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Ichthyoplankton recruitment from mainstream of the Changjiang River into the Dongting Lake, the second largest freshwater lake in China*

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Abstract Floodplains are important and distinctive ecosystems around the world, and the recruitment of ichthyoplankton from river to floodplain lakes is crucial to maintain this unique ecosystem. However, this process has not been well documented. In this study, ichthyoplankton were sampled to investigate the details of ichthyoplankton recruitment from the Changjiang (Yangtze) River to the Dongting Lake via a floodway channel, the Songzi River, from May to July in 2013 and 2014. During the study period, 41 species of eggs and larvae were sampled. Among the samples, 16 were river-lake migratory species (RL), representing 23.5% of the species in the Dongting Lake. In 2013, an estimated 130 million eggs and 3 180 million larvae drifted through the sampling section, and in 2014, an estimated 1 060 million eggs and 1 040 million larvae drifted through the sampling section. The amount of eggs and larvae of RL reached 3 210 million in 2013 and 1 850 million in 2014, respectively. These results demonstrated the importance of ichthyoplankton recruitment from the river to the lake, as species diversity will decrease sharply without this recruitment. Canonical correspondence analysis (CCA) showed that water temperature and water flow are the two most important factors influencing the spawning activities of fish. To maintain the high fish diversity in the Changjiang floodplain, we suggest to irrigate the channel to increase water discharge and increase the transport of ichthyoplankton from the Changjiang mainstream into the Dongting Lake.

Keyword: ichthyoplankton; recruitment; Changjiang floodplain; Dongting Lake

1 INTRODUCTION

Riverine floodplains are among the Earth's most distinctive landscapes, characterized by their high biodiversity and productivity and their corresponding recreational and aesthetic values (Tockner and Stanford, 2002). Floodplains are also considered centers of biocomplexity and bioproduction, with more species of plants and animals occurring on floodplains than in any other landscape unit in most regions of the world (Tockner and Stanford, 2002). As a typical example, the Changjiang (Yangtze) River and its floodplain lakes were listed as one of the seven large river ecosystems with the highest biodiversity and endemicity in the world (Martens and Segers, 2009) and suggested as hotspots of freshwater biodiversity (Kottelat and Whitten, 1996) and one of the 200 global conservation priority ecoregions by the World Wide Fund (Olson and Dinerstein, 2002).

A key feature of the Changjiang floodplain lakes is their high diversity of fish species. More than a thousand lakes occupy the middle Changjiang floodplain, and almost all of these lakes are rich in fish

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species. For example, 134 species are found in Poyang Lake (Fang et al., 2016), 116 species in Dongting Lake (Li et al., 2013a), and 87 species in Wuhu Lake (Liang et al., 1981). This high diversity is attributed to the river-lake migratory species (RL). After a long geological period, as adaptation to the East Asian monsoon climate, the Asian cypriniforms, such as the Chinese major carps, evolved spawning of drift eggs (Cao, 2011). When water temperature is above 18°C and with flooding resulting in a water rise >0.55 m/day, these fishes may migrate to the spawning ground and spawn drift eggs (Yi et al., 1988a; Li et al., 2013b). The eggs need to float for a certain duration until they hatch, then the larvae mature to the swimming stage. This development process needs a specific duration and flow velocity; thus, successful spawning can only occur in large rivers (Li et al., 2013b) and never in lakes. Given that lakes can provide rich food, larvae and juveniles of river spawning fishes often enter the affiliated lakes and grow there. Thus, these river-lake migratory fishes significantly increase fish diversity in lakes (Ru et al., 2008).

River-lake migratory fishes are important components of lake ecosystems. For example, in Dongting Lake, river-lake migratory fishes once accounted for 32% of the catch of commercial fisheries (Liao et al., 2002), and in Wuhu Lake, they can reach as high as 77.6% (Liang et al., 1981). Liang et al. (1981) documented ~40 species with river-lake migration or semi-migration behavior. Without these river-lake migratory species, fish diversity in lakes will drop sharply and the fish community will remarkably differ. Potentially, environmental changes such as eutrophication could occur in the lakes (Fang et al., 2006; Liao et al., 2006). Despite the importance of river-lake fishes to the lake ecosystem, the recruitment mechanisms of river-lake fish ichthyoplankton have not been investigated thoroughly.

Dongting Lake (28°44′–29°35′N; 111°53′–113°05′E), located in Central China, is the second largest freshwater lake in China. With approximately 1 428 plant species, 116 fishes, 217 birds, and the unique finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) (Li and Shen, 2005; Li et al., 2013a), this lake is famous for its valuable and exclusive biodiversity. The fisheries catches alone, account for almost 1/4 to 1/3 of the total amount of fishes in the Changjiang River (Chen et al., 2002; Xie, 2017), and therefore bears importance in the fish industry. This lake also serves as an important water supply and helps with flood mitigation, wastewater treatment, and transportation.

Dongting Lake receives water from four tributaries (Xiangjiang, Yuanjiang, Zishui, and Lishui Rivers) and through three inlet channels (Songzi, Ouchi, and Taiping channels) of the Changjiang mainstream, but it only features one outlet channel (Chenglingji) to the Changjiang River (Dou and Jiang, 2000). Historically, ichthyoplankton recruitment is roughly estimated as the percentage of water discharge flowing through the three inlet channels and varies between 5.2% to 11.8% for the different channels (Zhou et al., 1986). However, in situ field investigations have never been conducted. In recent decades, the inlet channels shrank, and siltation occurred due to heavy human activities, such as flow regulation, damming, and agricultural practices or extractions, resulting in lower water discharge flowing into the Dongting Lake (Han and Zhou, 1999; Hu et al., 2014; Sun and Shen, 2015).

In this study, we surveyed the ichthyoplankton flowing into the Dongting Lake through the largest of its three inlet channels, the Songzi channel. We aimed to assess the current situation and temporal variations of ichthyoplankton recruitment to the Dongting Lake and determine the environmental factors related to ichthyoplankton production to provide suggestions for future fish resource conservation and management.

2 MATERIAL AND METHOD

2.1 Study area

Currently, Songzi channel is the largest floodway channel connecting the Changjiang River mainstream and the Dongting Lake. On average 12% of the mainstream discharge into the Dongting Lake via the Songzi channel, which in turn plays an important role in fish recruitment to the Dongting Lake (Sun and Shen, 2015).

The Songzi channel, with a length of 353 km, is primarily divided into east and west branches. The samples were collected in the west branch of Songzi channel. The sampling site was situated in Songzi city, about 37 km away from the inlet (111°77′E, 30°17′N). The channel is 220–270 m wide, with corresponding discharge of 350–3 300 m^3/s from May to July. Sampling was conducted 10–60 m away from the bank, and the depth ranged from 2 m to 8 m depending on water discharge (Fig.1).

2.2 Drift eggs and larvae sampling

Fish eggs and larvae were collected daily from May 23 to July 24 in 2013 and from May 1 to July

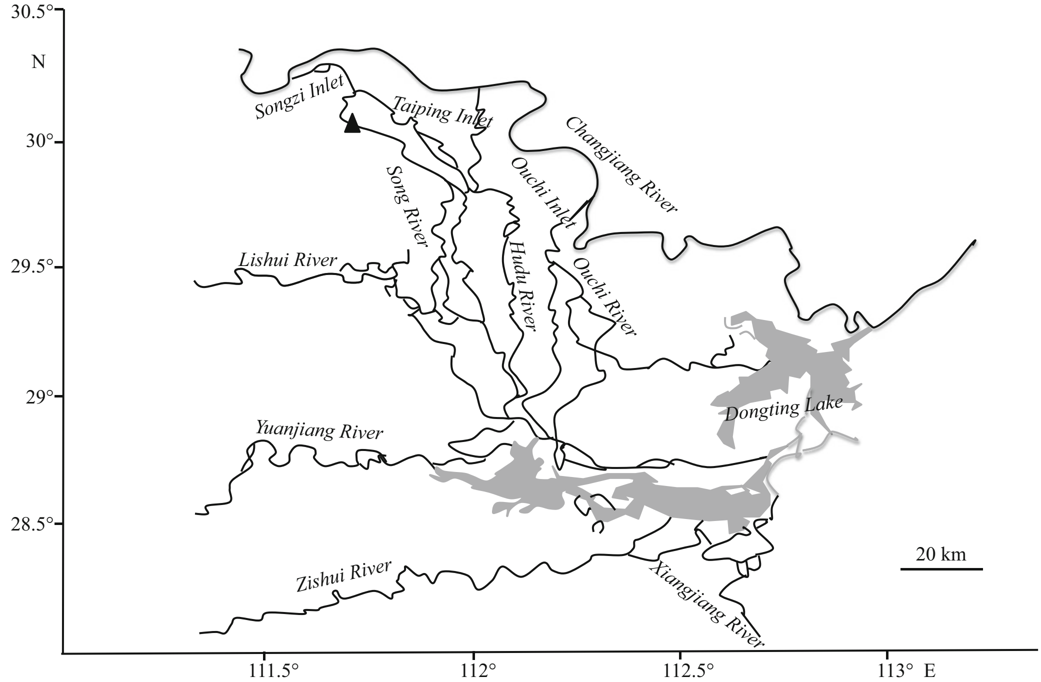

Fig.1 Map of the Changjiang floodplain showing the study area on the middle Changjiang River

The black triangle indicates the sampling location.

26 in 2014 in the Songzi channel. Routine sampling was conducted twice a day, generally from 6:00 to 7:30 and 17:30 to 19:00. Each collection lasted for 15–60 min, depending on water transparency and velocity.

A semi-conical net was used to collect eggs and larvae (Yi et al., 1988a, Duan et al., 2009); it had a 0.39-m^2 semi-circular mouth opening, was 2 m in length with a mesh-size of 500 µm and was placed just below the water surface (0.5 m water depth). A collection box (40 cm×30 cm×30 cm) at the end of the net, was used to collect eggs and larvae. The semi-conical net and the collection box were made of thin silk like material. The upper part of the box was open to allow removal of samples and remained above the water surface by buoyancy. The sampling net was fixed to a shipboard with ropes and kept perpendicular to the current.

To standardize the results of routine sampling, cross-section sampling (as Mu et al. (2014) defined as special sampling) was conducted along a transect across the river once or twice each sampling period. This method can obtain the distribution coefficient ("C", see formulae in the "Data analysis" section) of fish eggs and larvae in the sampling section and was used to estimate the total number of eggs and larvae in subsequent computations (Yi et al., 1988a; Humphries et al., 2002; Duan et al., 2009; Mu et al., 2014; Li et al., 2016). We used a conical net (2 m long, 0.5 m in diameter, with 500 µm in mesh size) for cross-section sampling (Cao et al., 2007). Five sites were specifically selected evenly along the transect (next to the left bank, halfway between the left bank and the river center, the central midpoint of the river, halfway between the central midpoint and the right bank and next to the right bank). At each site three water depths were sampled (0.2, 0.5, and 0.8 times of the depths under the water level in the sampling site; Mu et al. (2014)). The routine sampling site was next to the right bank.

2.3 Sample processing

After sampling, fish eggs and larvae were separated and counted immediately, and the stages of development were identified. The stages of development and developmental time of each stage were defined according to the method of Yi et al. (1988b). According to development, the eggs were incubated in paper cups for five to eight days and identified at the species level. Each cup was stocked with one to ten eggs which were at the same development stage. During incubation, water temperature was maintained between 22°C and 26°C by air conditioner, and the water was aerated (see also Li et al., 2013b). Species were identified under a stereomicroscope to the lowest practical taxa according to the works of Yi et al. (1988b) and Cao et al. (2007).

2.4 Definition of fishes with different ecotypes

Based on ecotype, the collected fishes can be categorized into three types, namely, river-lake migratory species (RL), lake-residence species (LS), and riverine species (RI). River-lake migratory species spawn in rivers but use lakes as their nursery ground due to the rich food resource or spawn in lakes but overwinter in the mainstream. Lake-residence species stay in lakes during their whole life stage with no evident migration. Riverine species usually live in rivers but occasionally move to lakes (Chang and Cao, 1999).

2.5 Environmental data collection

Environmental parameters were measured by YSI multi-parameter water quality meter on each sampling occasion, including water temperature (°C), water velocity (m/s), dissolved oxygen, conductivity, water hardness, and oxidation-reduction potential were measured. Water transparency was measured by a secchi disk. The daily water discharge and water level data from the Songzi gauge station (0.5 km downstream from sampling site), were downloaded from the National Water and Rainfall Information Network (http://xxfb.hydroinfo.gov.cn/index.html).

2.6 Data analysis

Densities of fish eggs and larvae were calculated as number of organisms/1 000 m^3. Water volume was calculated by area of the net entrance (m^2), mean current velocity at the net entrance (m/s), and sampling duration (s).

The total number of eggs and larvae were calculated according to the following formulae (see also Mu et al., 2014; Li et al., 2016):

$$A=M+M',$$

$$M=\sum_{i=1}^{n} T_i C Q_i D_i,$$

$$M'=\sum_{i=1}^{n-1} T'_{(i,i+1)} \times C \times \frac{Q_i+Q_{i+1}}{2} \times \frac{D_i+D_{i+1}}{2},$$

$$D_i=N_i/(SV_iT_i),$$

$$C=(\sum_{j=1}^{m} D_j)/(mD_r),$$

where A refers to the total number of eggs and larvae that drifted through the sampled river section during the entire sampling season; M represents the total number of eggs and larvae counted during all routine samplings; M' stands for the total number of eggs and larvae collected during the time interval between each two adjacent routine sampling occasions; n denotes the number of routine samplings; i corresponds to one specific routine sampling; i+1 indicates the next sampling after the ith sampling; Q_i is water discharge of the river reach during the ith sampling (m^3/s); D_i specifies the drifting density of eggs and larvae during the specific ith sampling (ind./m^3); C expresses the distribution coefficient of fish eggs and larvae in the sampled section; $T_{(i,\ i+1)}$ signifies the time interval between the ith sampling and (i+1)th sampling (s); N_i identifies the number of fish eggs and larvae collected during the ith sampling; S describes net mouth area (m^2); V_i depicts water velocity (m/s) at the net mouth during the ith sampling; T_i is duration of the specific ith sampling (s); D_j denotes the density of eggs and larvae at each sampling site as determined by sampling on the transect (ind./m^3); j is the specific transect sampling site; m is the number of sampling sites when sampling on the transect; and D_r symbolizes the density of eggs and larvae in the surface of the site next to the right bank when sampling on the transect (ind./m^3).

Canonical correspondence analysis (CCA) was used to examine the relationships between the ichthyoplankton drift density and environmental variables. To remove highly correlated variables, all environmental variables whose inflation factors reached more than 20 should be screened. A stepwise process, the manual forward-selection procedure, was used to identify the minimal set of environmental variables that can best explain the variation in species data (Ter Braak, 1988). Forward selection sequentially tested the statistical significance of environmental variables that contributed most strongly to the canonical model. Selected environmental variables were added to the model when their F-ratios were as high or higher than 5% of the simulated F-values generated by 1000 Monte Carlo permutations (i.e., P<0.05). Analyses were performed using CANOCO 4.5 software (Ter Braak and Smilauer, 2002).

3 RESULT

3.1 Species composition and total amount of ichthyoplankton

A total of forty-one species of eggs and larvae belonging to five orders and nine families were identified on 150 sampling days in two years. Among these samples, 16 were RL, such as the four major Chinese carps (*Mylopharyngodon piceus*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Aristichthys nobilis*) (Table 1). All the egg

Table 1 Species composition, egg type, number captured and amount of eggs and larvae in the Songzi River from May to July in 2013 and 2014

Species	Ecotype	2013				2014			
		Eggs		Larvae		Eggs		Larvae	
		Number	Amount (×10⁶)	Number	Amount (×10⁶)	Number	Amount (×10⁶)	Number	Amount (×10⁶)
Squalidus argentatus (Sauvage et Dabry)	RL	1035	25.69	7	1.22	2492	362.24	44	2.52
Hemiculter bleekeri Warpachowski	RL	632	22.04	18 960*	2 573.75*	914	151.63	20 554*	881.46*
Hemiculter leucisculus (Basilewsky)	LS	5	0.08			0	0.00		
Saurogobio dabryi Bleeker	RL	413	14.92	4	0.25	815	125.28	33	1.85
Culter mongolicus (Basilewsky)	LS	260	30.66	0	0.00	8	1.62	0	0.00
Culter alburnus Basilewsky	RL	131	12.87	4	0.54	222	107.11	0	0.00
Siniperca kneri Garman	LS	99	10.61	9	1.35	0	0.00	0	0.00
Parabramis pekinensis (Basilewsky)	RL	83	7.00	138	21.03	33	15.48	64	2.53
Squaliobarbus curriculus (Richardson)	RL	70	3.63	2	0.24	272	62.92	0	0.00
Leptobotia taeniops (Sauvage)	RI	38	3.32	40	6.15	14	5.59	5	0.16
Parabotia fasciata Dabry	LS	36	1.64	1	0.17	97	32.44	0	0.00
Botia robusta Wu	LS	3	0.17	0	0.00	0	0.00	0	0.00
Siniperca chuatsi (Basilewsky)	LS	3	0.07	3	0.27	4	0.93	5	0.21
Hypophthalmichthys molitrix (Cuvier et Valenciennes)	RL	2	0.06	224	37.46	2	0.65	44	1.69
Mylopharyngodon piceus (Richardson)	RL	1	0.03	24	3.82	3	0.56	13	0.55
Aristichthys nobilis (Richardson)	RL	1	0.03	22	3.75	0	0.00	17	0.67
Cyprinus carpio (Linnaeus)	LS	1	0.04	5	0.25	282	44.95	4	0.15
Xenocypris argentea Günther	RL	1	0.04	0	0.00	2	0.41	0	0.00
Pseudolaubuca engraulis (Nichols)	RL	1	0.10	4 130*	494.49*	4	0.97	3 652*	119.97*
Pseudolaubuca sinensis Bleeker	RL	0	0.00			0	0.00		
Ctenopharyngodon idellus (Cuvier et Valenciennes)	RL	0	0.00	83	13.18	9	3.59	10	0.47
Elopichthys bambusa (Richardson)	RL	0	0.00	16	2.46	7	1.34	68	3.22
Pseudobrama simoni (Bleeker)	RL	0	0.00	6	0.92	0	0.00	1	0.06
Neosalanx taihuensis (Chen)	LS	0	0.00	27	1.14	0	0.00	294	14.21
Rhinogobius giurinus (Rutter)	LS	0	0.00	98	12.96	0	0.00	65	3.07
Mugilogobius myxodermus (Herre)	LS	0	0.00	16	0.89	0	0.00	0	0.00
Opsariichthys bidens Günther	LS	0	0.00	1	0.04	0	0.00	0	0.00
Carassius auratus (Linnaeus)	LS	0	0.00	9	0.56	0	0.00	0	0.00
Hyporamphus intermedius (Cantor)	LS	0	0.00	3	0.22	0	0.00	32	1.64
Pelteobagrus vachelli (Richardson)	RI	0	0.00	3	0.44	0	0.00	0	0.00
Acheilognathus macropterus (Bleeker)	LS	0	0.00	0	0.00	0	0.00	0	0.00
Acheilognathus tonkinensis (Vaillant)	LS	0	0.00	1	0.09	0	0.00	1	0.03
Sarcocheilichthys nigripinnis (Günther)	LS	0	0.00	0	0.00	0	0.00	0	0.00
Pseudorasbora parva (Temminck et Schlegel)	LS	0	0.00	2	0.05	0	0.00	0	0.00
Xenocypris davidi (Bleeker)	LS	0	0.00	5	0.48	0	0.00	0	0.00
Culter dabryi dabryi Bleeker	LS	0	0.00	1	0.09	0	0.00	0	0.00
Rhinogobio cylindricus Günther	LS	0	0.00	2	0.34	0	0.00	6	0.31
Mystus macropterus (Bleeker)	RI	0	0.00	0	0.00	0	0.00	0	0.00
Silurus asotus Linnaeus	LS	0	0.00	0	0.00	2	0.20	0	0.00
Odontobutis potamophila (Günther)	LS	0	0.00	0	0.00	0	0.00	3	0.18
Coreius heterodon (Bleeker)	RL	0	0.00	0	0.00	0	0.00	2	0.12
Total		3 659	133	23 849	3 178	5 784	918	24 918	1 035

The larvae of *H. bleekeri* and *H. leucisculus*, *P. engraulis* and *P. sinensis* were difficult to distinguish with each other for their similar features. So we counted them together and therefore combined them. RL: river-lake migratory species; LS: lake-residence species; RI: riverine species. "*" are the sum of two similar species.

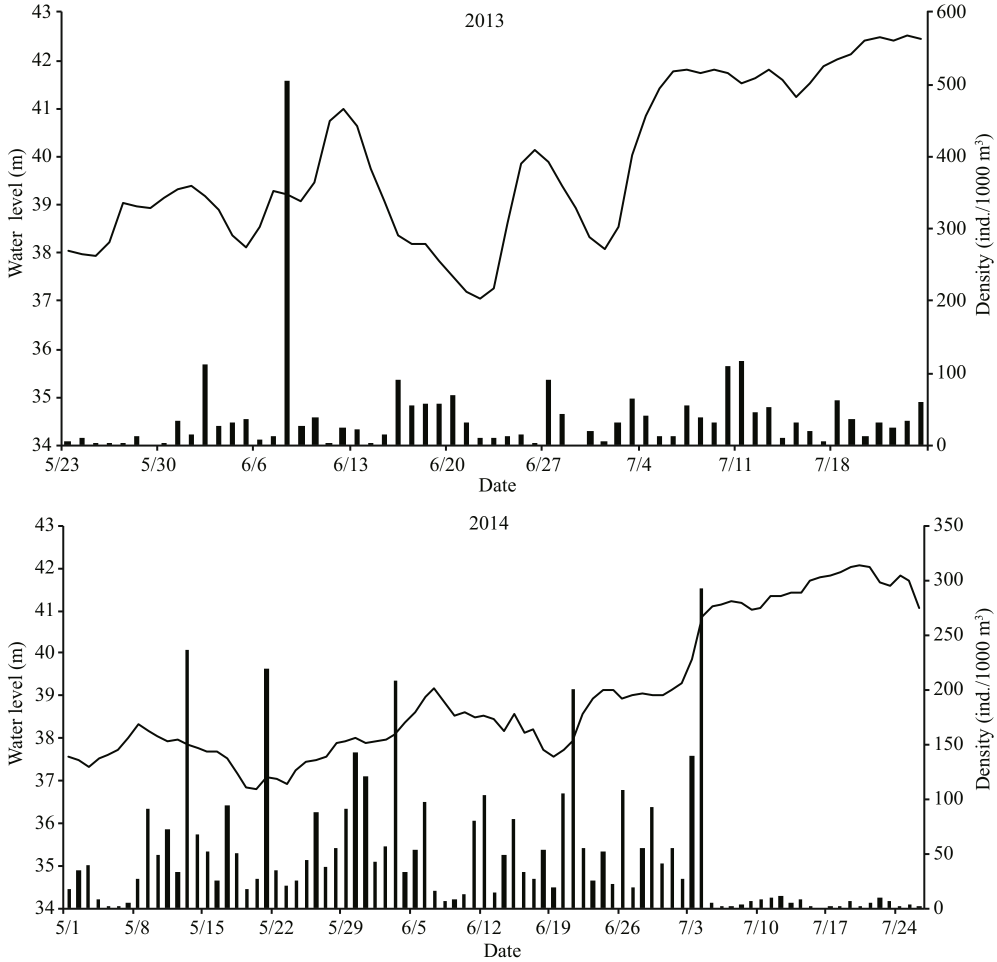

Fig.2 Daily variation in egg drift density (column) and water level (solid line) in the Songzi channel from May to July in 2013 and 2014

samples belonged to 21 species, including 13 RL. Meanwhile, the larvae specimens belong to 34 species, including 15 RL.

A total of 130 million eggs and 3 180 million larvae were estimated drifting through the sampling section from May 23 to July 24 in 2013. The eggs comprised an estimated 25.7 million *Squalidus argentatus*, 14.9 million *Saurogobio dabryi*, 22.0 million *Hemiculter bleekeri*, 12.9 million *Culter alburnus*, and 30.7 million *Culter mongolicus*. All the larvae mainly consisted of *Hemiculter* (2 570 million) and *Pseudolaubuca* (490 million). The estimated total amount of eggs and larvae for the RL reached 3 210 million, accounting for 97.0% of all the ichthyoplankton captured (Table 1).

From May 1 to July 26 in 2014, an estimated 1 060 million eggs and 1 040 million larvae drifted through the sampling section. The eggs comprised an estimated 362 million *S. argentatus*, 125 million *S. dabryi*, 152 million *H. bleekeri*, 107 million *C. alburnus*, 62.9 million *Squaliobarbus curriculus* and 44.9 million *Cyprinus carpio*. *Hemiculter* (880 million) and *Pseudolaubuca* (120 million) dominated the larvae. A total of 1 850 million eggs and larvae were recorded for RL, accounting for 94.6% of all the ichthyoplankton captured (Table 1).

3.2 Temporal variations in recruitment

3.2.1 Temporal patterns of eggs

A total of 8 443 fish eggs were collected on 150 sampling days. In the Songzi channel, seasonal changes in drift density followed a multimodal pattern (Fig.2). Five peaks of drift eggs measured by density were evident from late May to July in 2013. The first peak appeared on June 2 dominated by *S. argentatus* and *S. dabryi*. The second peak, which was the highest of the five (506 ind./1 000 m^3), appeared on June 8 and was dominated by *H. bleekeri*, *S. argentatus*, and *S. dabryi*. The following three peaks appeared in mid-June (June 16), late June (June 27) and mid-July (July 11). The third peak was dominated by species similar

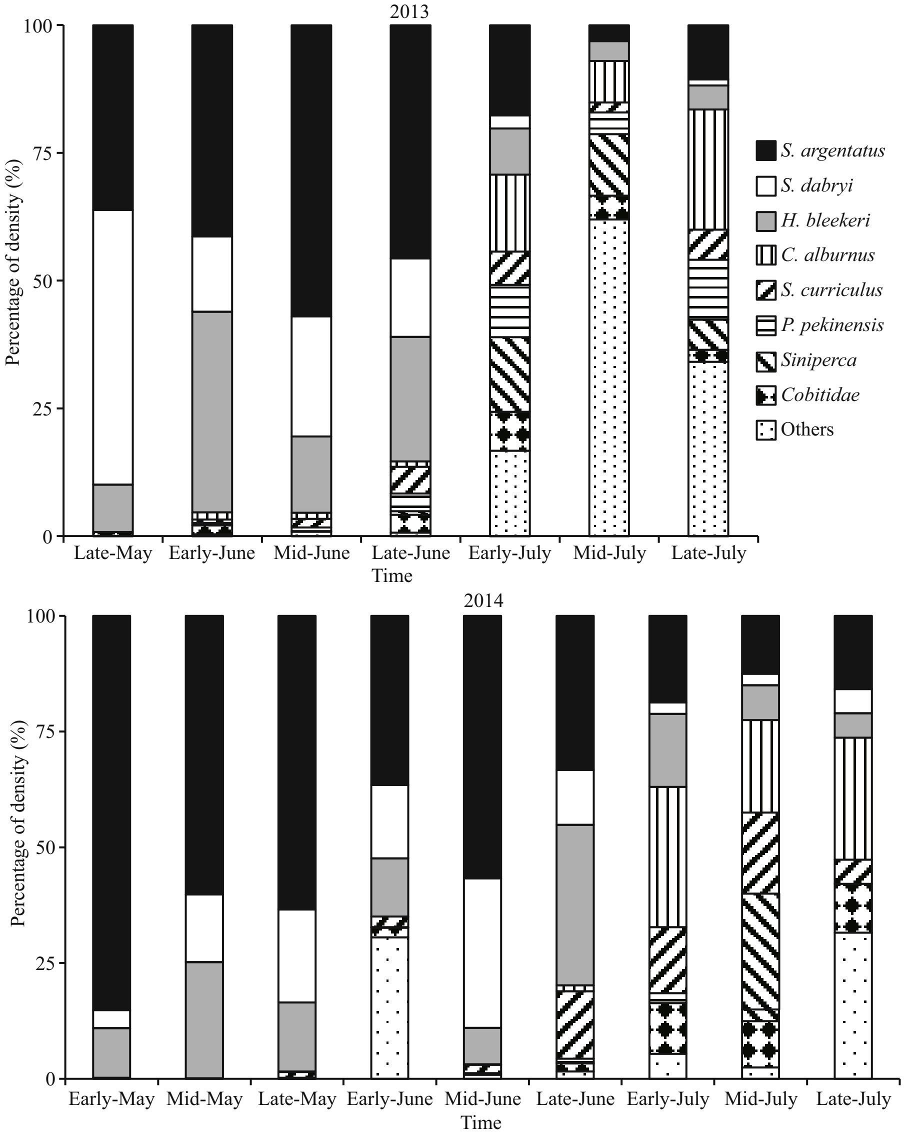

Fig.3 Monthly density percent (%) of the dominant groups in eggs collected in the Songzi channel from May to July in 2013 and 2014

to those of the second peak, whereas *H. bleekeri* dominated the fourth peak. The fifth peak was dominated by *C. alburnus*, *C. mongolicus* and *Siniperca kneri*.

In 2014, five peaks of egg density were observed, and they appeared in mid-May (May 13), late May (May 21), early June (June 3), late June (June 21), and early July (July 4). *H. bleekeri* dominated the first, third, and fourth peaks, *S. argentatus* dominated all four peaks, and *S. dabryi* dominated the first three peaks. However, in the fifth peak, the highest peak, the dominant species changed, and only *C. alburnus* remained abundant.

Species composition showed distinctly varied from May to July in both years. Several species, such as *S. argentatus*, *S. dabryi* and *H. bleekeri*, spawned from early May to late July and dominated in May. On the other hand, other species, such as *C. alburnus*, *Parabramis pekinensis*, *S. curriculus* and *Parabotia fasciata*, started spawning from late June (Fig.3).

3.2.2 Temporal patterns of larvae

A total of 48 767 fish larvae were collected on 150 sampling days. Larvae mainly appeared in late July, corresponding to the water level and (or) water discharge (Fig.4). In 2013, larvae drift density was the highest on July 14th and dominated by *Hemiculter* and *Pseudolaubuca*. In 2014, three peaks of drift density appeared on July 12 (2 424 ind./1 000 m^3), 20 (1 403 ind./1 000 m^3), and 24 (3 561 ind./1 000 m^3). The peaks were all dominated by *Hemiculter* and *Pseudolaubuca*.

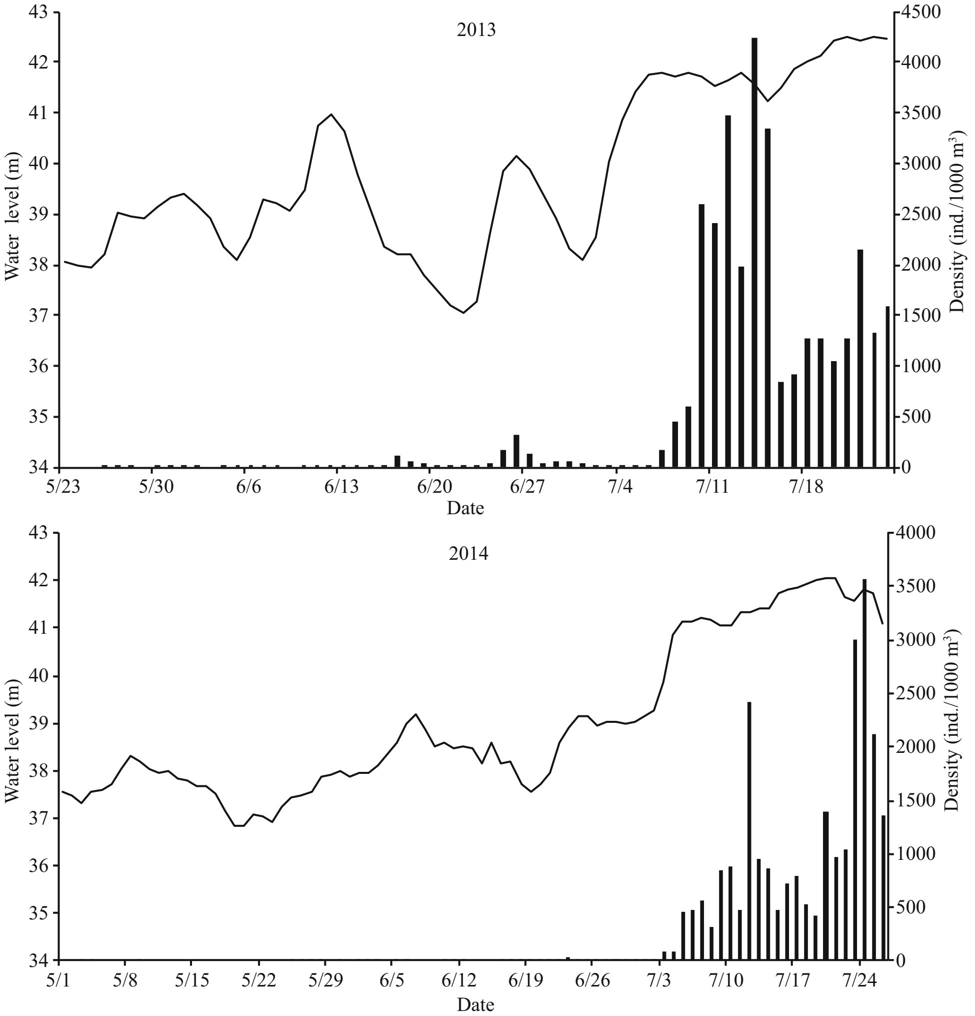

Fig.4 Daily variation in larva drift density (column) and water level (solid line) in the Songzi channel from May to July in 2013 and 2014

3.3 Ichthyoplankton drift density and environmental associations

By screening the environmental variables whose inflation factors reached more than 20 and variables with $P>0.05$ using Monte Carlo permutation tests, we identified two variables, flow and water temperature, relating with egg drift density. With CCA, we plotted species in an ordination figure with environmental variables representing as vectors. The direction and length of vectors represented the influence of environmental variables on ichthyoplankton drift density. We estimated the correlation between ichthyoplankton drift density of different species and environmental variables by vertical projection of species on the vectors. The projections in the direction of the vectors indicated positive correlation between ichthyoplankton drift density and environmental variables against the direction implied negative correlation. Results showed that spawning of *S. curriculus*, Cobitidae, *P. pekinensis*, *C. alburnus*, *Siniperca* and *C. mongolicus* were strongly influenced by flooding (represented by water discharge or water level) and water temperature, whereas *H. bleekeri*, *S. argentatus* and *S. dabryi* spawned with little requirement for the two environmental factors (Fig.5).

4 DISCUSSION

4.1 Ichthyoplankton recruitment from the Changjiang mainstream to the Dongting Lake and the importance of river-lake migratory species

Floodplain channels are the main sources and paths of rivers supplying water to floodplains. Some fish species may use floodplain channel systems as corridors to spawning grounds or nursery grounds during high water flow periods (Copp, 1989), which

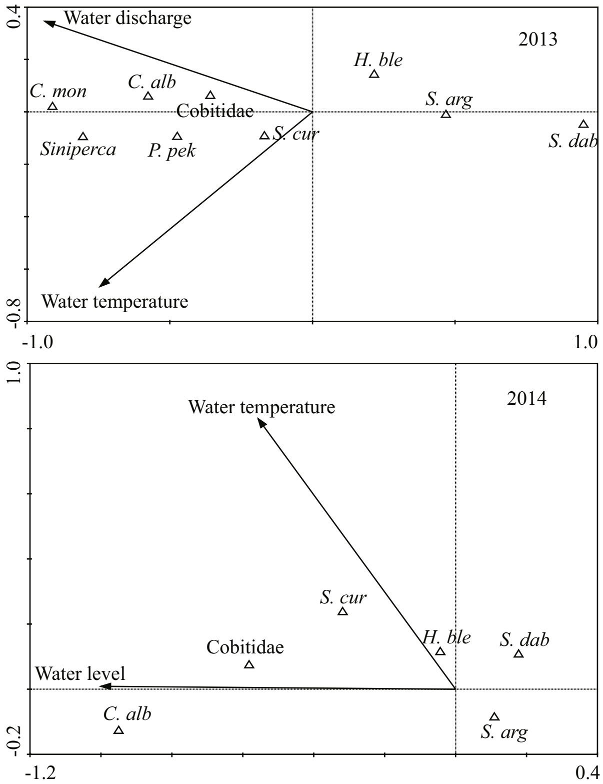

Fig.5 Biplot of species and environmental variables in 2013 and 2014

H. ble: *Hemiculter bleekeri*; *S. arg*: *Squalidus argentatus*; *S. dab*: *Saurogobio dabryi*; *C. mon*: *Culter mongolicus*; *C. alb*: *Culter alburnus*; *P. pek*: *Parabramis pekinensis*; *S. cur*: *Squaliobarbus curriculus*.

are linked with increased diversity and yield of fishes in riverine systems (Burgess et al., 2013). Bénech and Peñáz (1995) reported that the considerable portion of recruitment in fish populations in the floodplain originates from the main river, with larvae and young juveniles entering the floodplain for nursery and growth in the Central Delta of the Niger River. Sixteen species of RL were sampled in the present study, these fish species will play important roles in fish diversity in the Dongting Lake. According to studies, these sixteen fish species represent 23.5% of the species in the west Dongting Lake (a part of the Dongting Lake directly connecting with the Songzi channel) (Zhu et al., 2014). In the present study, huge amuont of ichthyoplankton (3 350 million in 2013 and 2 100 million in 2014), especially RL, flow into the Dongting Lake and play important roles in fish recruitment in the Dongting Lake.

The river-lake migratory fish of Dongting Lake partly originate from its own tributaries and mostly from the Changjiang mainstream (Zhou et al., 1986). River-lake migratory fishes represent 23.6% of the fishes in the Dongting Lake (Tang and Qian, 1979). In 1963, the production of river-lake migratory fishes accounted for 32% of the fishery yield in the Dongting Lake (Li et al., 2013a). The river-lake migratory fishes from the Changjiang River also play vital roles in the fish resources in the Dongting Lake.

In recent decades, reduction in fish diversity and abundance occurred in numerous Changjiang lakes due to the construction of sluice gates leading to river-lake disconnection, environmental pollution, and overfishing. For example, in Honghu Lake, fish species decreased from 74 in the 1960s to 57 in the 1990s (Chen and Xu, 1995) and in Donghu Lake, fish species dropped from 67 in the 1960s to 38 in the 1990s (Huang and Xie, 1996). We suspect that without ichthyoplankton recruitment from the Changjiang mainstream, fish diversity and abundance in the Dongting Lake will also dramatically decrease.

4.2 Environmental factors and fish resource conservation

While water level and (or) water flow fluctuated, ichthyoplankton recruitment also fluctuated over time during the sampling period. In the present study, evident temporal patterns were observed for ichthyoplankton recruitment. Some species bred earlier in the season, for example *S. argentatus*, *S. dabryi*, and *H. bleekeri* while some species bred relatively late, for example, *C. alburnus*, *C. mongolicus*, and *P. pekinensis*. Spawning of most fish species was significantly correlated with flooding (Figs.2 and 5). For example, rheophilic species (i.e. *S. curriculus*) and some eurytopics (i.e. *C. mongolicus*, *C. alburnus*, *P. pekinensis and Siniperca*) show strong requirement for flood pulse for spawning (Fig.5). These findings agree with the results of other researchers (Yi and Liang, 1964; Yi et al., 1988a; Qiu et al., 2002; Wang et al., 2008). Flooding plays an important role in spawning of RL such as the four major Chinese carps, *Coreius guichenoti*, *C. heterodon*, and *Leptobotia elongata* (Yu et al., 1984; Yi et al., 1988a; Cao et al., 2007). As the typical river-lake migratory fishes, the four major Chinese carps are also important commercial fish species and have been studied extensively in the Changjiang Basin (Wu et al., 1988; Yi et al., 1988a; Qiu et al., 2002; Tan et al., 2007; Jiang et al., 2010). Li et al. (2013b) reported that the most favorable flood condition for spawning of the four major Chinese carps involves the diurnal increase in water level and water discharge to values higher than 0.55 m/d and

2 100 $m^3/(s·d)$, respectively. Meanwhile, the drift density of most fish species was also suggested to correspond with water discharge (Jiang et al., 2010). Particularly, Zhou et al. (1986) considered that the percentage of ichthyoplankton of the four major Chinese carps flowing through the three inlet channels is approximately equal to the percentage of water discharge. Therefore, water discharge is very crucial to ichthyoplankton drift.

Given the heavy human activities, the water discharge flowing through the three inlet channels has sharply decreased (Li et al., 2009; Fang et al., 2014; Hu et al., 2014). In 1994–2002, and 2003–2011, the mean discharge was 616×10^8 m^3/s and 500×10^8 m^3/s, 32.1% and 44.9% less than long term average one (911×10^8 m^3) (Hu et al., 2014), respectively. This decrease in discharge not only caused the shrinking and siltation of the channel, but also hindered the recruitment of ichthyoplankton to the Dongting Lake (Zhou et al., 1986).

To prevent the further demise of the channels, irrigation measures were proposed for the three channels, and a sluice gate was suggested for the Songzi channel (Wang et al., 2013). For the conservation of fish resource and increasing ichthyoplankton recruitment, we suggested to irrigate the channel to increase water discharge as this action may increase the transport of ichthyoplankton from the Changjiang mainstream to the Dongting Lake. However, we advised against building the sluice gate because such structure may prevent ichthyoplankton flow into the lake.

5 CONCLUSION

As a result of the construction of sluice gate, which led to river-lake disconnection, environmental pollution, and overfishing, fish diversity in a number of Changjiang lakes sharply decreased. Dongting Lake, as one of the only three lakes remaining connected with the Changjiang mainstream, maintains high fish diversity and production. Our research shows the still high abundances of ichthyoplankton recruitment to the Dongting Lake from the Changjiang River. Owing to heavy human activities, water discarge flowing through the three inlet channels, which flow into the Dongting Lake, has sharply decreased, which will cause a decrease in ichthyoplankton recruitment. Therefore, we suggest the irrigation of the channel to increase water discharge.

6 DATA AVAILABILITY STATEMENT

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

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