

SPECIES COMPOSITION AND ABUNDANCE OF EGG AND LARVAL FISH IN THE LOWER REACHES OF GANJIANG RIVER UNDER CASCADED DEVELOPMENT

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Abstract. Egg and larval fish investigation can be deduced the distribution and reproductive characteristics of adult fish. Ganjiang River is the longest river flowing into the Poyang Lake, and one of the important tributaries of the Yangtze River. Due to the construction of cascade water conservancy projects on the mainstream of the river, the fish resources have been affected. In order to correctly design protection measures of fish resources, egg and larval fish species composition and abundance at Fengcheng section in lower reaches of the river were investigated between May and June 2019. The results indicated that: (a) of the 29 species of egg and larval fish collected, and the individuals of *Hemiculter bleekeri*, *Rhinogobius giurinus*, *Parabramis pекinensis*, *Squalidus argentatus* and *Xenocypris argentea* were most abundant; (b) egg abundance was higher through May while larval abundance was higher during June; (c) the egg abundance of the four carps further declined and two new spawning grounds were found. Therefore, we suggested that the ecological regulation of the Ganjiang River should be managed to create flood peaks and make the daily increment of water level greater than 0.55 m when water temperature was between 18-24 °C during May to July.

Keywords: *Ganjiang River, hydraulic complex, early-stage fish recourse, diurnal variation, ecological regulation*

Introduction

The resources and spawning grounds of most fish have been negatively affected by some factors, such as water pollution, hydraulic engineering construction, overfishing, and so on (Sun et al., 2015; Xu et al., 2015). The dynamics of egg and larval fish resources are sensitive indicators of environmental changes (Gogola et al., 2013). In addition, early life history stages play an important role in fish population dynamics (Kamler, 1992). Meanwhile, knowledge about the mechanisms underlying recruitment success during the early life history stages provides essential information to explain population dynamics (Trippel and Chambers, 1997). The abundance, spawning grounds, and reproductive traits of adult fish can be inferred from information on the distribution patterns of egg and larval fish (Doyle et al., 1993; Nonaka et al., 2000; Bialecki et al., 2001; Cao et al., 2007). Therefore, knowledge of egg and larval fish assemblages provides fundamental information that is valuable for conservation and management.

The black carp (*Mylopharyngodon piceus*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Hypophthalmichthys*

nobilis), referred to as the “four major Chinese carps”, are all commercially important freshwater fish species in China. Ganjiang River is the largest river flowing into the Poyang Lake, and one of the important tributaries (the 7th largest) of the Yangtze River (Xiong, 2007). Historically, a total of 118 fish species were recorded in the Ganjiang River (Tian, 1989). And in 1960s, there were 12 spawning grounds for the four major Chinese carps in the river (Tian, 1989). Due to the separation of dams in the Ganjiang River, the water environment has changed, and the fishery resources have been affected (Tang et al., 1993). Meanwhile, the function of these spawning grounds has begun to decrease, and the 12 spawning grounds in the Ganjiang River had been investigated and found that only three spawning grounds were well preserved and other spawning grounds had degenerated (Liu et al., 2009; Hu et al., 2015; Guo et al., 2020). At present, six hydro-junctions on the Ganjiang River has been gradually completed, which has blocked the connection between the upstream and downstream of the Ganjiang River. After the cascade hub construction on the Ganjiang River have been completed and put into operation, it is expected that the larval fish abundance will be further reduced. In this case, a pressing matter of the moment is to explore the ecological impact of the larval fish, and to correctly design and implement protection measures.

In order to further understand the existing fishery resources in the Ganjiang River, the larval fish abundance was investigated through the fixed-point collection in the lower reaches of Ganjiang River. The present study was to evaluate: 1) species composition of egg and larval fish, 2) diurnal pattern of egg and larval abundance, 3) spawning grounds and scale of the four major Chinese carps, and 4) relationships of larval assemblages to environmental variables. The results of the research will benefit to fill in the blank of the early fish resources information after the construction of water conservancy project in the Ganjiang River, and clarify the ecological functions of the fish in this region.

Materials and methods

Study area

Studies on early-stage fish resources have been conducted in China since the early 1950s (Cao et al., 2007). Subsequently, a number of researchers investigated the early-stage fish resources of important rivers such as the Yangtze River, especially the four major carps in China, and identified many important spawning grounds by extrapolating the developmental periods of eggs and larvae and water flow rates (Cao et al., 2007). By the 1990s, due to the completion of the Three Gorges Water Conservancy Project, researchers conducted long-term and continuous surveys of Yangtze River eggs and larvae. The Ganjiang River, however, is one of the eight major rivers of the Yangtze River and is an important river for replenishing fish resources in the Yangtze River (Guo, 2018).

Ganjiang River, the longest river in Jiangxi Province, is more than 823 km long and has a drainage basin area of 82809 km² (Xiong, 2007). The riverhead is located on the Shiliaodong (in Yangdi Town) with a geographical coordinate of 116°22' E and 25°57' N, and the estuary is located on the Wangjiangting (in Wucheng Town) with a geographical coordinate of 116°01' E and 29°11' N (Xiong, 2007). The lower reaches of the river are below Xingan and have a length of about 208 km, and from Ganzhou to Xingan is the middle reaches with a length of about 303 km, and the upper reaches are above Ganzhou and have a length of about 312 km (Xiong, 2007; Fig. 1). The basin presents a mid-subtropical humid climate, and the mean annual precipitation and river runoff are about 1580.8 mm and 2125 m³/s, respectively (Xiong, 2007).

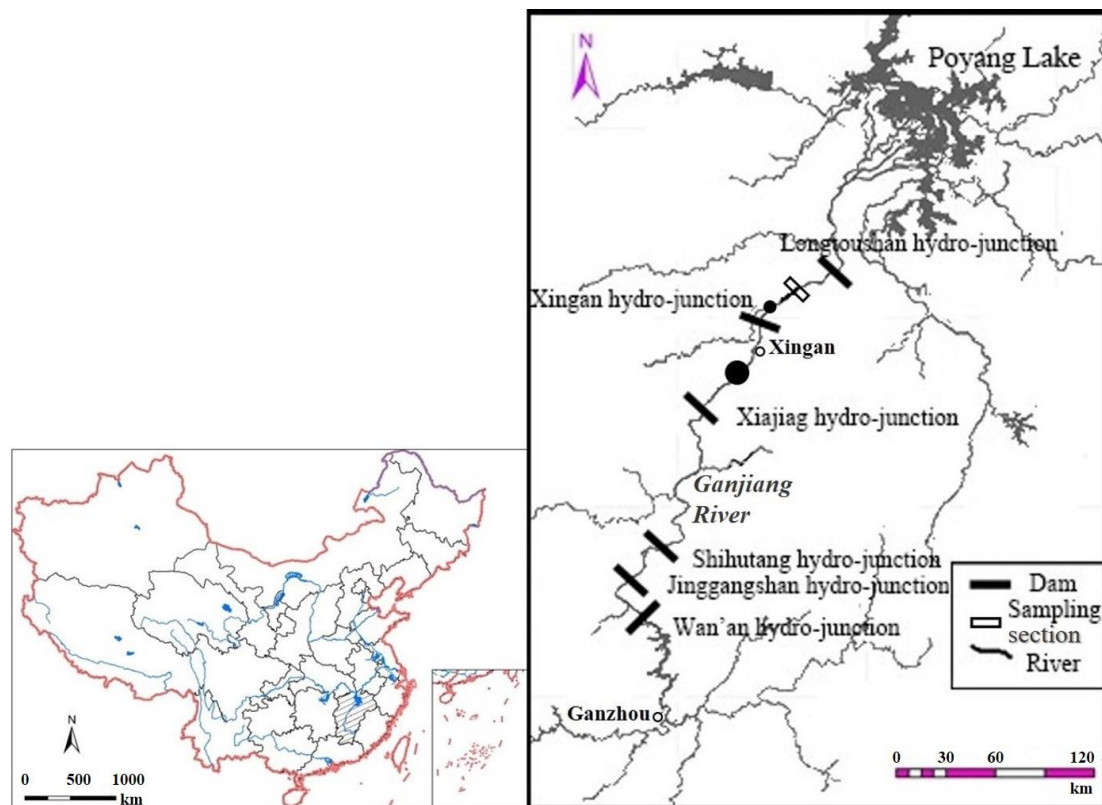


Figure 1. Locations of sampling section and spawning grounds (●) of the four major Chinese carps in the Ganjiang River

Samples collection

Based on the results of the survey of eggs and larvae in the Ganjiang River during the historical period (Liu et al., 2009; Hu et al., 2015; Guo et al., 2020), as well as the findings of some other rivers (Hu et al., 2019; Wang et al., 2020), it was concluded that the peak period of eggs and larvae occur mostly from May to July, so the eggs and larvae were collected day by day at the Fengcheng section (28°12'4"N, 115°46'47"E) during May 3 to June 23, 2019 (Fig. 1). Diurnal sampling was carried out twice between 7: 00 and 8: 00, and between 17: 00 and 18: 00 (Yi et al., 1988; Li et al., 2016). Each collection lasted about 30 min. Sampling was conducted with a conical net (1.0 m length, 0.5 m in diameter, with 0.3 mm in mesh size) to collect eggs and larvae just below the water surface (water depth, 0.5 m) (Yi et al., 1988, 2016; Guo et al., 2020). A mechanical flow meter was attached to the mouth of the net to calculate the water volume filtered during sampling. Sampling was conducted near the shore because of the high current velocity in the middle of the river (Li et al., 2016; Guo et al., 2020).

Eggs and larval fish were separated and counted immediately after sampling. The developmental stages and developmental times of each stage were defined according to Yi et al. (1988) and Cao et al. (2007). Eggs were incubated in a tank (0.18 m high, 0.2 m in diameter) and identified to species level. Each aquarium was stocked with 5–10 eggs, water temperature was maintained at 22–24 °C with air conditioning and the water was aerated (Li et al., 2016). The larvae were preserved in 5% sodium phosphate-buffered formalin (Ren et al., 2016). Species were identified according to Yi et al. (1988) and Cao et al. (2007).

Water temperature, pH and transparency were obtained at sample site with a YSI recorder. Daily water level and water runoff were acquired from the Jiangxi Hydrology Information Network (<http://www.jxssw.gov.cn/>) measured at Fengcheng section.

Data analysis

The runoff of eggs and larvae in the sampling section was calculated according to the method of Yi et al. (1988, 2016) and Guo et al. (2020):

$$d = m / (v \times a \times t) \quad (\text{Eq.1})$$

$$D = \sum_{i=1}^n di / n \quad (\text{Eq.2})$$

$$M = \left(\frac{Q}{q}\right) \times D \quad (\text{Eq.3})$$

where d is the density of eggs and larvae collected at the sampling site (ind./m³), m is the number of eggs and larvae obtained in a single sampling, v is the velocity of river water passing through the mouth of conical net (m/s), a is the area of cone net mouth (m²), and t is the duration of single sampling (s); di is the density of eggs and larvae at the i sampling point (ind./m³), D is the average density of cross-section eggs and seedlings (ind./m³); q is the river water flow in the network (m³/s), Q is the average water flow of sampling site (m³/s), M is the runoff of eggs and larvae in a single sampling (ind./m³).

The runoff of eggs and larvae flowing through the section is calculated by interpolation method in the free time between the two samples, and the calculation is as follows: $M' = t' / 2 (M_1/t_1 + M_2/t_2)$. Where t' is the interval time between the two acquisitions (s), t_1 and t_2 represent the duration of the two acquisitions, M_1 and M_2 are the number of eggs and larvae collected before and after two times.

The runoff (N_m) of fish eggs and larvae passing through the survey section per day and night is the sum of the runoff of eggs and larvae collected regularly within 24 h and the sum of the runoff of eggs and larvae collected in non-collection time between the two samplings, and the calculation is as follows: $N_m = \sum M + \sum M'$.

According to the development period of fish eggs and larvae, combined with the calculation of river water velocity, the location of spawning ground is inferred, and the calculation is as follows: $L = V \times T$. Where L is the drifting distance of eggs from spawning ground (m); V is the water flow velocity of sampling site (m/s), T is the time that fish eggs have drifted in the water from spawning to sampling site (s).

The daily recorded hydrological data such as water temperature, pH, flow, water level and transparency are input and calculated by SPSS 20.0, and the graph is drawn by using GraphPad. The relationship between spawning quantity and environmental factors was compared by variance analysis, and the relationship between environmental factors and larval density was calculated by redundancy analysis.

Results

Environmental factors

Water level ranged from 23.1 m to 31.5 m with a mean of 25.5 ± 2.1 m (mean $\pm$ SD) during May to June in 2019. And it had a peak on 11 June. Water flow, ranging from

3260 to 17279 m³/s with a mean of 6212 ± 3436 m³/s, showed a similar pattern to that of water level. Water temperature ranged from 21.5 to 27.8 °C with a mean of 24.8 ± 1.7 °C. It showed an increased slowly through May to June in 2019. Transparency ranged from 0.17 to 0.54 m and showed a clear daily variation with higher values during May and lower values during June. There was no clear diurnal pattern for pH value (Fig. 2).

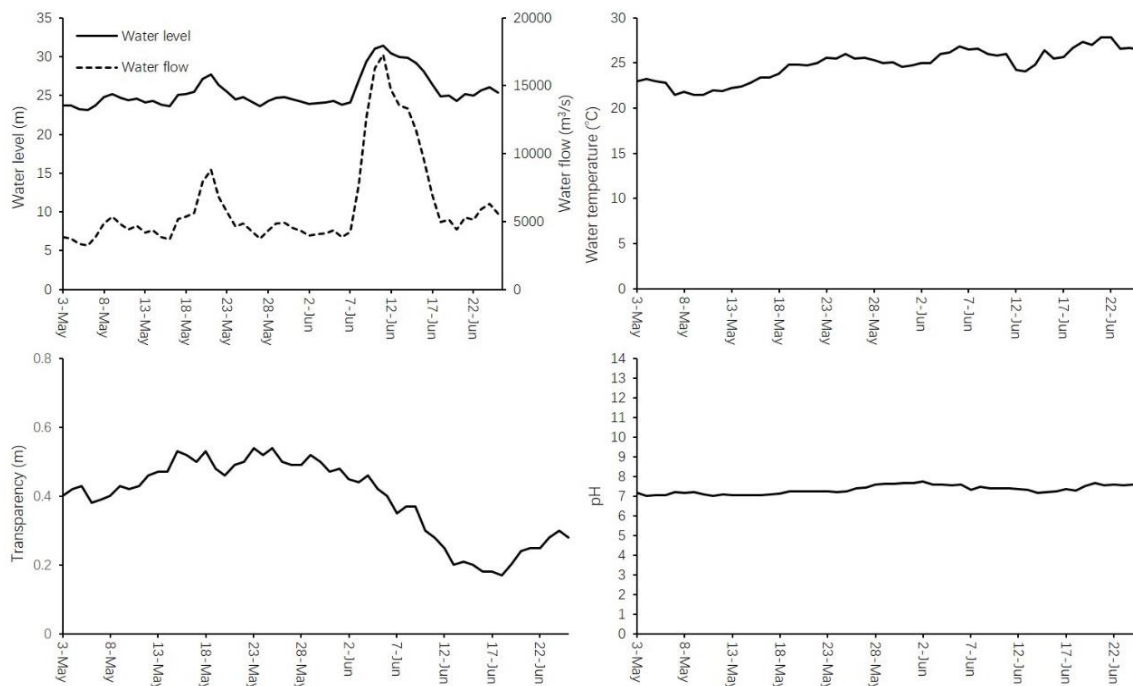


Figure 2. Environmental variables measured at Fengcheng section in the Ganjiang River during May to June 2019

Species composition of egg and larval fish

A total of 100 eggs and 3816 larvae, belonging to 7 families and 29 species, were collected during the study period (Table 1).

Squalidus argentatus was the most egg abundant species, comprising 33% of the total number of fish eggs, followed by *Parabramis pekinensis* (25%) and *Xenocypris argentea* (18%). And egg abundance of the four major Chinese carps accounted for 10% (Table 1).

In addition, the larval abundance of *Hemiculter bleekeri* was over half of the total number larval fish, followed by *Rhinogobius giurinus* (28.69%) and *Parabramis pekinensis* (6.18%). And larval abundance of the four major Chinese carps accounted for 2.86% (Table 1).

Diurnal pattern of egg and larval abundance

The mean densities of eggs and larval fishes during May to June in 2019 were 4.27 ind./1000 m³ and 66.09 ind./1000 m³, respectively.

The diurnal trend of egg and larval density during May to June in 2019 was different (Fig. 3). Egg abundance was higher in May 2019 and peaked on 11 May (10.78 ind./1000 m³). But larval abundance was higher during June than that in May,

with three peaks on 24 May (131.79 ind./1000 m³), 7 June (176.03 ind./1000 m³), and 21 June (191.70 ind./1000 m³), respectively.

Egg abundance and spawning ground of four major Chinese carps

The egg abundance of four major Chinese carps was 6.1 million during May to June in 2019. Moreover, grass carp, silver carp and bighead carp were accounted for 41.0%, 50.8% and 8.2%, respectively.

Table 1. Number of eggs and larvae of fishes collected in the Fengcheng section of Ganjiang River from May to June 2019

Family and species	No. of egg	Ratio	No. of larvae	Percentage (%)
Salangidae				
<i>Neosalanx taihuensis</i>			16	0.42
Cyprinidae				
<i>Ctenopharyngodon idellus</i>	3	0.03	46	1.21
<i>Squaliobarbus curriculus</i>	2	0.02	30	0.79
<i>Opsariichthys bidens</i>			2	0.05
<i>Parabramis pekinensis</i>	25	0.25	236	6.18
<i>Megalobrama amblycephala</i>			6	0.06
<i>Zacco platypus</i>			3	0.08
<i>Hemiculter bleekeri</i>	6	0.06	1987	52.07
<i>Pseudolaubuca sinensis</i>			74	1.94
<i>Pseudolaubuca engraulis</i>	3	0.03	117	3.07
<i>Culter alburnus</i>	1	0.01	8	0.21
<i>Culter mongolicus</i>			7	0.18
<i>Cultrichthys erythropterus</i>			7	0.18
<i>Hypophthalmichthys molitrix</i>	3	0.03	59	1.55
<i>Aristichthys nobilis</i>	4	0.04	4	0.10
<i>Squalidus argentatus</i>	33	0.33	14	0.37
<i>Xenocypris argentea</i>	18	0.18	15	0.39
<i>Xenocypris davidi</i>			11	0.29
<i>Xenocypris microlepis</i>			6	0.16
<i>Pseudorasbora parva</i>			4	0.10
<i>Spinibarbus sinensis</i>			36	0.94
<i>Acheilognathus tonkinensis</i>			3	0.08
<i>Saurogobio dabryi</i>			3	0.08
<i>Gobiobotia filifer</i>	2	0.02	5	0.13
Cobitidae				
<i>Leptobotia elongate</i>			2	0.05
Serranidae				
<i>Siniperca kneri</i>			15	0.39
Odontobutidae				
<i>Odontobutis obscura</i>			2	0.05
Gobiidae				
<i>Rhinogobius giurinus</i>			1095	28.69
Adrianichthyidae				
<i>Orizias latipes</i>			3	0.08

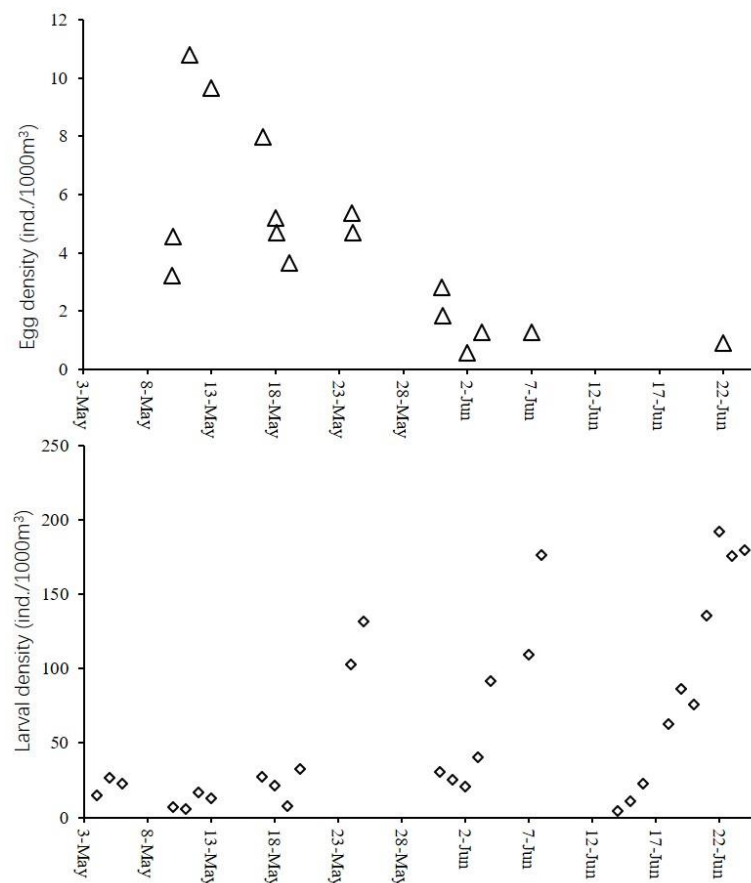


Figure 3. Diurnal trend of egg and larval density in the Fengcheng section of the Ganjiang River during May to June 2019

Among the samples, the egg developmental stages were divided into neurula stage, closure of blastopore stage, tail bud stage and rudiment of heart stage. Approximately 86% of the eggs were in the tail bud and rudiment of heart stages, which last 19-29 h after fertilization (Yi et al., 1988). Mean current velocity at the sampling site was 1.01 ± 0.23 m/s. Based on the egg developmental stages and mean river velocity, two main spawning grounds were identified upstream the Fengcheng section in the Ganjiang River during 2019. One was about a 4 km stretch between Zhoushang to Yongtai, and the other was about an 18 km stretch from Kengdong to Renhe (Fig. 1).

Relationships of egg and larval assemblages to environmental variables

The egg density had a significant negative correlation with water temperature and pH ($P < 0.01$). But larval density had a significantly positive relationship with water temperature and pH ($P < 0.01$), and a negative relationship to transparency ($P < 0.05$).

Five environmental factors (i.e., water temperature, transparency, pH, water level and flow) were contributed significantly to the explanation of the larval fish assemblages. The correlation efficiencies of the first and second RDA axes were 0.94 and 0.87 of the species-environment relationships, respectively. The first axis was highly correlated with the water temperature; the second axis was highly correlated with the water level (Fig. 4). The ordination diagram showed that *Hypophthalmichthys*

molitrix scattered near the origin, which indicated average values in relation to the environmental variables for the species; *Parabramis pekinensis*, *Pseudolaubuca engraulis*, *Hemiculter bleekeri* and *Rhinogobius giurinus* were along the first axis, showing mainly a positive relationship with water temperature; *Pseudolaubuca sinensis* was mainly along the second axis, showing a negative correlation with the water level (Fig. 4).

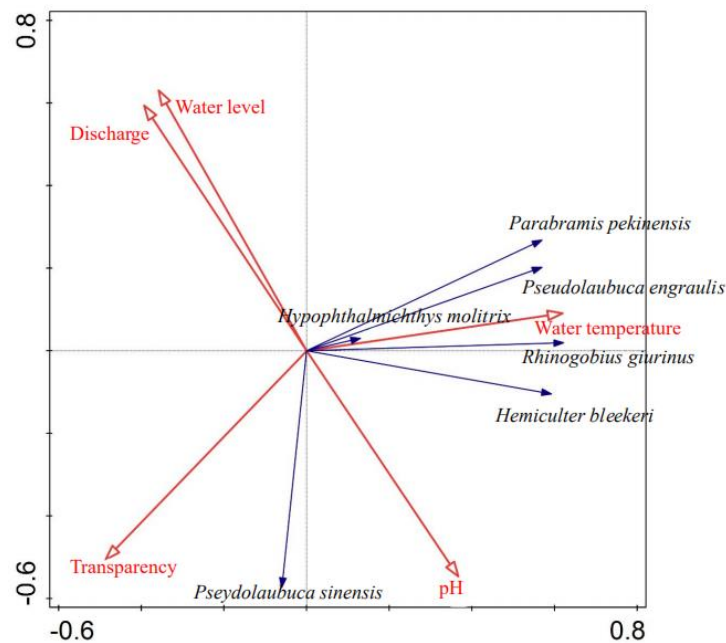


Figure 4. Biplots of the first two axes of the redundancy analysis (RDA) ordination of larval fish assemblages in the Fengcheng section of the Ganjiang River

Discussion

A total of 29 species of egg and larval fish were identified at Fengcheng section in the lower reaches of Ganjiang River from May to June during 2019. And *Hemiculter bleekeri*, *Rhinogobius giurinus*, *Squalidus argentatus*, *Xenocypris argentea* and *Parabramis pekinensis* were dominant species. Meanwhile, the mean densities of eggs and larval fishes were 4.27 ind./1000 m³ and 66.09 ind./1000 m³, respectively. The species richness and mean densities of eggs and larval fishes in the present study were less than that recorded in the recent research (Guo et al., 2020), while dominant species of egg and larval fish at the section of the river were similar. Compared to the egg and larval fish assemblage in the Yangtze River, the number of species collected in the present study was much less than those recorded in some recent research, e.g., 51 species recorded in Li et al. (2011), 52 species recorded in Ren et al. (2016), 44 species recorded in Guo et al. (2017), 34 species recorded in Hu et al. (2019), 37 species recorded in Chen et al. (2020) and 49 species recorded in Chang et al. (2021). In addition, the mean densities of eggs and larval fishes that occurred in the upper (Tang et al., 2010), middle (Li et al., 2011; Guo et al., 2017; Hu et al., 2019), or lower (Ren et al., 2016) reaches of the Yangtze River were much higher than that presented in this research. Egg and larval fish collection are proposed as a more efficient approach to investigate fish diversity and to assess the resource status of fish populations for the

higher abundance and usually lower labor investment compared to traditional methods targeting adults (Cao et al., 2007; Ren et al., 2016). The sampling in this research was conducted using a conical net by placing it facing the water flow and thus mainly targeting the drifting egg and larval fish. Thus, further research should be designed with sedimentary larvae included.

The diurnal patterns of egg and larval fish assemblages at Fengcheng section in the lower reaches of Ganjiang River were clearly observed. Briefly, larval fish were highly abundant through June, while the emergence of a high abundance of eggs occurred during May. This temporal patterns of egg and larval fish occurrence were also observed in the recent research (Guo et al., 2020). The timing of fish reproduction has evolved through time to optimize recruitment success by matching the emergence of larvae with appropriate water temperature and physical habitat conditions (Lowe-McConnel, 1987; Munro et al., 1990). In temperate regions, optimal conditions for reproduction of most riverine fishes are predicted to occur when flooding coincides with the appropriate temperature (Bayley, 1991). The spawning of most fish in the middle and lower reaches of the Yangtze River occurs when the water temperature is above 18 °C (Cao et al., 2007). Water temperature at Fengcheng section in the lower reaches of Ganjiang River rose to this temperature and remained increased through May to June (Fig. 2); meanwhile, the water flow and water level increased sharply and maintained a high-level during May to June (Fig. 2). The results suggested that spawning of most fish occurred at a high-water level and water flow and when water temperature was appropriate. Thus, the results demonstrated that egg and larval fish assemblages in the lower reaches of the Ganjiang River were mainly determined by water temperature, water flow, and water level.

The four major Chinese carps (i.e., black carp, grass carp, silver carp, and bighead carp) lay their drifting eggs in rivers, the fertilized eggs hatch and the larvae develop during downstream drift, the larvae and juveniles then enter floodplain lakes to grow and mature (Yi et al., 1988; Cao et al., 2007). So far, reproduction of these carps has declined since the construction of dams due to an altered water flow and thermal regime in key river systems in China (Hu et al., 2015). Historically, 12 spawning grounds for the four carps were found in the mainstream of the Ganjiang River, located from Ganzhou to Xingan within a range of 303 km (Tian, 1989). After construction of the Wan'an Dam (completed in 1990), Shihutang Dam (closed in 2012) and Xiajiang Dam (completed in 2017), nine spawning grounds were inundated by these reservoirs (Guo et al., 2020). This caused that the egg abundance of the four domestic fishes had decreased from 2.5 billion in the 1960s, 1.9 billion in the 1970s, 1.3 billion in the 1980s, 0.5 billion in the 1990s, to just 20 million in 2000 (Liu et al., 2009; Hu et al., 2015). By 2017, their egg production had dropped further to 11 million (Guo et al., 2020). In present study, the egg abundance of the four carps in the Fengcheng section of Ganjiang River was only 6.1 million during May to June in 2019; and based on the egg developmental stages and mean river velocity, two main spawning grounds were identified upstream the Fengcheng section in the Ganjiang River during 2019 (Fig. 1). But along with the Xingan Dam (completed on November 2019), Jinggangshan and Longtoushan dams (under construction) have been gradually completed (Fig. 1), all spawning grounds of the four major Chinese carps in the Ganjiang River will be flooded. Some studies indicated that the density of drifting eggs of the four carps was mainly influenced by the diurnal variation of water level, the diurnal variation of water discharge, water temperature, humidity, and air pressure (Duan et al., 2009; Li et al.,

2013). When water temperature was between 18 °C and 24 °C, especially in association with the diurnal increase of water level greater than 0.55 m/d, spawning activities was always favored (Li et al., 2013). Thus, in order to ensure the successful spawning of the four carps during May to July, we suggested that the ecological regulation of the Ganjiang River should be managed to create flood peaks and make the diurnal increase of water level greater than 0.55 m/d when water temperature was between 18-24 °C.

Conclusion

Ganjiang River is the longest river flowing into the Poyang Lake, and one of the important tributaries of the Yangtze River. Historically, 12 spawning grounds for the four major Chinese carps were recorded in the river. Due to the construction of dams (such as Wan'an Dam, Shihutang Dam and Xiajiang Dam) in mainstream of the river, the egg abundance of the four carps had been declined. Although two new spawning grounds for the four carps were found in present study, but all spawning grounds will be flooded along with the cascade water conservancy projects have been gradually built. In order to ensure the successful spawning of the four carps, the ecological regulation of the Ganjiang River should be managed to create flood peaks and make the diurnal increase of water level greater than 0.55 m/d when water temperature was between 18-24 °C during May to July. Meanwhile, in order to better protect the fish resources of Ganjiang River, it is recommended that: (1) scientific scheduling of water conservancy hubs at all levels of Ganjiang River according to fish breeding rhythms; (2) regular monitoring of fish resources; and (3) ecological supplementation of important species, such as the stocking of sexually mature individuals or fry, to increase the abundance of fish populations in Ganjiang River water bodies.

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Conflict of interests. The authors declare that they have no conflict of interests.

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