in summer, while the mean total length of *R. giurinus* was the lowest in autumn (Fig.7).

4 DISCUSSION

In this study, a total of 21 small fish species were collected and most of them were omnivorous. Dominance of omnivorous species in small fish communities were also reported for other Changjiang lakes (Ye et al., 2006; Xiong et al., 2015). The omnivorous species employ a generalist feeding strategy and are capable of exploiting a wide range of food resources such as detritus, macroinvertebrates, zooplankton and plant materials (Sibbing, 1988; García-Berthou, 2001). Hence, they can better adapt to the aquatic ecosystem of the Changjiang lakes and have become the dominant.

The distribution of freshwater fish communities is principally influenced by biotic factors (e.g. food availability, competition, predation) and abiotic factors (e.g. habitat heterogeneity, water depth, and presence or absence of macrophytes) (Brind'Amour et al., 2005; Bertolo and Magnan, 2006; Ye et al., 2006; Yeager et al., 2011; Zhou et al., 2016). The present study shows that aquatic vegetation biomass had significant impacts on small fish community in Kuilei Lake. The *Sr*, *D* and *H′* were significantly positively correlated with submerged macrophyte biomass, which is in accordance with the results obtained by others (Xie et al., 2000, 2001; Ye et al., 2007; Dibble and Pelicice, 2010; Li et al., 2010; Massicotte et al., 2015). The positive association was in all probability due to the benefits offered by the submerged macrophytes. Firstly, small fish may be attracted toward aquatic vegetation habitats to access extra food resources (Werner et al., 1983). Given that the aquatic vegetation habitat provides a substrate for a vast amount of food organisms (such as periphytic algae, invertebrates and particulate organic matter) which are the most common feeding items consumed by small fish species (Bian, 1999; Liu, 1999; Taniguchi et al., 2003; Sánchez-Botero et al., 2007; Thomaz et al., 2008; Schneck et al., 2011). Secondly, the submerged macrophyte habitat is regarded as effective refuge for small fish species, a consequence of the habitat with complexly physical structure (Meerhoff et al., 2007; Sánchez-Botero et al., 2007). Reducing the risk of prey by the complex structure, the habitat is more effective refuge than other

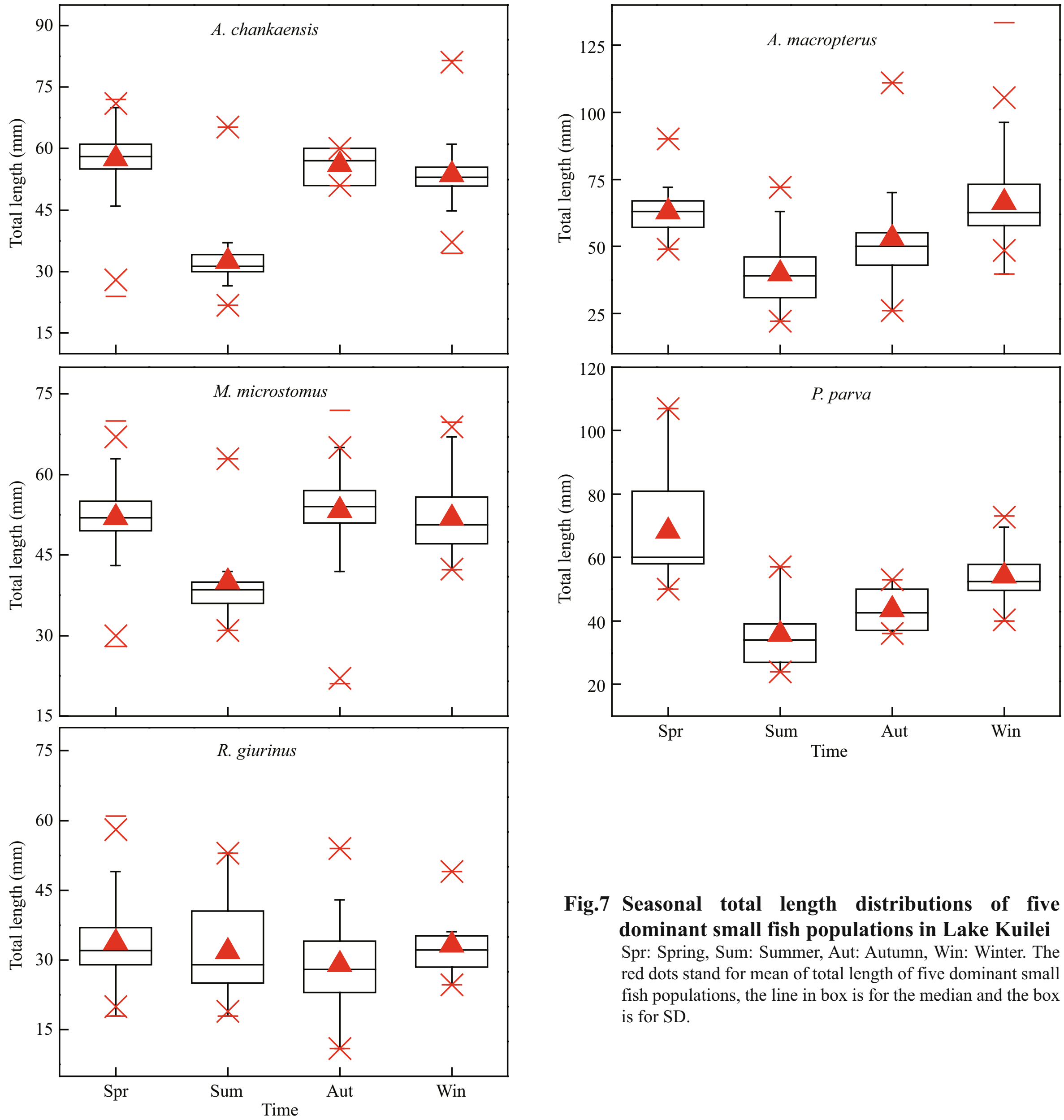

Fig.7 Seasonal total length distributions of five dominant small fish populations in Lake Kuilei

Spr: Spring, Sum: Summer, Aut: Autumn, Win: Winter. The red dots stand for mean of total length of five dominant small fish populations, the line in box is for the median and the box is for SD.

freshwater habitats (Clark et al., 2003; Kovalenko et al., 2012). Thirdly, aquatic macrophytes also provide spawning grounds for some species. The adhesive or semi-adhesive eggs are deposited by many small fish species on the fine leafy submerged aquatic macrophytes, where hydro-chemical environment and oxygen content are favorable for the eggs to develop (Petr, 2000). Except the aquatic vegetation, water depth has been identified as the other crucial determinant to influence the fish community structure (Laffaille et al., 2001; Cheng et al., 2012; Zhou et al., 2016). In the present study, although water depth did not have observably negative impact on $CPUE_B$, it was significantly negatively correlated with the *Sr*, *D* and *H′* of small fish community of Kuilei Lake. Our results are different from some previous studies (Xie et al., 2000, 2001; Ye et al., 2007; Li et al., 2010). The inconsistency might be attributed to lack of obvious change of gradient in the water depth of the sampling sites that were used in the previous studies such as in Lake Liangzi, Lake Niushan and Lake Xiaosihai (Xie et al., 2001; Ye et al., 2007; Li et al., 2010). Furthermore, the light is another key factor to influence the distribution of submerged macrophytes. The euphotic zone was calculated as 2.7 times the Secchi depth (Cole, 1994). The average euphotic zone of Kuilei Lake is less than 5 m. The sample areas with water depth exceeding 4.0 m do not have submerged macrophytes. Submerged macrophytes potentially impact the small fish communities to change the proportions of food resources such as shifting the distribution of macroinvertebrate (e.g. mollusk and shrimp), plankton and periphyton (Bian, 1999; Liu, 1999; Dibble and Pelicice, 2010). These can be used to explain why *Sr*, *D* and *H′* of small fish community were significantly negatively correlated with water depth in Kuilei Lake.

In previous studies, differences of environmental variables among seasons leading to seasonal changes in fish community structures have been detected (Brosse et al., 2007; Melcher et al., 2012). Our study showed the fish $CPUE_B$ was higher in the summer compared to others seasons. This can be attributed to several reasons. Firstly, the peak of spawning time of most small fish species in lakes of the middle and lower Changjiang River basin is from late April to July (Zhang, 2005; Ye et al., 2006; Ren et al., 2016). Secondly, fish resources were replenished by reproduction in summer and then decreased soon after spawning because of the removal of adults of small fish species as most of them with a 1-year lifespan (Zhang, 2005). The biomanipulation enhancing piscivorous fish population has become an ecosystem management approach to strengthen water quality (Mehner et al., 2002). Thus, we argue that the build-up of the piscivorous fish population is a prerequisite for successful biomanipulation. Meanwhile, it is necessary to formulate an adequate fish stocking program. The present study showed that *A. chankaensis*, *A. macropterus*, *M. microstomus*, *P. parva* and *R. giurinus* were the dominant species in Kuilei Lake, and they are the main prey of the native piscivorous fish such as *Siniperca chuatsi* and *Channa argus* (Li et al., 2013). Based on these results, we suggest stocking of *S. chuatsi* and *C. argus* to reduce the abundance of small fish and improve water quality in domestic tap water lakes. Because they are not only the native piscivirous fish but also self-sustained populations in such standing water. Most small fish species in the Changjiang lakes spawn between April and July, and more larval and juvenile individuals of several species in our study were observed in summer. In addition, our results confirmed that small fish species prefer aquatic macrophyte habitat. Furthermore, the availability of small fish as prey for piscivorous fish can be impacted by the size structure and predator′s size-selective feeding (Claessen et al., 2002). In order to reduce the mortality of piscivorous fish fry, we suggest that the favorable seasons for stocking juvenile piscivorous fishes should be late spring or early summer when the small fish of suitable size are most abundant in the lake. Moreover, the juvenile piscivorous fishes should be stocked in the aquatic macrophyte habitat, where they can not only obtain higher abundant prey fish but also decrease risk of predation by other large predators.

5 CONCLUSION

This study provides basic information on distribution, abundance and community structure of 21 small fish species in the domestic tap water Kuilei Lake, and confirms that the *Sr*, *H′* and *D* were significantly negatively correlated with water depth, but positively correlated with submerged macrophyte biomass. Furthermore, we suggest that stocking of *S. chuatsi* and *C. argus* is beneficial to reduce the abundance of small fish and improve water quality in domestic tap water lakes, and juvenile piscivorous fishes should be stocked in the aquatic macrophyte habitat in late spring or early summer.

6 DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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