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STUDY ON PHYSICAL AND FUNCTIONAL HABITAT CHARACTERISTICS OF RIVERS BASED ON PROTECTION TARGET

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ABSTRACT

Physical and functional habitats are two important components of river environments, both reflecting the adaptability of aquatic organisms to their surroundings and the shaping of their ecological habits by the habitat environment. Studying the two aspects together can lead to an in-depth understanding of aquatic organism living environments and is more conducive to the comprehensive protection and restoration of aquatic ecosystems. We simulated and analyzed the physical habitat characteristics of *Plecoglossus altivelis* in the Nanxi River and carried out four water ecological surveys in the main channel of the Nanxi River. The research and current stage survey analyses showed that the rapids and deep pools of the Nanxi River mainstream physical habitat are both alternatively and evenly distributed, and each account for more than 20% of the total length of the river. Under extreme flow conditions, a relatively stable distribution of riffles and deep pools are maintained, providing habitats for fish. Under certain water conditions, changes in permanganate index, total phosphorus, and total nitrogen observed during the fattening and spawning periods were consistent with the migration habits of *P. altivelis*. Algae growth was related to water quality, species diversity, quantity, and distribution characteristics of benthic algae, and was closely related to the migration time and habitat selection of *P. altivelis.*

Keywords: Physical habitat, functional habitat, *Plecoglossus altivelis*, benthic algae, water ecology survey

1 INTRODUCTION

Climate change and the development and utilization of water resources by humans have caused major changes in the natural ecological environments of rivers, resulting in a widespread reduction in suitable habitats for various organisms. It is more important and urgent than ever before to maintain high-quality, stable habitats for wildlife to further protect the land and environments upon which the organisms depend for survival and reproduction and to maintain the health of river systems. River habitat health depends on both biotic and abiotic factors. The assessment of river habitat includes many factors. Most studies divide habitats into two categories: functional habitats, which are ecologically defined habitat units; and flow biotopes or physical habitats, which are habitat units within river channels defined by geomorphologists (Shi Ruihua et al., 2008). The first category focuses on a biological environment consisting of plants and animals with self-organizing functions; the second focuses on abiotic factors, including riverbed topography, discharge process, and water quality conditions. The study of hydraulic parameters to characterize physical habitat characteristics (Yang Yu et al., 2007, Wang Xiuying et al., 2011) and the establishment of its relationship with functional habitats has gained recognition in recent years. Harper (Harper DM et al., 1998) and Kemp (Kemp et al., 2000) studied the relationship between different water flow structures and habitats and concluded that there is a non-random distribution of Froude number and functional habitat. C. Li et al. (LI Chong et al., 2006) and J. Li (LI Jian et al., 2010) studied the relationship between amount of spawn and three eco-hydrological factors, which are number of discharge-rise events, total days of discharge rise (DDS), and average DDS for discharge rise process during May and June, at the spawning sites of the Yangtze River's four major fishes. Thorne (Thorne C R, Easlon K,1994) used a mixture of qualitative observation and morphometric measurement to build up a record of the form of a river on the basis of a field visit, and the results were used to assess the current morphological stability of the channel and draw conclusions about the natural fluvial processes operating in the channel and the impacts of past engineering intervention or on-going operational maintenance and to infer channel stability which can be taken to restore the river to a more natural state. Nagayama (SHIGEYA NAGAYAMA, FUTOSHI NAKAMURA. 2018) showed that the shape of a riverbed is closely related to habitat diversity. The hydrodynamic indicators studied in the current literature mainly include water depth, flow velocity, flow velocity gradient, and Froude numbers (LI Qian, 2013). Habitat analyses and assessment methods, such as habitat suitability indices, habitat assessment models, and physical habitat simulations, are based on the relationship between physical habitat characteristics and functional habitats, and to a certain extent reflect the status of river habitats. These methods analyze physical habitats by studying fish or study physical habitats with large benthic invertebrates or large plants as the primary study organisms. Now that research has provided some understanding of physical habitat characteristics, it is necessary to consider the relationship between functional habitat characteristics and the behavior of organisms in a certain type of physical habitat environment. An in-depth study of this process is an important step to understand complex ecosystems.

Based on knowledge of the suitability of existing physical habitats, we (1) simulated and analyzed the physical habitat characteristics of *Plecoglossus altivelis* habitats in the Nanxi River, (2) analyzed the relationship between physical habitat and fish migration characteristics in combination with *P. altivelis* migration time, (3) conducted water ecological surveys on the main stream of the Nanxi River during four periods, and (4) monitored the correlation between benthic algae and *P. altivelis* migration based on the feeding characteristics of *P. altivelis*.

2 RESEARCH AREA AND STUDY METHODS

2.1 Research area

The Nanxi River originates from Daqinggang at the southeast junction of Xianju and Yongjia counties on the eastern coast of Zhejiang Province in China. It flows through Xikou, Yantou, Shatou, and Shangtang in Yongjia County, and then reaches Oubei Town on the opposite side of Wenzhou, where it merges into Oujiang. The Nanxi River is the largest tributary on the left bank of Oujiang's lower reaches. The drainage area is 2,436 km^2, and the mainstream river is 142 km long, with an average gradient of 6.0%. The main stream can be divided into upstream, midstream, and downstream areas. The upstream area stretches from the river source to Xikou, and is known as Dayuan Brook. This stretch of river is 61 km long, with an average gradient of 10.5%. Flowing through the high-elevation mountains and valleys, the river is meandering and with a fast current. The two main tributaries of Nanxi River, Yantan Brook and Dayuan Brook, merge at Xikou. The reach from Xikou to Shatou is midstream. The midstream also meanders, and there are small sporadic terraces and shoals on both sides. It is 48 km long with an average gradient of 1.1%. The estuary is 33 km downstream from Shatou. The downstream is affected by tides, and the average gradient is 0.1%; in this reach, the channel meanders and there are more shoals present. The total runoff of the basin is 2.68 billion m^3, the average annual discharge of the block areas upstream of Shatou is 73.6 m^3/s, and the runoff is 2.32 billion m^3. The Nanxi River Water Supply Project (Blocking River for Water Acquisition Project) was built at the end of the tidal reach in the upstream section of the Nanxi River mainstream in Shatou Town. The project-controlled catchment (water-collecting) area is 2,103 km^2, the average annual runoff is 2.32 billion m^3, the normal reservoir water level is 9.0 m, and the corresponding storage capacity is 5 million m^3.

The Nanxi River Basin is located in a subtropical monsoon climate zone. The main features include a warm and humid climate, abundant precipitation, four distinct seasons, and abundant sunshine. According to the statistics of Yongjia Meteorological Station, the average annual temperature is 18.2°C, the average annual maximum temperature is 22.6°C, the average annual minimum temperature is 14.9°C, and the average annual rainfall is 1,810 mm. The precipitation in the basin varies greatly from year to year, and the distribution is uneven during the year. The rainfall in April to September accounts for more than 70% of the total annual rainfall; this amount includes rainfall during the rainy season (April to June) and typhoon season (July to September).

The Nanxi River Basin has abundant species and biological community diversity. In recent decades, the exploitation of natural resources and the construction of industry in the basin have been restricted so that the ecosystem preservation is relatively intact. The Nanxi River Basin is a national AAAA scenic location, the second highest level of tourist attraction as defined by the Quality Grade of Tourist Attractions in China, and a global geological park. Because the natural level of environmental protection is good, the investigation of the basin background value is likely to reflect the state of the area accurately, and the protection measures implemented according to the survey data are meaningful. Due to recent economic development in the river basin, there is an increasing demand for water resources in the mainstream region of Nanxi River, which has become increasingly stressful on the aquatic ecosystem. Thus, it is urgent to explore the ecological characteristics of the Nanxi River and identify new ways to develop and utilize water resources while simultaneously protecting the aquatic ecosystem.

2.2 Study species

Plecoglossus altivelis is a small and expensive economic fish distributed in the Japanese archipelago, throughout South Korea, and in the sea-connecting streams from the Yalu River in Liaoning Province, China, to the Beilun River in Guangxi Province, China, as well as Taiwan and northern Vietnam (TRAN HAU DUC et al., 2018). In recent years, due to water pollution of the channels connecting rivers and seas, partitioning of water conservancy projects, and overfishing, *P. altivelis* has been on the verge of extinction and is now included in the *China Red Data Book of Endangered Animals* (Wang Song, 1998).

Plecoglossus altivelis is in the order of *Salmoniformes*, the family of *Plecoglossidae*, and the genus of

Plecoglossus. It is commonly known as perfume-fish because of the cavity full of balsam on its back that can emit a pleasant fragrance. The life cycle of *P. altivelis* is very short, approximately one year, so it commonly called “year fish.” The *P. altivelis* in the Nanxi River were well known as early as the Qing Dynasty. Every year from March to May, when the water temperature of the river gradually rises to 10–15°C, the juvenile fish (2–3 cm in length) that survived through winter in the sea enter the Nanxi River estuary for anadromous migration. From May to June, these fish are commonly seen in Xikou Town, approximately 35 km away from Miaohuo Village in Shatou Town. These fish are also distributed in Gumiaokou, Sanjiaoyan and Shiziyan. At this time, large individuals are approximately 20 cm long (Chen Zhijian, 2003). From September to October, *P. altivelis* migrate from upstream to downstream in the Nanxi River, and the fish return to the spawning site around October 8 each year. The *P. altivelis* spawning sites are approximately 9 km from Qukou Tangwan (Shuangxikou) to Shatou. The main spawning site is located in the area from Shatou Xiafulin to Miaohuo; this reach is approximately 3 km long and is located 25 km away from the estuary tidal zone (Chen Zhijian, 2003). After spawning, the adult fish die. Around November, as the water temperature continues to drop, the juvenile fish enter the sea for the winter.

The feeding behaviors of *P. altivelis* vary across their life cycle by age. They are carnivorous at the larval stage in the sea and become herbivorous and omnivorous as the individual develops and goes back to in the river. Four to five days after hatching, the larvae begin to feed on cladocerans, copepods, and other small crustaceans, which continues until the anadromous migration. During the journey to the river, the feeding organs of the *P. altivelis* change, and the preferred prey gradually transitions to lower algae; the *P. altivelis* scrape the algae attached to stones with their teeth. This type of algae is very thin. *P. altivelis* consume an amount of algae equivalent to one-fifth of their body weight daily, therefore it is necessary to feed from morning to night. An individual with a body length of 45–70 mm mainly consumes the “stone flower” attached to the gravel on the river bottom, which is composed of diatoms, cyanobacteria (blue algae), and chlorophyta (green algae). When *P. altivelis* is close to adulthood, the feeding habits change according to the environment, and food abundance and availability. When the river bottom lacks the “stone flowers”, such as after a flood, the adult *P. altivelis* feed on aquatic insects (Zheng Gaohai, 2017).

P. altivelis inhabit clear streams, and have strict requirements for water temperature and the quality of their habitat. A continuous flow is needed to maintain a suitable temperature, and fresh algae is required to ensure the sweetness of *P. altivelis*. *P. altivelis* complete their entire life cycle in the same year; therefore, if the habitat is destroyed, all adult fish may perish. Thus, *P. altivelis* can be used as a symbolic indicator species for the health of the Nanxi River.

2.3 Hydrological terrain data and its processing method

The Shizhu Hydrological Station is located in the downstream area of the Nanxi River, whose controlled catchment area is 1,273 km^2 in size. It was established in 1956 and is a provincial hydrological station. We acquired daily discharge data from 1957 to 2012 of Shizhu Hydrological Station from water department of local government.

The river cross-section topographic data were assessed by Zhejiang Design Institute of Water Conservancy & Hydro-electric Power for some research on Nanxi River. In this study, the HEC-RAS (Hydrology Engineering Center’s River Analysis System), one-dimensional mathematical model, was used to simulate and calculate the hydraulic characteristics of the river habitat.

2.4 Survey content and indicators

Benthic algae are the main food source during the fattening and spawning periods of *P. altivelis*, and the changes in the quantity and variety of available algae reflect changes in habitat food supply (Zhang Runjie, 2012). The light, temperature, pH, dissolved oxygen (DO), total nitrogen (TN), and total phosphorus (TP) conditions in the water not only affect the water quality, but also directly affect the growth of benthic diatoms (Wu Chunxue, 2008). The chemical oxygen demand permanganate index (COD_{MN}) and ammonia nitrogen (NH_3-N) levels reflect the effects of human activities. Therefore, water quality survey indicators in this study included water temperature, DO, pH, water transparency (SD), NH_3-N, TN, TP, and the COD_{Mn}, which includes benthic algae, the main food source for fattening *P. altivelis*.

2.5 Sampling time and sampling point arrangement

In this study, on-site sampling surveys during four time periods were conducted: November 1st–2nd in 2013 (catadromous migration period), May 26th–27th in 2016 (anadromous migration period), October 20th–21st in 2016 (spawning period), and June 28th–29th in 2017 (fattening period). Sampling was carried out from 9:00 to 17:00 on the same day. Sampling locations were determined according to the distribution of *P. altivelis* habitat. Sampling was completed from Baojiang Brook to the Yongjia County Yuejiang Bridge, with a total of nine points (S1–S9); an additional sampling point at the Qubei Bridge was surveyed during the fourth period, resulting in a total of 10 points (S1–S10). Among them, the S1–S4 points were located in the fattening site, the S5–S8 points were located in the spawning site, and the S9–S10 points were located in the tidal reach of the water supply gate. The benthic algae surveys were conducted on October 20th–21st in 2016 (spawning period) and on June 28th–29th in 2017 (fattening period).

2.6 Sampling and determination

Water temperature, pH, dissolved oxygen and transparency indicators were determined on site. The pH value was measured by a HI8424 pH instrumentation (HANNA, Italy). DO and water temperature were measured by an HQ30D Dissolved Oxygen Meter (Hach, US), and the transparency was measured with a Secchi disk. All indicators were measured three times and averaged. The NH_3-N, TN, TP, and COD_{MN} were determined according to the method specified in *Surface Water Environmental Quality Standard* (GB3838-2002) (China Environmental Protection Administration, 2002). The method of sampling benthic algae was to randomly select three stones with benthic algae from the same water depth at each sampling point, which was performed at three different depths of water, and a 3×3 cm^2 plot was scraped on each stone to collect the algae. Each sample was placed in a separate vial containing distilled water, and Lugol's solution and a formaldehyde solution were added to the vial on site. Samples were transported to the laboratory and concentrated to 20 mL. One milliliter was diluted to 20 mL, and then 0.1 mL of the diluted material was examined microscopically. The benthic algae sampling sites were concentrated at the fattening site (S1–S5). The sampling point positions are shown in Figure 1.

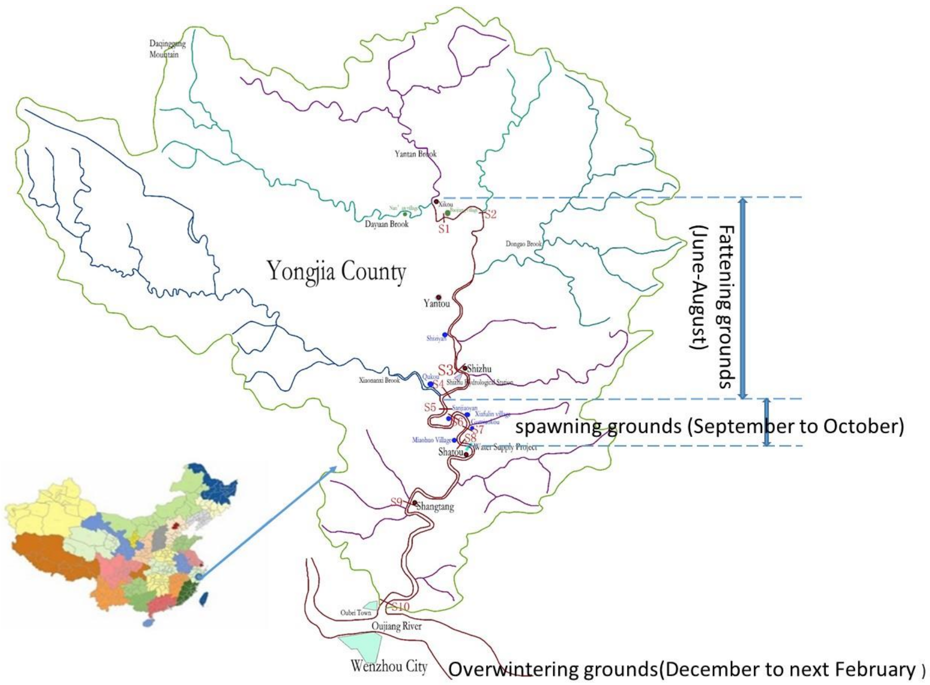

Fig. 1. The Nanxi River Basin and Plecoglossus altivelis habitat distribution

3 RESULTS

3.1 Physical habitat characteristics of the studied river sections

In order to better reflect the physical habitat characteristics, the hydraulic parameters were used t. The maximum water depth along the river under different discharge from the section at the upstream starting point of the mainstream (near South Bank Village) to the section of the Nanxi River Water Supply Project is shown in Figure 2. The river section below 40,000 m enters the Water Supply Project area. The main stream of the Nanxi River is characterized by alternating deep pools and riffles. The distance between the deep pools is approximately 2 km, and there is a riffle every 1 km; a deep pool is present around 1 km. The depth of a small deep pool is generally between one and two meters. Even when the discharge of the river is low, the water depth can be maintained at approximately 1 m. This topographic feature is conducive to the intermittent anadromous migration of *P. altivelis* and ensures that a certain number of habitats remain during intervals of low current.

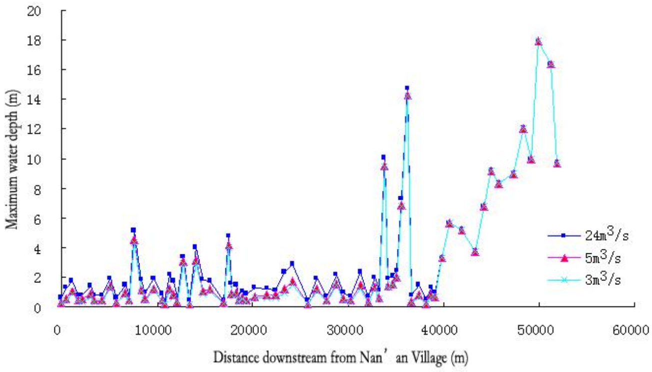

Fig. 2. Maximum water depth along the Nanxi River mainstream

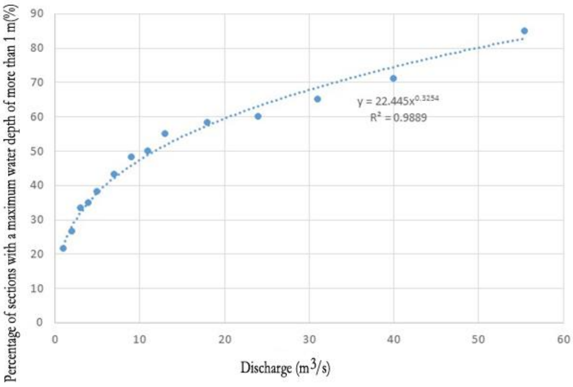

Fig.3. Percentage of Nanxi River sections with water depth over 1 m and its relationship with flow rate

The average annual discharge at Shizhu station is 45.8 m^3/s, and the percentage of the section with a maximum water depth of more than 1 m under different discharge is shown in Figure 3. The six lowest flow rates (1 m^3/s,3 m^3/s, 5 m^3/s, 7 m^3/s, 11 m^3/s, and 18 m^3/s) were used to calculate the habitat parameters of the Nanxi River mainstream as shown in Table 1. Table 1 illustrates that the distribution of riffles and troughs in the main stream of Nanxi River is stable. The number of deep pools with water depths of greater than 1 m at the 40 km reach varies with discharge. Even at a very low discharge, there is still a certain number of deep pools, which provides fish with stable habitats to avoid drought.

Table 1 Habitat parameters of the Nanxi River mainstream flow

Flow rate (m^3/s)	1	3	5	7	11	18
Maximum water depth point of the section with the minimum average water depth (m)	0.07	0.13	0.18	0.21	0.26	0.33
Proportion of sections with area greater than 0.2 m (%)	66%	93%	96%	100	100	100
Average water depth of 95% river sections (m)	0.06	0.11	0.14	0.17	0.20	0.24
Average flow rate of 95% river sections (m/s)	0.01	0.02	0.03	0.04	0.06	0.08
Water surface width of 95% river sections (m)	5.1	11.9	14.6	16.5	20.2	22.7
Cross-sectional area of 95% river sections (m^2)	0.8	2.3	3.5	4.5	6.4	9.4
River sections with rapids and riffles (%)	23	30	33	36	38	44
Deep troughs with water depth >1 m at the upstream of water intake project (%)	22	33	38	43	50	58

In the inhabited reach, the water depth of each section can still ensure the continuous flow of the river under extremely low discharges (minimum annual average daily discharge of 2.32 m^3/s; Table 1). The number of deep pools with water depths greater than 1 m is an important habitat parameter. Rapids can occupy a certain proportion at low flow rates, which is close to the distribution proportion of deep pools. Rapid sections and deep pool sections each account for more than 20% of investigation sections. They provide a variety of water flow conditions for the spawning and foraging *P. altivelis*. Based on observation, the *P. altivelis* fry are generally 3–5 cm in length, and the adult fish are usually 20–30 cm in length by the spawning period. The fry migration can travel long distances under low flow conditions. Judging from the relationship of fry size to preferred water depth, the discharge of 3–5 m^3/s can ensure the migration channel is unblocked from March to May. In contrast, during the spawning migration period from September to October, the river flow must reach 18 m^3/s or more. From this point of view, the four indicators, including continuity of water flow (expressed by the maximum water depth point of the section with the lowest average water depth), the proportion of the rapid flow section, the proportion of deep pool, and the average depth of the section larger than the average height of the fish body, directly reflect the overall conditions of the habitat of the *P. altivelis*.

3.2 Water quality characteristics of river sections

Table 2 is the result of water quality monitoring. The water temperature at each sampling point from May to November is suitable for *P. altivelis* habitat, and the downstream water temperature is often slightly higher than the upstream. The pH of the river channel is 6.98–8.77, and the SD of the downstream tidal reach is slightly low. The reach above section S7 has a high SD value. The concentration of DO in the river is high, especially in the upstream and midstream sections. During the anadromous migration and spawning periods, the COD_{MN} of the other sampling points was less than 2 mg/L, meeting Class I water quality standards (≤t mg/L), except for points S2, S8, and S9. The COD_{MN} at S9 and S2 were slightly greater than 2 mg/L, meeting the Class II water quality standards (ta mg/L). The COD_{MN} of S6–S8 were larger than those observed during the anadromous migration and spawning periods. S7 met the Class II water quality standards, and S6 and S8 met the Class III water quality standards (≤6 mg/L). The sampling results of the S9–S10 points only met the Class IV and V water quality standards (tan mg/L, ≤g/ mg/L).

The sampling values of NH_3-N at the spawning and fattening sites of *P. altivelis* were between 0.01 and 0.30 mg/L, which met the Class I and II water quality standards (tanda mg/L, ≤g/L g/L). The NH_3-N indicators at points S9 and S10 met the Class II water quality standards. In terms of TN and TP, the samples at the fattening sites in the anadromous migration and spawning periods met the Class III (≤1.0 mg/L, ≤0.2 mg/L) and Class I (≤0.2 mg/L, ≤0.02 mg/L) water quality standards, respectively. The samples of the spawning site collected during the spawning period met the Class II (≤0.5 mg/L, ≤0.1 mg/L) and Class III water quality standards, and the samples of the spawning site during the anadromous migration period was Class V (≤2.0 mg/L, ≤0.4 mg/L). The TN and TP concentrations at S9 varied widely. Specifically, the S9 samples in the anadromous migration period met the Class IV (≤1.5 mg/L, ≤0.3 mg/L) and V water quality standards, whereas the S9 samples in the fattening period met the Class III water quality standards. The TN at S10 during the fattening period met the Class III water quality standards, and the TP met the Class I water quality standards.

In general, the Nanxi River is weakly alkaline. The pH value of the water during the fattening period is slightly more basic than during other periods, and the pH value of the downstream sections is more acidic than that of the upstream and midstream (sections). The upstream and midstream sections of the *P. altivelis* fattening and spawning sites exhibit excellent values for DO conditions. The COD_{MN} and NH_3-N concentration are low. The TN and TP concentrations in the fattening period were better than those in the anadromous migration period. The TN and TP concentrations at the spawning site was improved during the spawning period relative to the migration period. The values for COD_{MN}, NH_3-N, and TP in the upstream fattening site during the fattening period were slightly better than those in other periods, and the TN content was slightly higher. The downstream tidal reaches have poor water quality; the COD_{MN} is high, the water body is highly contaminated by organic pollution, and the nitrogen and phosphorus concentrations are high. The water quality of the upstream and midstream sections of the Nanxi River are decent. In particular, the overall water quality conditions of the upstream fattening site are better than those of the spawning site in the midstream section during the fattening period, and the water quality of the spawning site is improved during the spawning period. Therefore, when the water temperature, DO, pH, and NH_3-N indexes were suitable, any changes in COD_{MN}, TP, and TN during the fattening and spawning periods were generally consistent with the migration time of *P. altivelis*.

Table 2 Water quality monitoring results

Parameter		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Water temperature (°C)	1	19.7–22.9									
	2	21.8	25.5	25.1	24.5	-	25	27.4	26.4	26.1	-
	3	22.1	24.1	22.9	22.9	23.5	23.6	23.5	23.8	24.6	-
	4	21.2	21.2	23	24.4	22.9	23.7	23.7	23.3	23.4	23.8
pH	1	8.77	7.35	7.98	8.32	7.54	-	7.65	7.34	7.46	7.52
	2	7.7	7.45	7.7	8.08	-	7.88	7.94	7.99	7.79	-
	3	7.82	7.61	7.8	7.39	7.61	6.98	7.55	7.23	7.36	-
	4	8.46	8.04	8.05	8.02	7.94	8.16	7.78	7.58	7.33	8.41
SD (cm)	1	ND	ND	ND	ND	ND	-	ND	120	80	70
	2	ND	ND	ND	ND	-	ND	132	ND	-	-
	3	ND	ND	ND	ND	ND	ND	ND	88	>100	-
	4	>100	>100	>100	>100	>100	>100	>100	>100	22	18
DO (mg/L)	1	8.14	6.96	8.91	9.97	9.51	-	9.54	8.66	6.72	5.63
	2	9	8.5	9.04	8.73	-	8.37	8.41	8.21	6.85	-
	3	8.05	10.27			7.96	8.45	7.92	8.36	6.09	-
	4	9.59	9.26	9.23	8.86	9.22	8.13	8.55	8.59	7.75	7.47
COD_{MN} (mg/L)	2	1.37	1.33	1.29	1.48	-	1.94	1.79	1.86	2.17	-
	3	1.93	2.07	1.42	1.64	1.2	1.31	1.53	3.75	1.82	-
	4	1.03	1.44	1.44	1.44	0.7	5.91	3.49	4.23	14.37	8.21
NH_3-N (mg/L)	1	<0.03	<0.03	<0.03	<0.03	<0.03	-	<0.03	0.04	0.21	0.31
	2	0.07	0.14	0.11	0.12	-	0.23	0.06	0.06	0.1	-
	3	0.03	0.17	0.24	0.3	0.25	0.14	0.24	0.04	0.54	-
	4	0.02	0.28	0	0.01	0.01	0.04	0.01	0.01	0.16	0.47
TN (mg/L)	1	0.33	0.45	0.48	0.52	0.58	-	0.54	0.46	0.93	1.78
	2	1.06	0.78	0.91	1	-	3.22	2.11	3.06	1.93	-
	3	0.9	0.06	0.2	1.36	0.33	0.44	0.54	0.57	0.18	-
	4	0.35	0.31	0.54	0.49	0.51	0.94	0.54	0.55	0.93	0.89
TP (mg/L)	1	<0.01	<0.01	<0.01	<0.01	<0.01	-	<0.01	0.02	0.04	0.04
	2	0.15	0.22	0.12	0.15	-	0.45	0.19	0.31	0.21	-
	3	0.05	0.05	0.06	0.07	0.07	0.06	0.06	0.05	0.06	-
	4	<0.01	<0.01	0.02	0.01	<0.01	0.03	0.02	0.01	0.02	0.02

ND: not detected.

3.3 Characteristics of benthic algae community

3.3.1 Species and density of benthic algae groups

While sampling during the spawning period of *P. altivelis* in October 2016, a total of 4 phylum and 41 species of benthic algae were collected from S1–S5, including 9 species of Cyanophyta, 8 species of Chlorophyta, 23 species of Bacillariophyta, and 1 species of Euglenophyta. The density of benthic algae at each sampling point ranged from 27,500 to 636,700/cm^2, with an average of 320,900/cm^2 (Figure 4).

While sampling during the fattening period of *P. altivelis* in June 2017, a total of 4 phylum and 34 species of benthic algae were collected, including 8 species of Cyanophyta, 10 species of Chlorophyta, 15 species of Bacillariophyta, and 1 species of Euglenophyta. The total density of benthic algae at each sampling point varied from 79,400 to 1,280,900/cm^2, with an average of 526,900/cm^2 (Figure 5).

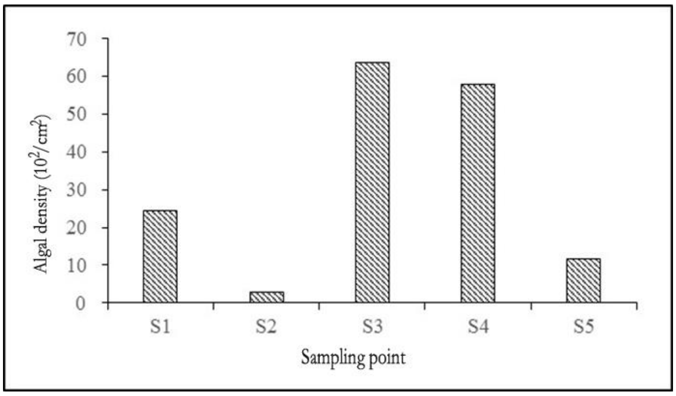

Fig.4. Density distribution of benthic algae during the spawning period

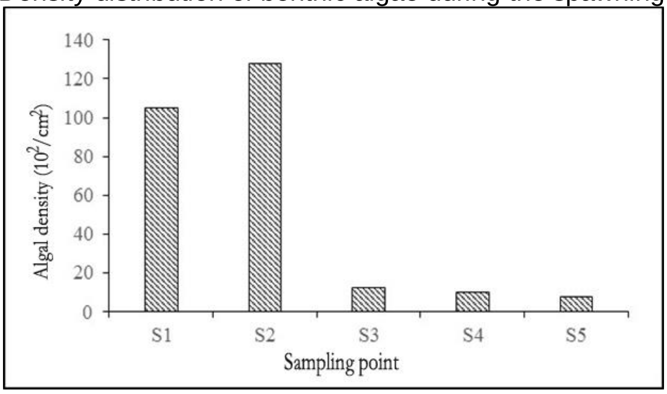

Fig.5. Density distribution of benthic algae during the fattening period

From a time perspective, compared with the *P. altivelis* fattening period (June), the total density of benthic algae at each sampling point in the spawning period (October) decreased by 39%. Regarding spatial variation, the density of benthic algae varies widely at different sampling points during different time periods. The density of benthic algae at sampling points within the fattening site and during the fattening period is larger than at the spawning site. The density of benthic algae at the spawning site throughout the spawning period is greater than that at the fattening site.

3.3.2 Benthic algae community structure

The sampling results during the *P. altivelis* spawning period in October 2016 showed that, except for points S3 and S4, the proportion of algae cells of *Bacillariophyta* was higher at all other sampling points. Both S1 and S2 exceeded 85%. The order of the proportion of each algae is as follows: diatom > blue algae > green algae > euglena (Figure 6). In contrast to the spawning period, the sampling results from the fattening period (June 2017) are mainly diatoms, among which the proportion of diatoms in the three points of S1, S2 and S3 was over 95%, as shown in Figure 7.

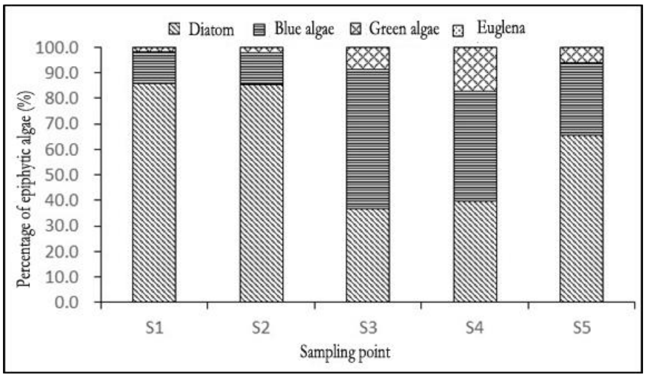

Fig.6. Benthic algae composition during the spawning period

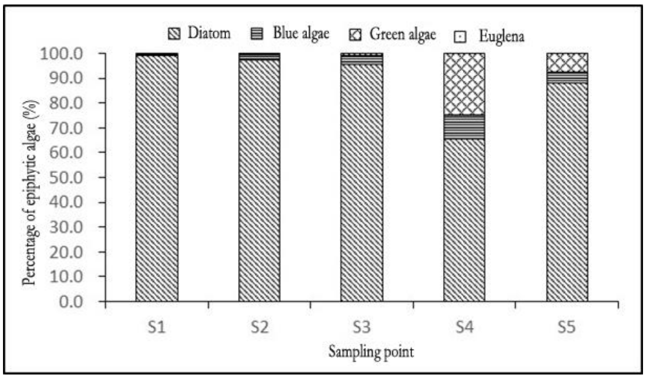

Fig.7. Benthic algae composition during the fattening period

In October, the dominant algae species were *Cymbella parva*, *Pseudoanabaena sp*., *Aphanizomenon flosaquae*, *Navicula cryptocephala*, and *Eunotia sp*.; *Pseudoanabaena sp*. and *Aphanizomenon flosaquae* belong to Cyanophyta, while the other species belong to Bacillariophyta. In the fattening period, *Cymbella sp*., *Leptolyngbya sp*, *Fragillia capucina*, and *Fragilia crotonensis* were the dominant algae.

4 MAIN CONCLUSIONS AND DISCUSSION

In order to comprehensively identify the habitat characteristics of river fish, and to explore the relationship between habitat characteristics and fish migration habits, it is necessary to analyze physical habitats and investigate functional habitat characteristics through time. In this study, we used *P. altivelis* in the Nanxi River as the characteristic species, analyzed the physical habitat characteristics of the Nanxi River mainstream, and monitored functional habitat characteristics of *P. altivelis* during different migration periods.

Our results showed that:

(1) During the anadromous migration period from March to May, 3–5 m^3/s of river flow was adequate to ensure that the migration channel remained unblocked. During the spawning migration period from September to October, the river flow must reach 18 m^3/s or more to generate enough current for fish returning to the channel. Four indicators, including the continuity of water flow (the maximum water depth of the section with the lowest average water depth), the proportion of river sections with rapids (and riffles), the proportion with deep troughs, and the proportion with an average water depth greater than average fish height, directly reflected the overall conditions of the *P. altivelis* habitat.

(2) Under suitable conditions, the changes in COD_{MN}, TP, and TN during the fattening and spawning periods were consistent with the migration habits of *P. altivelis*. The water quality conditions of the upstream fattening site were better than those of the mid-stream spawning site, and the water quality conditions of the spawning site improved during the spawning period comparing to the migration period.

(3) Preliminary investigation and analysis of benthic algae showed that the density of benthic algae at the sampling points of the fattening site during the fattening period was higher than at the spawning site during the same period. Similarly, the density of benthic algae at the sampling points of the spawning site during the spawning period was higher than at the fattening site. Based on the results from the two periods, the algae of *Bacillariophyta* in the benthic algae of the Nanxi River mainstream are dominant, providing an ideal source of sustenance for *P. altivelis*. The algae of *Bacillariophyta* are an important source of food during the spawning and fattening periods of *P. altivelis*. The community structure of benthic algae at the fattening and spawning sites in the Nanxi River mainstream are beneficial to the spawning and fattening of *P. altivelis*.

(4) The physical and functional habitats of the Nanxi River mainstream fattening and spawning sites were both favorable for *P. altivelis*. Physical habitat characteristics, water quality, and benthic algae distribution characteristics all reflected the differences in habitats of the Nanxi River *P. altivelis* throughout the migration

cycle, which, to some extent, reflects the potential impact of changes in habitat conditions on *P. altivelis* migratory habits. Of course, longer periods of observation and monitoring are needed to obtain more useful evidence to support these findings.

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