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Spatial distribution and abundance of small fishes in Xiaosihai Lake, a shallow lake along the Changjiang (Yangtze) River, China*

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Abstract Spatial distribution and abundance of small fishes were studied in autumn 2007 in the Xiaosihai Lake, a shallow lake along the middle reach of the Changjiang (Yangtze) River. Based on the plant cover, the lake was divided into three major habitats: *Myriophyllum spicatum* habitat (MS habitat), *Trapa bispinosa* habitat (TB habitat), and non-vegetation habitat (NV habitat). A modified pop-net was used for quantitative sampling of small fishes in the three habitats, and the Zippin's removal method was used for estimating densities of the small fishes. A total of 13 species belonging to 5 families were collected, with 11 species in MS habitat, 7 species in TB habitat, and 5 species in NV habitat. Habitat type had significant effect on the spatial distribution of small fishes. The Shannon-Wiener diversity index in the MS, TB and NV habitats were 1.28, 0.56 and 0.54, respectively. The total density and biomass of small fishes were significantly higher in the MS habitat (13.68 ind/m^2 and 4.44 g/m^2) than in the TB habitat (1.41 ind/m^2 and 0.54 g/m^2) and the NV habitat (1.08 ind/m^2 and 0.40 g/m^2), and were not significantly different between the TB habitat and the NV habitat. Water depth had no significant effect on spatial distribution of the small fishes. It was suggested that vegetation type played an important role in habitat selectivity of small fishes, and the presence of submersed vegetation should be of significance in the conservation of small fish diversity.

Keyword: small fishes; spatial distribution; abundance estimation; habitat selectivity; Xiaosihai Lake

1 INTRODUCTION

There are numerous lakes spreading along the middle and lower reaches of the Changjiang River, which cumulatively represent about 71.5% of the total area of freshwater lakes in China (Liu et al., 1992). These lakes are typically shallow (without thermal stratification) with abundant vegetation and usually have high biological productivity (Xie et al., 1996). One important function of these lakes is exploitation for commercial fisheries, with artificial stocking of commercial fish species. Typically, the herbivorous grass carp *Ctenopharyngodon idellus* (Cuvier et Valenciennes.) is stocked to utilize the macrophytes, and the bighead carp *Aristichthys nobilis* (Richardson) and silver carp *Hypophthalmichthys molitrix* (Cuvier et Valenciennes) are stocked to utilize plankton (Liu et al., 1992). Such fishery practices often cause a series of ecological problems. Overstocking of grass carp have resulted in a drastic reduction or elimination of submersed macrophytes and consequently an increase in algae and a decline in the fish and shellfish dependent upon macrophytes (Xie, 2000a). Sewage and fertilizers are used in some lakes to increase the bighead and silver carp production, which accelerates the eutrophication of these lakes (Chen, 1989). Overfishing of commercially important piscivorous fishes has induced the miniaturization of fish community (Cao et al.,1991; Liu et al., 2005).

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In recent years, there has been a shift in fish stocking from common carps to piscivorous fishes (such as mandarin fish *Siniperca chuatsi*) to utilize the abundant small-sized fish resources and to prevent small fish population from growing excessively in lakes along the Changjiang River (Cui et al., 2005; Xie et al., 2000b). Stocking of piscivorous fishes has been proposed as a strategy to improve water quality in North American and European lakes, based on the principle of trophic-cascading effects (Carpenter et al., 1988; Liere et al., 1992). Therefore, an understanding of the food organisms of piscivorous fishes is important for the successful management of fisheries.

Many studies on small fishes have focused on growth, reproduction and feeding (Fang et al., 1995; Zhang et al., 1998; 2002), while some studies have been conducted on the effects of environmental factors on fish assemblages of European and North American lakes and rivers (Garro-Tejerina et al., 1998; Dumas et al. 2007; Habit et al., 2007). However, there is little information on the abundance, community structure and spatial distribution of small fishes in lakes along the Changjiang River (Xie et al., 2000a, 2001; Ye et al., 2007). In this study, spatial distribution, density and biomass of small fishes in different habitats in the Xiaosihai Lake were investigated. Our objective is to evaluate the resource status of small fishes, which is essential for enhancement of piscivorous fishes in the lakes.

2 MATERIALS AND METHODS

2.1 Study area

Xiaosihai Lake (30°16′N, 114°41′E) is on the south bank of the middle reach of the Changjiang River, in Hubei Province of central China. The lake, with an area of 133.3 ha (1 ha=10 000 square meters) and depths ranging from 1.0 to 1.7 m, has been separated from a larger lake (Baoan Lake) by a dyke. For several years prior to this study, the major form of fishery had been the stocking of the Chinese mitten crab *Eriochier sinensis*, which resulted in a reduction of submersed vegetation. In 2007, the lake was heavily covered by water caltrop *Trapa bispinosa*. The mean physicochemical parameters of the lake in four seasons of 2007 are given in Table 1. According to the trophic state index (TSI), Xiaosihai Lake was lightly eutrophic.

2.2 Habitat characterization

Habitat features, including aquatic macrophytes, water depth, transparency and bottom characteristics of the lake, were investigated prior to fish sampling. Based on the distribution of dominant aquatic macrophytes, the lake was divided into three major habitats: *Myriophyllum spicatum* habitat (MS habitat), *Trapa bispinosa* habitat (TB habitat), and non-vegetation habitat (NV habitat) (Fig.1). *M. spicatum* is a submersed plant and *T. bispinosa* is a floating-leaf plant. The main characteristics of the three different habitats are shown in Table 2.

Table 1 Annual means and ranges of physicochemical parameters in Xiaosihai Lake in 2007

Parameters	Mean ± SE	Range
Water temperature (°C)	19.2±2.00	6.4–29.2
Secchi depth (cm)	63.7±4.01	35–100
pH value	7.88±0.10	7.24–8.73
Conductivity (μS/cm)	322±8.78	257–372
Dissolved oxygen (mg/L)	8.28±0.39	6.80–11.84
Total nitrogen (mg/L)	0.714±0.070	0.234–1.467
Total phosphorus (mg/L)	0.052±0.005	0.009–0.094
Chlorophyll *a* (μg/L)	7.988±0.996	2.184–21.106

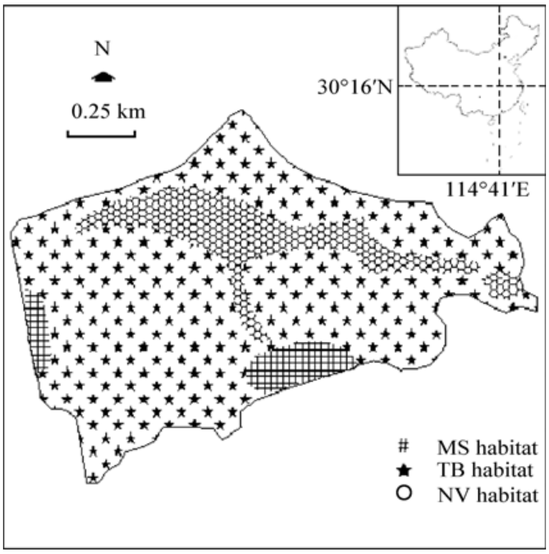

Fig.1 **The Xiaosihai Lake, showing the distribution of different habitats**

2.3 Fish sampling

Fish were quantitatively sampled using a pop-net (area 10 m^2) modified from Morgan et al. (1988). Sampling was carried out in autumn of 2007. Seven samples were taken in each of the three different habitats. When sampling, the pop-net was set on the bottom for at least 4 hours, after which the top frame was released to float up, trapping any fish in the area. Macrophytes were removed, and at least 3 seines (of area 10 m^2 and made from 1 mm mesh nylon screen attached to a metal pipe on the bottom) were then

Table 2 Characteristics and areas of different habitats of the Xiaosihai Lake

Habitat Type	Macrophyte	Area (ha)	Biomass (kg/m^2)	Water depth (cm)	Secchi depth (cm)	Bottom characteristics
MS Habitat	*Myriophyllum spicatum*	6.5	2.1±0.18	101±9.9	88±5.4	Soft muddy bottom
TB Habitat	*Trapa bispinosa*	93.2	3.2±0.37	119±6.7	68±3.2	Soft muddy bottom
NV Habitat		33.6	0	122±2.3	64±4.1	Soft muddy bottom

made within the pop-net. All the fish collected in a seine were kept in a plastic bag, labeled, refrigerated and later analyzed. The habitat type, water depth and bottom type of each sampling site were recorded.

2.4 Data collection

All the fish collected were identified to species, counted and individually measured and weighed. The density of each species at each sampling site was estimated using the Zippin's removal method (Zippin, 1956). In this method, a coefficient R_{js} was calculated for species *j* in site *s* by:

$$R_{js} = \sum[(t-1)C_{jt}]/ \sum C_{jt} \quad (1)$$

where C_{jt} is the number of species *j* collected in the *t*-th seining; $\sum C_{jt}$ is the total number of species *j* collected in site *s*. Then value for $(1-\mathrm{q}^k)$ corresponding to R_{js} was estimated from the $R-(1-\mathrm{q}^k)$ graph given by Zippin (1956), and the number (N') of species *j* in site s was estimated by:

$$N' = \sum C_{jt}/(-\mathrm{q}^k) \quad (2)$$

where *k* is the number of seining conducted in site *s*; q is a coefficient. At sites where the Zippin method could not be applied, the density was calculated by multiplying the real number collected in lake (N) by the N'/N ratio which had been estimated for species in the same habitat where the method could be applied (Qin et al., 2005). The sum of counts was used for species where the total number of fish taken did not exceed two individuals in more than three catches in a given sampling site (Qin et al., 2005). The total biomass of species *j* in habitat *i* (B_{ji}) was estimated from the total number of species *j* in habitat *i* (N_{ji}) multiplied by the average weight of sampled individuals. Mean density (D_{ji}) of species *j* in habitat *i* in the lake was estimated from the average value of density estimates at all the sampling sites of habitat *i*. The population number (N_j) of species *j* in the whole lake was estimated from D_{ji} and the area of habitat *i* (A_i):

$$N_j = \sum A_i D_{ji} \quad (3)$$

Shannon-Wiener's diversity index (H) was used to calculate fish diversity at each sampling site (Pielou, 1966; Wilhm, 1968):

$$H = -\Sigma(P_i \ln P_i) \quad (4)$$

where P_i is the number of individuals of species *i* as a proportion of the total number of fish individuals; *n* is the number of fish species collected.

Bray-Curtis's index was used to measure the degree of similarity of fish assemblages between two different habitats (Bray et al., 1957):

$$C_N = 2N_j/(N_i + N_s) \quad (5)$$

where N_i and N_s are the sum of abundances of all species found in habitat *i* and *s*, respectively, and N_j is the sum of the lower of the abundance values for species common to both habitats. The Bray-Curtis's index ranges from 0 to 1, with increasing values indicating increased similarities between communities.

2.5 Data analysis

Data on density and biomass of fishes were log(x+1) transformed to stabilize variances before statistical analysis. Analysis of covariance (ANCOVA) was used to analyze the effects of habitat and water depth (covariate) on dependent variables (density, biomass or diversity), and chi-square test was used to examine the difference in fish assemblages between each pair of habitat type. Differences were regarded as significant when $P<0.05$. The analyses were performed using the SPSS version 13.0 software package.

3 RESULTS

3.1 Species composition

A total of 984 fish of 13 species belonging to five families were collected at the 21 sampling sites (Table 3). In the MS habitat, 834 individuals comprising 11 species were collected, the dominant species being *Micropercops swinhonis* (38.6%), *Pseudorasbora parva* (27.9%) and *Rhodeus ocellatus* (16.3%). In the TB habitat, 85 individuals comprising 7 species were collected, dominated by

Rhinogobius giurinus (68.2%). In the NV habitat, 65 individuals comprising 5 species were collected, dominated by *R. giurinus* (70.8%) and *Hemiculter leucisculus* (20.0%). The five species, *M. swinhonis*, *P. parva*, *R. ocellatus*, *R. giurinus* and *H. leucisculus*, are regarded as the major species of the small-sized fish community in the lake, and their mean standard lengths are 23.1, 29.4, 25.9, 25.0, and 45.8 mm, respectively (Table 3).

3.2 Distribution pattern

The effect of habitat on density and biomass varied with species (Table 5). For *P. parva*, the density and biomass were significantly affected by habitat type (Table 5), both being significantly higher in the MS habitat than in the TB and NV habitats. They were not significantly different between the TB habitat and the NV habitat (Table 4). For *M. swinhonis*, both density and biomass were significantly affected by habitat type (Table 5), being highest in the MS habitat, and lowest in the TB habitat (Table 4). For *H. leucisculus*, only the density was significantly affected by habitat type (Table 5), which was lower in the TB habitat than in the MS habitat and in the NV habitat (Table 4). The biomass was not significantly

Table 3 Species composition and number of fish sampled with pop-nets in the three different habitats

Species	MS habitat		TB habitat		NV habitat		Standard length (mm)	
	No.	%	No.	%	No.	%	Mean±SE	Range
Cyprinidae								
Pseudorasbora parva	233	27.94	3	3.53	2	3.08	29.4±0.88	16.4–56.4
Hemiculter leucisculus	4	0.48			13	20	48.5±2.46	35.5–65.5
Carassius auratus	21	2.52					46.9±3.38	21.3–78.8
Cultrichthys erythropterus	8	0.96					61.0±4.91	41.3–83.3
Rhodeus ocellatus	136	16.31	3	3.53			25.9±0.38	21.9–34.1
Rhodeus lighti	20	2.40	7	8.24			26.4±1.12	19.3–37.8
Rhodeus fangi	24	2.88					29.7±1.13	21.6–38.1
Paracheilognathus imberbis	46	5.52	7	8.24			27.0±0.45	19.9–33.7
Abbottina rivularis			2	2.35			55.9±5.15	50.8–61.1
Gobiidae								
Rhinogobius giurinus	19	2.28	58	68.23	46	70.77	25.0±0.69	13.3–39.0
Eleotiidae								
Micropercops swinhonis	322	38.61			1	1.54	23.1±0.38	13.6–38.4
Bagridae								
Pelteobagrus fulvidraco	1	0.12					48.9	
Salangidae								
Neosalanx oligodontis			5	5.88	3	4.61	39.4±0.84	36.9–43.6
Total	834	100	85	100	65	100		

Table 4 Estimated densities and biomass of small fishes in three different habitats

Species	MS habitat		TB habitat		NV habitat	
	Density(ind/m^2)	Biomass(g/m^2)	Density(ind/m^2)	Biomass(g/m^2)	Density(ind/m^2)	Biomass(g/m^2)
Pseudorasbora parva	4.70	1.33	0.04	0.05	0.03	0.02
Rhinogobius giurinus	0. 30	0.07	1.03	0.27	0.8	0.19
Micropercops swinhonis	4.71	0.95	0	0	0.01	0.01
Rhodeus ocellatus	2.07	0.10	0.04	0.01	0	0
Paracheilognathus imberbis	0.69	0.04	0.1	0.05	0	0
Rhodeus fangi	0.43	0.03	0	0	0	0
Carassius auratus	0.31	1.47	0	0	0	0
Hemiculter leucisculus	0.06	0.09	0	0	0.2	0.17
Rhodeus lighti	0.29	0.07	0.1	0.06	0	0
Cultrichthys erythropterus	0.11	0.27	0	0	0	0
Neosalanx oligodontis	0	0	0.07	0.01	0.04	0.01
Abbottina rivularis	0	0	0.03	0.09	0	0
Pelteobagrus fulvidraco	0.01	0.02	0	0	0	0
Total	13.68	4.44	1.41	0.54	1.08	0.40

Table 5 Analysis of covariance of the effect of habitat and water depth on density and biomass of five major species in Xiaosihai Lake

Species	Density		Biomass	
	Habitat	Depth	Habitat	Depth
Pseudorasbora parva	0.000 0	0.133 4	0.000 0	0.152 4
Rhinogobius giurinus	0.174 3	0.707 8	0.131 0	0.844 1
Micropercops swinhonis	0.000 0	0.098 0	0.000 8	0.153 0
Rhodeus ocellatus	0.010 0	0.749 4	0.251 8	0.576 4
Hemiculter leuciscululs	0.036 7	0.609 3	0.058 1	0.426 4
All of small fishes	0.000 0	0.314 0	0.000 1	0.105 8

affected by habitat type (Table 5). For *R. giurinus*, the density and biomass were not significantly affected by habitat type (Table 5).

The total density and biomass of small fishes were significantly affected by habitat type (Table 5), being higher in MS habitat than in both TB and NV habitats (Table 4). Water depth had no significant effect on either density or biomass of any fish species. Similar results were found for all small fishes (Table 5).

3.3 Species diversity

Habitat type had a significant effect on species diversity of small fishes (F=7.326, P<0.05), but water depth had no significant effect on the species diversity (F=0.242, P>0.05). The diversity index of small fishes in the MS habitat was 1.36±0.13 (mean±SE), being significantly higher than that in the TB (0.56±0.09) and NV (0.54±0.07) habitats.

3.4 Community structure similarity

The Bray-Curtis's index of fish assemblages was estimated to be 0.08 between the MS and TB habitats, 0.06 between the MS and NV habitats, and 0.68 between the TB and NV habitats. The fish assemblages were significantly different between each habitat (between the MS and TB habitats, X^2=145.3, P<0.05; between the MS and NV habitats, X^2=174.7, P<0.05; between the TB and NV habitats, X^2=44.3, P<0.05).

3.5 Density and biomass

The total density and biomass of small fishes in the MS habitat were 13.68 ind/m^2 and 4.44 g/m^2, which were significantly higher than those in the TB habitat (1.41 ind/m^2 and 0.54 g/m^2) and the NV habitat (1.08 ind/m^2 and 0.40 g/m^2) (Table 4). In the whole lake, the number of small fishes was estimated to be 2.57×10^6 and the density was estimated to be 1.93 ind/m^2 (Table 6).

4 DISCUSSION

Fish communities are generally closely related to habitat heterogeneity (Keast, 1978). According to habitat mosaic theory, a lake is a mosaic of different habitats and sub-habitats (Keast, 1978). Fish species composition, diversity and density in the different habitats were found to be different (Gaudreau et al., 1998; Jackson et al., 2001). Vegetation cover and water depth are two of the most important factors influencing spatial distribution of fish (Holland et al., 1984; Hosn et al., 1994). The present study showed that vegetation cover had significant effects on distribution of small fishes in the Xiaosihai Lake (Table 5). Species density, biomass and diversity in the MS habitat were higher than in the TB and NV habitats, and there were no significant differences between the TB and NV habitats. High concentrations of small fish in submersed macrophytes has also been reported in some other waters, e.g. Varzea (Henderson et al., 1995), Biandantang Lake (Xie et al., 2000a) and Liangzi Lake (Xie et al. 2001). It has been suggested that submersed macrophyte habitat is abundant in prey resources, provides shelter from predation for small fishes and also serves as a spawning ground for small species (Jackson et al., 2001). The reason for the high concentration of small fish in the submersed MS

Table 6 Estimated abundance of small fishes in Xiaosihai Lake

	MS Habitat	TB Habitat	NV Habitat	Whole lake
Number of species	11	7	5	13
Number of individuals (×10^5 ind.)	8.89	13.14	3.63	25.66
Density (ind./m^2)	13.68	1.41	1.08	1.93

habitat in the Xiaosihai Lake needs to be further investigated by analyzing feeding efficiency, predation risk and spawning activities of the small fishes in this habitat.

Water depth was generally found to be an important factor affecting spatial patterns of fish communities in North American and European deep lakes (Keast, 1978; Laffaille et al., 2001). In the present study, water depth had no significant influence on density, biomass and species diversity of small fishes in the Xiaosihai Lake. Water depth was also reported as not being a significant factor determining small fish distribution in two other lakes along the Changjiang River middle reach (Xie et al., 2000a; 2001). Generally, habitat factors affect fish habitat choice through physiochemical factors such as temperature, oxygen and habitat complexity (Pierce et al., 1994; Tonn et al., 1982). Compared with North American lakes, lakes along the Changjiang River middle reach are shallow (usually less than 5 m), without apparent depth related variation in physical and chemical factors.

The present study also demonstrated that habitat selection varied between fish species in the Xiaosihai Lake. Generally, habitat selection was related to living habits and morphological characteristics of the fish (Hosn et al., 1994). *R. ocellatus*, *P. parva* and *M. swinhonis* were more abundant in the MS habitat than in the TB and NV habitats. These small species have a high activity level, and may depend on the complexity of the submerged macrophyte habitat to reduce predation risk. *H. leucisculus* was collected only in the MS habitat in Xiaosihai Lake. It is an epipelagic fish which swims rapidly and mainly feeds on plankton. In contrast, *R. giurinus* prefer the TB and NV habitats to the MS habitat. This fish is a demersal species, with two pelvic fins forming a small sucking plate. It thus can attach itself to the lake bottom to shelter from predation risk.

Suitable and effective method of small fish sampling is fundamental for the quantitative study of fish communities. Most lakes along the middle and lower reaches of the Changjiang River, China, are shallow (less than 5 m depth) with heavy coverage of submersed macrophytes. A major part of the dominant small fish species in these lakes are demersal (Xie et al., 2000a). Traditional methods for small fish quantitative investigation are usually difficult to apply in these lakes. Direct counting, poisoning and electrofishing are not suitable in submersed vegetation habitat, as the fish cannot be efficiently counted or collected (Morgan, 1988). Demersal fishes generally have limited movement, making it difficult to use multimesh gillnets and impractical to use mark-recapture methods in a large water body. In this study, the pop-net modified from Morgan et al. (1988) were used for quantitative sampling of small fishes. Compared with other methods, pop-net could embowel small fishes in a fixed area, had little disturbance to their natural distribution and activity, and did little damage to the vegetation structure. Previous studies have shown that density and biomass of small fishes estimated using pop-nets were much higher than those estimated using other methods (Dewey et al., 1989; Dewey, 1992). In this study, a total of 13 species were collected by pop-net, which was much lower than previously reported small fish species richness (Fang et al., 1995). This may be a result of the small area (10 m^2) of the pop-net, which could be overcome by expanding sampling area and increasing the number of samples. Species composition and number of fish collected in the present study suggested that pop-net might be more efficient for demersal small fish with low swimming activity than for epipelagic small fishes with high swimming activity. Ye et al. (2007) showed that a block net with relatively large area (100 m^2) was more efficient for collecting epipelagic small fish with high activity than for collecting demersal small fish species with low activity. A combination of pop-net and block net should be an ideal method for quantitative sampling of small fish in shallow lakes with dense vegetation, as along the middle and lower reaches of the Changjiang River.

Small fish density estimated in the Xiaosihai Lake (Table 6) in the present study is much lower than that in Biandantang Lake (Xie et al., 2000a). Both lakes are actually two coves of the Baoan Lake, and are separated from the latter by dykes. We suggest that declined vegetation cover and heavy stocking of piscivorous fish may account for the low density of small fish in the Xiaosihai Lake. Results in the present study suggested that vegetation cover is essential to maintain small fish diversity and abundance in shallow lake. However, over-vegetated habitat was demonstrated to result in low feeding efficiency and poor growth of both small fishes and piscivorous fishes (Miranda et al., 1997; Xie et al., 2005). Further studies should be conducted to investigate the effects of macrophyte cover on predator-prey interactions, and to provide the basis for vegetation management and development of a reasonable piscivorous fish stocking strategy in such lakes.

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