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Original Articles

Longitudinal and seasonal patterns of fish assemblage structure in the Zhougong River, Sichuan Province, southwest China

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ABSTRACT

The Zhougong River is one of the most important tributaries of the Qingyi River in upper Yangtze River drainage, Sichuan Province, southwest China. The river has been dammed in several places by hydroelectric stations and thus, we aimed to characterize the longitudinal and seasonal patterns of fish assemblage structure in it and whether anthropogenic perturbations have impacted fish assemblages. An extensive survey of fish was conducted in spring (April), summer (August) and autumn (November) of 2015, and winter (February) of 2016 at a total of 18 sampling locations across the river's watershed. It was found that fish abundance, richness and Shannon-Wiener diversity all increased from upstream to downstream. Fish assemblage showed significant spatial differences between the upstream, midstream and downstream, while there were no differences between seasons as was expected. The spatial variation in the abundance of *Rhodeus sinensis*, *Schizothorax prenanti*, *Pseudorasbora parva*, *Zacco platypus* and *Abbottina obtusirostris* were considered to contribute most to the spatial pattern in fish assemblage. The canonical correspondence analysis (CCA) results revealed that spatial variations of fish community in the Zhougonng River were significantly correlated with water velocity, total phosphorus and water depth. Our findings indicate that spatial differences and no seasonal change in fish assemblage were partially attributed to the physicochemical changes caused by cascade hydroelectric dams (e.g., channel blocking, hydrological alterations) and water pollution (e.g., phosphorus) and it is also likely that overfishing has exacerbated impacts. We recommend that pollution prevention, dam removal, modifying dam ecological operations and fishery control may effectively lessen the impacts on fish biodiversity in the Zhougong River.

1. Introduction

Stream and river systems are extremely spatio-temporal heterogeneous ecosystems (Ward et al., 2002; Bêche et al., 2006; Leung and Dudgeon, 2011). Spatial and seasonal dynamics in river fish communities may occur at micro- or macro-scales, such as from microhabitats to river basins, and may temporally vary across days or decades (Adams et al., 2004; Nazeer et al., 2016). Fish communities can be influenced by a range of biotic, abiotic and historical factors (Araújo et al., 2009), and, consequently fish community structure can signify the current and previous characteristics of an environment, and probable influences (Martins et al., 2008; Sá-Oliveira et al., 2015a). Therefore, studying the spatio-temporal patterns of fish assemblages has been a main focus of river ecology (Rahel and Hubert, 1991), improving our comprehension of freshwater fish ecology, anthropogenic and natural effects on fish assemblages, and evaluation and conservation of biological diversity.

Globally, anthropogenic perturbations (e.g., hydropower dam constructions, overfishing, agriculture and urbanization) have resulted in habitat modification, resource decline, changes in fish community structure, and alteration of fish distribution along upstream-downstream gradients (Allan, 2004; Nazeer et al., 2016; Li et al., 2017). Particularly, dams have been considered as a preeminent threat to global freshwater diversity (Vörösmarty et al., 2010). Many studies have shown that hydropower dam construction and anthropogenic hydraulic management can negatively impact upon the ecology of rivers (e.g., Nadon et al., 2015; Santos et al., 2017; Zhang et al., 2018). Key impacts include a change in river discharge and suppression of the seasonal and inter-annual streamflow variability, submersion of channel fluvial systems, restriction of fish reproductive and feeding behavior by channel damming and blockages, and obstruction of fish

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migratory paths and disruption of natural gene flow (de Carvalho Freitas et al., 2012; Pelicice et al., 2015; Sá-Oliveira et al., 2015b). However, the impact on spatio-temporal dynamics in fish species communities is difficult to predict because the physiochemical and ecological interaction between upstream and downstream reservoirs is unclear (Tundisi and Straškraba, 1999; Petesse and Petrere, 2012).

In China, more than 96,000 hydropower dams have been built since the 1950s and this has directly or indirectly resulted in river fragmentation, loss of fish species, and reduced fish diversity (Fu et al., 2003; Zeng et al., 2017). Although it is clear there has been a decline in fish diversity, it is challenging to quantify the exact loss because there is a lack of before and after comparisons, the general difficulties in quantifying biodiversity and the rapid change of ecological conditions in a dammed river (i.e., before to after). Anthropogenic river alteration occurs much more rapidly than natural processes and any rapid changes are likely to affect sensitive species first because they are unable to cope with even small changes to their environment (Sá-Oliveira et al., 2015a). Considering this, the measurement of anthropogenic stressors on river systems should always be two-fold, using physicochemical parameters and ecological variables, such as fish diversity (Fausch et al., 1990).

Zhougong River is one of the most important tributaries of the Qingyi River in the upper Yangtze drainage, Sichuan Province, southwest China. The river is characterized by mountain stream habitats that are suitable for a variety of rare fishes. However, the fish resources of the Zhougong River have not been systematically surveyed, especially after anthropogenic impacts such as the construction of seven cascade dams in the mainstream (Table 1), overexploitation of fish populations and water pollution. The paucity of available data on the current fish assemblage and distribution extremely restricts the formulation of appropriate management programs for the river. Therefore, it is necessary to evaluate fish diversity and assemblage variations in the Zhougong River across longitudinal and seasonal scales and the impact of anthropogenic and natural stressors on spatio-temporal dynamics.

In this study, we conducted a survey of the longitudinal and seasonal patterns of fish assemblages in the Zhougong River. We sampled fish across four seasons between 2015 and 2016 from the river's headwaters, middle reaches and downstream to the confluence with the Qingyi River. Our main purposes were to: (i) provide a whole watershed estimate for fish species composition, size structure and dietary guilds, (ii) characterize the longitudinal and seasonal patterns of fish assemblage structure, (iii) evaluate whether and how cascade hydropower dams affect fish assemblages, (iv) determine the key environmental factors structuring fish assemblages, and (v) outline implications for conservation and management.

2. Materials and methods

2.1. Study area

Zhougong River (25°25′12″~31°00′00″ N, 103°07′12″~103°49′12″ E), one of the most important tributaries of the Qingyi River and originates from the junction of the three counties of Yingjing, Hanyuan and Hongya, Sichuan Province, within southwestern China (Fig. 1). The river lies in the western edge of the Sichuan Basin, along the transitional zone between the Sichuan Basin and the Tibetan Plateau. The water flow is from south to north and discharges directly into the Qingyi River two kilometers downstream of Yaan City. The full-length of the river and drainage area are 95.6 km and 1120 km^2, respectively. The river drop and average gradient of the Zhougong River are 2438.9 m and 25.5%, respectively. Seven hydropower dams have been constructed within the mainstream of the River.

The Zhougong River is within a region that experiences a subtropical monsoon climate with an average annual rainfall of 2085.6 mm. The annual average temperature is 16.1 °C, while temperatures range from 35.4 °C to −3.9 °C. The river flows through the

Table 1
Key parameters of the cascade hydropower stations in the mainstream of the Zhougong River.

Name	Dam				Reservoir		Installed capacity	Ecological flow discharge	Quotative discharge	Year built	Type of hydroelectric station
	Height	Normal water storage level	Segment of water reduced	Location altitude	Volume	Reservoir length					
	m	m	km	m	m^3	km	MW	m^3/s	m^3/s		
Wawushan	138.76	1080	8	1001	5.843×10^8	10.85	240	1.27	116.16	2008	Diversion-type hydropower station
Huluba	19	776.8	3	780	4.2×10^5	1	24	3.81	38.1	2006	Diversion-type hydropower station
Jiangjunpo	46.755	750	3	753	3.78×10^6	2	24	6.27	48	1999	Diversion-type hydropower station
Shaping	44.62	703	2	686	2.86×10^6	5	56	4.71	109.6	2007	Diversion-type hydropower station
Heping	24.5	641.5	0.5	637	1.99×10^6	2	4.8	7.26	33	1988	Diversion-type hydropower station
Dashiban	32.5	612	0	626	n.a.	0.8	5	7.86	37	1994	Run-of-river hydropower station
Zhougonghe	10	594.79	5	606	n.a.	0.2	5.44	7.86	34.8	1966	Diversion-type hydropower station

n.a. means data not available.

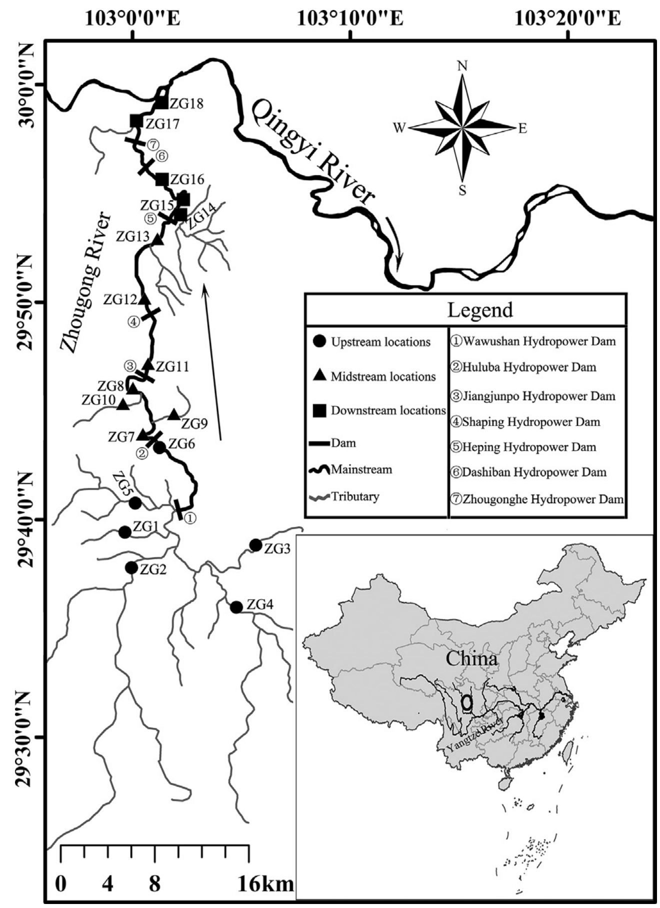

Fig. 1. Water system map of the Zhougong River, showing sampling locations in the present study, and constructed/operating dams.

Wawushan National Forest Park in upper reaches, and the Zhougongshan Provincial Forest Park in lower reaches where riparian vegetation is generally intact and of high quality.

The river can be divided into three sections, representing distinct geomorphic and ecological zones: the upstream, midstream and downstream (Fig. 1). The upstream is rich in small tributaries, with lotic characteristics, is characterized by high altitudes and steep gradient. The main substrates within the river channel are boulder, gravel and sand, with poor nutrient soils. The midstream and downstream, where the main river channel has a gentle slope, are dominated by lentic reservoir habitats interspersed with lotic areas with faster currents. The watercourse here is wider than that in the upstream. The main bed sediments are gravel, sand, silt and clay, with high-nutrient soils. Downstream is the most densely populated region of the whole watershed, which is frequently impacted by human disturbance, for instance, contaminants from industrial and domestic sewage, and agriculture activities and urbanization. The upstream and midstream are separated by the Huluba Hydropower Dam. The Heping Hydropower Dam separates the midstream and downstream reaches.

2.2. Sampling time and locations

The fish resources in main channel of the Zhougong River and its primary tributaries were surveyed in spring (April), summer (August), autumn (November) of 2015 and winter (February) of 2016. Eighteen sampling locations were established (six in the upstream, seven in the midstream and five in the downstream) based on geographical distance between two sampling locations, accessibility, habitat type, river hydrology, and human disturbance intensity. Ten of the locations (ZG6, ZG7, ZG8, ZG11, ZG12, ZG13, ZG15, ZG16, ZG17, ZG18) were established in the mainstream of the river, and eight (ZG1, ZG2, ZG3, ZG4, ZG5, ZG9, ZG10, ZG14) were in the tributaries. Fish were collected at most locations across the four seasons, but a few of them were replaced or eliminated during the flooding season because of inaccessibility. In addition, fish specimens were not captured at some sampling locations because some tributaries and immediately downstream of dams were in drought during the non-flooding season.

2.3. Sampling methods

A variety of sampling methods were used to adapt to the complex habitat types. When water depth was less than 1.5 m, we employed a battery-powered backpack electrofisher to capture fish (which was approved by the Bureau of Aquatic Products of Sichuan Province). We employed a single pass electrofishing method from bottom to top (Porter and Patton, 2016) in the different ecological habitats of each sampling location, for example riffles, backwaters and deep pools. Sampling effort (at each location) was allocated 45 min (a stretch of 200–300 m sampling distance, depending on river size). If water depth was more than 1.5 m, gill nets (22 m in length, 1.1 m in height and stretched mesh size ranging from 10 to 45 mm) were used for sampling. At each sampling location that allowed net placement and boat accessibility, three gill nets were deployed perpendicular to the bank at dusk and left in situ for about 15 h. Both sampling methods were most efficient in collecting fish under corresponding habitat types. The impact of different sampling methods on survey results was minimized by controlling the range (e.g., sampling distance) and intensity (e.g., duration) to maintain similar fishing efforts. Meanwhile, three to six cages (0.2 m in height, 0.25 m in width and 8 m in length, with mesh size of 5 mm) were placed near the bank at the sampling locations depending on river flow, water depth and channel width, mainly collecting demersal fish. The fish specimens were fixed with 10% formaldehyde solution after anesthesia by MS-222 solution and transported to the laboratory (Sichuan Key Laboratory of Conservation Biology on Endangered Wildlife, College of Life Sciences, Sichuan University) for identification and measurement. All fish individuals were identified to species level first, then the total lengths (TL) were measured to the nearest 0.1 mm and body weights (BW) were measured to nearest 0.1 g.

2.4. Measurement of environmental factors

A suite of physicochemical parameters was measured or retrieved for each of the sampling locations using standardized site protocols in summer (July) of 2019. The longitude, latitude and altitude were measured via global positioning system (GPS, GARMIN *eTrex* 10, 5–10 m accuracy). Channel width (CW; using a Ranger Laser Finder instrument, SW-600S) and water depth (WD) were averaged from at least five transects. Water velocity (V) was determined in the middle of the sampling location with a LS1206B flow-meter. Water temperature (T), hydrogen ions (pH), dissolved oxygen (DO), total dissolved solids (TDS) and electrical conductivity (EC) were measured with a H-BD5-WMS Multi-probe Water Quality Sonde. Water samples were collected and preserved in the field by acidification with concentrated H_2SO_4 and stored in a cool box for laboratory determination of chemical composition. Total phosphorus (TP) was analyzed according to the Ammonium Molybdate Spectrophotometric Method described in GB11893-89.

2.5. Data analysis

The rank-abundance and occurrence frequency diagrams were depicted to exhibit species abundance (Magurran, 2004). Then, we grouped all the fish species by their relative abundance (percentage of total fish individuals) and occurrence frequency (percentage of sampling locations in which fish species occurred). Fish species diversity for each location was calculated using Shannon-Wiener diversity index:

Table 2
Composition of fish species captured from the Zhougong River, with their abundance, relative abundance, occurrence, occurrence frequency, mean TL, TL range, and species code used in the analyses. The large and medium-sized species were in bold.

Name	Code	Abundance	Relative abundance (%)	Occurrence	Occurrence frequency (%)	Mean TL ± SD (mm)	TL range (mm)
Cypriniformes							
Cyprinidae							
1. *Zacco platypus* (Temminck & Schlegel, 1846)	ZPL	777	15.78	10	55.56	91.4 ± 19.2	41.4–165.0
2. *Rhodeus sinensis* Günther, 1868	RSI	1241	25.20	5	27.78	43.9 ± 5.2	29.8–73.2
3. *Hemibarbus labeo* (Pallas, 1776)	HLA	7	0.14	1	5.56	103.9 ± 72.3	43.1–224.0
4. *Belligobio nummifer* (Boulenger, 1901)	BNU	46	0.94	4	22.22	113.7 ± 26.3	53.7–173.4
5. *Pseudorasbora parva* (Temminck & Schlegel, 1846)	PPA	692	14.05	12	66.67	54.6 ± 14.2	18.5–100.4
6. *Gnathopogon imberbis* (Sauvage & Dabry de Thiersant, 1874)	GIM	100	2.03	9	50	66.1 ± 15.7	38.7–110.6
7. *Platysmacheilus nudiventris* Luo, Le & Chen, 1977	PNU	42	0.85	3	16.67	71.6 ± 10.6	43.8–92.7
8. *Abbottina rivularis* (Basilewsky, 1855)	ARI	14	0.29	2	11.11	64.6 ± 16.6	43.2–93.1
9. *Abbottina obtusirostris* (Wu & Wang, 1931)	AOB	830	16.86	11	61.11	59.4 ± 10.7	28.6–91.8
10. *Saurogobio dabryi* Bleeker, 1871	SDA	27	0.55	2	11.11	82.2 ± 22.9	50.4–129.8
11. ***Spinibarbus sinensis* (Bleeker, 1871)**	SSI	1	0.02	1	5.56	467.7	–
12. ***Schizothorax prenanti* (Tchang, 1930)**	SPR	109	2.21	8	44.44	108.9 ± 58.6	45.6–389.0
13. ***Schizothorax davidi* (Sauvage, 1880)**	SDAV	1	0.02	1	5.56	255.1	–
14. ***Cyprinus carpio* Linnaeus, 1758**	CCA	9	0.18	4	22.22	118.3 ± 71.2	67.4–247.0
15. *Carassius auratus* (Linnaeus, 1758)	CAU	178	3.61	9	50	79.8 ± 35.3	36.9–209.0
Nemacheilidae							
16. *Homatula variegata* (Dabry de Thiersant, 1874)	HVA	101	2.05	7	38.89	105.3 ± 26.4	51.3–199.0
17. *Homatula potanini* (Günther, 1896)	HPO	72	1.46	6	33.33	84.1 ± 21.9	41.1–125.5
18. *Claea dabryi* (Sauvage, 1874)	CDA	6	0.12	4	22.22	118.8 ± 51.3	73.9–188.5
19. *Triplophysa bleekeri* (Sauvage & Dabry de Thiersant, 1874)	TBL	489	9.93	11	61.11	77.3 ± 15.2	38.5–109.3
Cobitidae							
20. *Misgurnus anguillicaudatus* (Cantor, 1842)	MAN	18	0.37	6	33.33	112.2 ± 20.2	79.7–150.5
Balitoridae							
21. *Beaufortia szechuanensis* (Fang, 1930)	BSZ	7	0.14	2	11.11	58.5 ± 12.8	43.7–74.7
22. *Sinogastromyzon szechuanensis* Fang, 1930	SSZ	2	0.04	1	5.56	55.0 ± 6.5	50.4–59.6
23. *Sinogastromyzon sichangensis* Chang, 1944	SSIC	1	0.02	1	5.56	75.8	–
24. *Metahomaloptera omeiensis* Chang, 1944	MOM	5	0.1	1	5.56	39.4 ± 5.5	33.3–46.8
Siluriformes							
Siluridae							
25. ***Silurus meridionalis* Chen, 1977**	SME	10	0.2	4	22.22	169.1 ± 75.8	103.4–299.3
Bagridae							
26. *Pseudobagrus vachellii* (Richardson, 1846)	PVAC	2	0.04	2	11.11	130.8 ± 70.0	81.3–180.3
27. ***Tachysurus dumerili* (Bleeker, 1864)**	TDU	3	0.06	1	5.56	91.4 ± 8.9	84.4–101.4
28. *Pseudobagrus crassilabris* (Günther, 1864)	PCR	13	0.27	1	5.56	82.9 ± 9.1	59.0–95.3
29. *Pseudobagrus truncatus* (Regan, 1913)	PTR	24	0.49	3	16.67	88.0 ± 30.8	33.8–145.4
30. *Pseudobagrus pratti* (Günther, 1892)	PPR	14	0.29	4	22.22	74.9 ± 15.4	50.0–108.8
Amblycipitidae							
31. *Liobagrus marginatus* (Günther, 1892)	LMA	5	0.1	1	5.56	95.3 ± 6.6	86.3–101.2
Sisoridae							
32. *Glyptothorax sinense* (Regan, 1908)	GSI	11	0.22	1	5.56	79.2 ± 8.1	65.2–89.5
Perciformes							
Gobiidae							
33. *Rhinogobius giurinus* (Rutter, 1897)	RGI	64	1.3	4	22.22	61.2 ± 10.3	37.9–75.0
34. *Rhinogobius brunneus* (Temminck & Schlegel, 1845)	RBR	3	0.06	1	5.56	77.8 ± 7.5	69.9–84.9

$H' = -\Sigma Pi\ln(Pi)$, $P_i = N_i/N$, where N_i = the total individuals of species i collected in each location; N = the total individuals collected in each location (Magurran, 1988). Based on main feeding items through morphological features, personal observation and scientific literatures, the species were classified into different feeding guilds.

One-way, repeated-measures analysis of variance (ANOVA) was conducted on data (fish abundance, species richness and Shannon-Wiener diversity) to detect variations between the three reaches (upstream, midstream and downstream) and four seasons (spring, summer, autumn and winter). Prior to the application of this test, the normality of the data (Kolmogorov-Smirnov and Shapiro-Wilk tests) and homoscedasticity of variances (Levene and Bartlett tests) were checked. When these assumptions were not met, the data were $\log_{10}$ (x + 1)-transformed to reduce the influence of outliers and to adhere to the requirements of a parametric ANOVA. If there was a significant violation of Mauchley sphericity, the results of the within-subject effects were corrected with the Greenhouse-Geisser method for repeated measures (Quinn and Keough, 2002; Field, 2013). When the within-subject effects of the ANOVAs were significant, the Helmert contrasts were carried out on each sampling season with other ones. When the between-subject effects of the ANOVAs were significant, the differences between reaches were evaluated using LSD post hoc analysis. Statistical analyses were undertaken using SPSS version 19.0.

PERMANOVA (McCune et al., 2002), a non-parametric means of analyzing difference in structure or abundance between groups, was used to determine the significance of differences in fish community structure based on Bray-Curtis similarity measures of log (x + 1)-transformed data, with 9999 permutations. In order to group fish communities into different patterns in space and time, the un-weighted pair-group average agglomerative method was undertaken in a non-metric multidimensional scaling (NMDS) ordination plot based on Bray-Curtis similarity measures of log (x + 1)-transformed fish species abundance data (Clarke and Warwick, 1994; Rowe et al., 2009). To test whether pair-wise comparisons of fish assemblage structure between sampling locations differed significantly, a non-parametric permutation-based one-way analysis of similarity (ANOSIM; Clarke, 1993) based on Bray-Curtis similarity measures of presence/absence transformed fish abundance data was used. Finally, the similarity percentage procedure (SIMPER; Clarke and Warwick, 2001) was used to identify fish species contributing most to similarities between reaches within season and between seasons within reaches of the Zhougong River. The PERMANOVA, NMDS, ANOSIM and SIMPER were ran in PRIMER version 6 (Clarke and Warwick, 2001; Clark and Gorley, 2006).

Canonical correspondence analysis (CCA) was chosen to assess environmental factors from 18 sampling locations along with the corresponding fish abundance data, because preliminary detrended correspondence analysis (DCA) indicated a unimodal model (maximum of gradient length > 4 standard units) would best fit the fish data of this study (Lepš and Šmilauer, 2003). Fish abundance data were $\log_{10}$ (x + 1)-transformed to meet assumptions of multivariate normality and to moderate the influence of extreme data, and the downweighting option was used to reduce the influence of rare species. Environmental factors with high correlation ($r > 0.80$) and those with variation inflation factors > 20 were released to avoid high collinearity (McCune and Grace, 2002). Statistical significance of the CCA relationship between the set of physiochemical parameters and fish species was evaluated using a Monte Carlo permutation test with 999 unrestricted permutations (defined as $p < 0.10$). The CCA was processed using the software Canoco for Windows 4.5 version (Ter Braak and Smilauer, 2002).

3. Results

3.1. Fish composition

A total of 34 freshwater species and 4924 specimens (spring: 1287; summer: 1804; autumn: 792; winter: 1041) belonging to 26 genera, 9 families and 3 orders were collected in the Zhougong River (Table 2). The order Cypriniformes showed the highest number of species (24), followed by Siluriformes (8 species) and Perciformes (2 species). Cyprinidae was the dominant family in the fish community, represented by 15 species and accounting for 82.74% of the total individuals captured, followed by Bagridae (5 species), Nemacheilidae (4 species) and Balitoridae (4 species) (Table 2). No invasive species were recorded during the survey. The dominant species included *Rhodeus sinensis*, *Abbottina obtusirostris*, *Zacco platypus*, *Pseudorasbora parva* and *Triplophysa bleekeri* and accounted for 81.82% of the total individuals captured (Fig. 2, Table 2). These dominant species were characterized by high relative abundance (from 9.93% to 25.20% of the total individuals captured). Among them, *R. sinensis* had the highest relative abundance (25.20% of the total individuals) and lowest occurrence frequency (only 27.78% of the 18 sampling locations), yet was considered to be territorially dominant species in the downstream. The common species were *Carassius auratus*, *Schizothorax prenanti*, *Homatula variegata*, *Gnathopogon imberbis* and *Homatula potanini*, exhibiting moderate relative abundance (between 1.46% and 3.61%) and moderate occurrence frequency (from 33.33% to 50%). These common species accounted for 11.37% of the total individuals captured. The remaining 24 species were considered as rare species with a relative abundance below 1.3% and an occurrence frequency less than 33.33%, which contributed only 6.82% of the total individuals captured.

3.2. Size structure and dietary guilds

Of the 34 species, 28 were classified as small-bodied species because their first maturity ages were less than two years (Ye et al., 2006) and values of maximum total lengths were small (< 225 mm in this study; Table 2). Only six large and medium-sized species (their first maturity ages were over two years) were recorded and these were *S. prenanti*, *S. davidi*, *Spinibarbus sinensis*, *Cyprinus carpio*, *Silurus meridionalis* and *Tachysurus dumerili*, of which both the juvenile and adult individuals were captured in this study. The total lengths of the 34 species ranged from 18.5 to 467.7 mm. Twenty-three species (67.65% of the total fish species) were below 100.0 mm in mean TL, 9 species (26.47%) between 100.0 and 200.0 mm, and the other 2 species (5.88%) with mean TL above 250.0 mm (Table 2, Fig. 3).

On the basis of main feeding items, the 34 species were classified into four feeding guilds: herbivore, omnivore, invertivore and piscivore (Table 3). The whole watershed of the Zhougong River was dominated by omnivorous fish, having the highest number of species and total individuals (16 species, 2570 individuals) of all the trophic guilds (Table 4). The number of omnivorous species was highest in all three river reaches, followed by invertivorous species. There was only one herbivorous species (*S. prenanti*) in the upstream and midstream reaches. Piscivorous species (*S. meridionalis* and *T. dumerili*) were only distributed in the downstream reaches. The number of individuals also increased downstream the longitudinal gradient. Although the total number of individuals was lower in the upstream and midstream reaches than that in downstream, omnivorous individuals were still the most abundant. Herbivorous and omnivorous individuals dominated the downstream reaches.

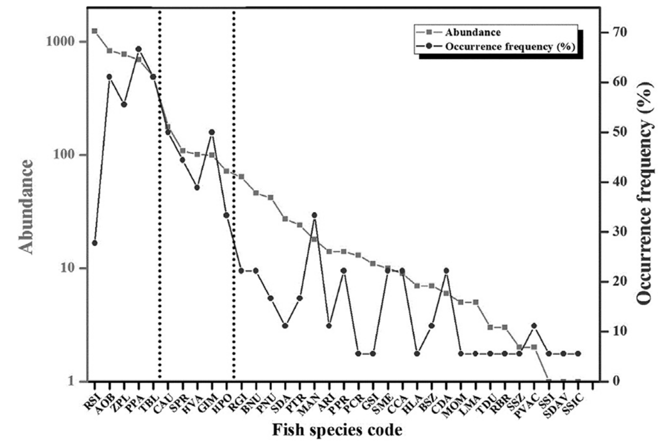

Fig. 2. Rank-abundance (total number of individuals captured) and occurrence frequency (percentage of sampling locations in which the species occurred) of the 34 species captured from the Zhougong River. Fish abundance was $\log_{10}$-transformed to reduce the influence of outliers. Fish species codes are in Table 2.

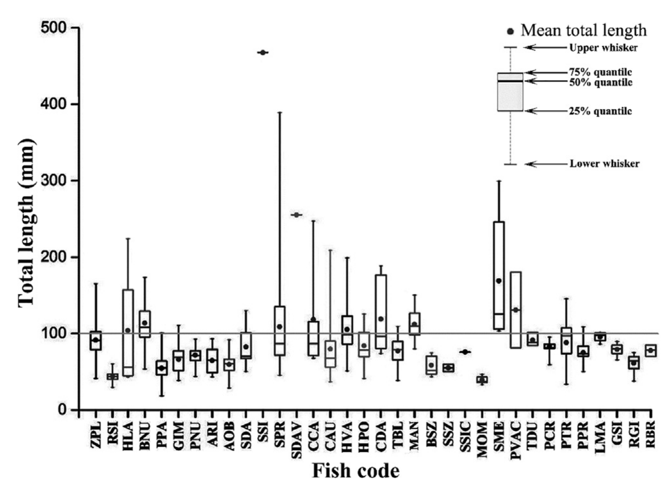

Fig. 3. Box-Whiskers plots of total length for the 34 species captured from the Zhougong River.

Table 3
Fish species distribution and trophic guilds in the three reaches of Zhougong River.

Name	Code	River reaches			Trophic guild			
		Upstream	Midstream	Downstream	Herbivore	Omnivore	Invertivore	Piscivore
1. *Zacco platypus* (Temminck & Schlegel, 1846)	ZPL		+	+		+		
2. *Rhodeus sinensis* (Günther, 1868)	RSI			+	+			
3. *Hemibarbus labeo* (Pallas, 1776)	HLA			+			+	
4. *Belligobio nummifer* (Boulenger, 1901)	BNU		+			+		
5. *Pseudorasbora parva* (Temminck & Schlegel, 1846)	PPA	+	+	+		+		
6. *Gnathopogon imberbis* (Sauvage & Dabry de Thiersant, 1874)	GIM		+	+		+		
7. *Platysmacheilus nudiventris* Luo, Le & Chen, 1977	PNU			+		+		
8. *Abbottina rivularis* (Basilewsky, 1855)	ARI			+			+	
9. *Abbottina obtusirostris* (Wu & Wang, 1931)	AOB		+	+			+	
10. *Saurogobio dabryi* Bleeker, 1871	SDA			+		+		
11. *Spinibarbus sinensis* (Bleeker, 1871)	SSI			+		+		
12. *Schizothorax prenanti* (Tchang, 1930)	SPR	+	+	+	+			
13. *Schizothorax davidi* (Sauvage, 1880)	SDAV			+			+	
14. *Cyprinus carpio* Linnaeus, 1758	CCA	+		+		+		
15. *Carassius auratus* (Linnaeus, 1758)	CAU	+	+	+		+		
16. *Homatula variegata* (Dabry de Thiersant, 1874)	HVA		+	+		+		
17. *Homatula potanini* (Günther, 1896)	HPO		+	+		+		
18. *Claea dabryi* (Sauvage, 1874)	CDA	+	+	+		+		
19. *Triplophysa bleekeri* (Sauvage & Dabry de Thiersant, 1874)	TBL	+	+	+		+		
20. *Misgurnus anguillicaudatus* (Cantor, 1842)	MAN	+	+	+		+		
21. *Beaufortia szechuanensis* (Fang, 1930)	BSZ		+			+		
22. *Sinogastromyzon szechuanensis* Fang, 1930	SSZ			+	+			
23. *Sinogastromyzon sichangensis* (Chang, 1944)	SSIC			+	+			
24. *Metahomaloptera omeiensis* (Chang, 1944)	MOM			+		+		
25. *Silurus meridionalis* (Chen, 1977)	SME			+				+
26. *Pseudobagrus vachellii* (Richardson, 1846)	PVAC		+	+			+	
27. *Tachysurus dumerili* (Bleeker, 1864)	TDU			+				+
28. *Pseudobagrus crassilabris* (Günther, 1864)	PCR			+			+	
29. *Pseudobagrus truncatus* (Regan, 1913)	PTR		+	+			+	
30. *Pseudobagrus pratti* (Günther, 1892)	PPR		+	+			+	
31. *Liobagrus marginatus* (Günther, 1892)	LMA			+			+	
32. *Glyptothorax sinense* (Regan, 1908)	GSI			+			+	
33. *Rhinogobius giurinus* (Rutter, 1897)	RGI	+		+			+	
34. *Rhinogobius brunneus* (Temminck & Schlegel, 1845)	RBR			+			+	
Total fish species		8	16	32	4	16	12	2

3.3. Fish assemblages

We found that there were significant differences in total fish abundance, total species richness, Cypriniformes abundance, Cypriniformes richness, dominant and common abundance, dominant and common richness and Shannon-Wiener diversity between the three river reaches (ANOVA: $F = 4.346$, $p = 0.032$; $F = 8.303$, $p = 0.004$; $F = 4.176$, $p = 0.036$; $F = 8.331$, $p = 0.004$; $F = 4.004$, $p = 0.040$; $F = 9.647$, $p = 0.002$; $F = 8.855$, $p = 0.003$, respectively) (Table 5). During the four seasons, fish abundance (i.e., total fish abundance, Cypriniformes abundance and dominant and common abundance), richness (i.e., total species richness, Cypriniformes richness and dominant and common richness), and Shannon-Wiener diversity all increased from upstream to downstream (Table 5, Fig. 4). However, there were no significant changes in fish abundance, richness, and Shannon-Wiener diversity between seasons (ANOVA: all $p > 0.05$) nor in the interaction between reaches and seasons (ANOVA: all $p > 0.05$) (Table 5).

Furthermore, we found that only the river reaches had a significant effect on fish assemblages (PERMANOVA: pseudo-$F = 4.6715$, $p = 0.001$). The season and the interaction between reaches and season did not significantly influence fish assemblages (PERMANOVA: pseudo-$F = 0.9946$, $p = 0.4365$; pseudo-$F = 0.5451$, $p = 0.9948$, respectively) (Table 6). This influence of river reaches on fish assemblages and not the other factor could be clearly seen in the NMDS, where the midstream locations (pale symbols) were mostly clustered at the top, upstream locations (dark symbols) clustered in the left and downstream locations (open symbols) distributed in the middle (Fig. 5; sampling locations with fish individuals less than 10 were omitted). Whereas there was no clear clustering of sampling locations according to the different seasons (Fig. 5). Similarly, we found that pair-wise comparisons of the fish assemblage structure between sampling sites located upstream and downstream of hydroelectric dams all showed significant differences (ANOSIM: sampling sites located above and below the dams: Global $R > 0.5$, $p < 0.05$) (Table 7). The paired sampling sites located within the dams only had significant differences in fish assemblage structure for one comparison (ANOSIM: sampling sites located within the dams: ZG7 vs. ZG8: $p < 0.05$) (Table 7).

Table 4
Number of species and individuals of trophic guilds in the whole watershed and three river reaches of the Zhougong River.

Trophic guild	Number of species				Number of individuals			
	Whole watershed	Upstream	Midstream	Downstream	Whole watershed	Upstream	Midstream	Downstream
Herbivore	4	1	1	4	1353	3	12	1338
Omnivore	16	6	11	14	2570	330	1045	1195
Invertivore	12	1	4	12	988	3	276	709
Piscivore	2	0	0	2	13	0	0	13

Table 5
One-way, repeated measures ANOVA of the effects of three reaches (upstream, midstream and downstream) in four seasons (spring, summer, autumn and winter) on total fish abundance, total species richness, Cypriniformes abundance, Cypriniformes richness, dominant and common abundance, dominant and common richness, and Shannon-Wiener diversity. The p-values < 0.05 are bold.

	F	p	Ranking (post hoc tests or contrasts)
Total fish abundance			
Between-subjects (reaches)	4.346	**0.032**	Upstream < Midstream, Downstream
Within-subjects			
Season	2.328	0.087	
Season × reaches	0.401	0.875	
Total species richness			
Between-subjects (reaches)	8.303	**0.004**	Upstream < Midstream, Downstream
Within-subjects			
Season	1.442	0.243	
Season × reaches	0.416	0.865	
Cypriniformes abundance			
Between-subjects (reaches)	4.176	**0.036**	Upstream < Midstream, Downstream
Within-subjects			
Season	2.393	0.081	
Season × reaches	0.421	0.861	
Cypriniformes richness			
Between-subjects (reaches)	8.331	**0.004**	Upstream < Midstream, Downstream
Within-subjects			
Season	1.449	0.241	
Season × reaches	0.408	0.870	
Dominant and common abundance			
Between-subjects (reaches)	4.004	**0.040**	Upstream < Midstream, Downstream
Within-subjects			
Season	2.526	0.069	
Season × reaches	0.502	0.803	
Dominant and common richness			
Between-subjects (reaches)	9.647	**0.002**	Upstream < Midstream, Downstream
Within-subjects			
Season	1.884	0.146	
Season × reaches	0.409	0.869	
Shannon-Wiener diversity			
Between-subjects (reaches)	8.855	**0.003**	Upstream < Midstream, Downstream
Within-subjects			
Season	0.410	0.746	
Season × reaches	0.593	0.734	

Our results showed that *T. bleekeri* was widely distributed throughout all river reaches and contributed to 44.78% of the similarity in the upstream reaches (Table 8). *T. bleekeri*, *A. obtusirostris* and *Z. platypus* were plentiful in the midstream and downstream, contributing respectively to 4.50%, 8.22% and 9.35% of the similarity in the midstream, and 2.39%, 4.26% and 2.80% of the similarity in the downstream. Moreover, *R. sinensis*, *S. prenanti* and *P. parva* were more abundant in the downstream and contributed to 3.90%, 3.53% and 3.28% of the similarity in the downstream, respectively. Shifts in abundances of *Z. platypus* and *A. obtusirostris* contributed most to variations between the upstream and midstream. Changes in abundances and occurrences of *R. sinensis*, *A. obtusirostris*, *S. prenanti*, *P. parva* and *Z. platypus* contributed most to differences between the upstream and downstream. The abundances of *R. sinensis*, *S. prenanti* and *P. parva* contributed most to differences between the midstream and downstream. Therefore, the spatial variation in the abundance of *R. sinensis*, *S. prenanti*, *P. parva*, *Z. platypus* and *A. obtusirostris* contributed most to the spatial pattern in fish assemblage structure.

The variability of the assemblage in the downstream (average similarity = 25.45%) was more prominent than that in the upstream (average similarity = 44.78%) and midstream (average similarity = 31.22%) (Table 8). *T. bleekeri* dominated the upstream reaches in spring, summer and autumn (excluding winter). In the midstream, *A. obtusirostris* was abundant in four seasons, *T. bleekeri* was common in spring, summer and autumn, *Z. platypus* was abundant in summer, autumn and winter, whereas *P. parva* was common only in spring. The downstream was dominated by *Z. platypus* and *T. bleekeri* in spring (average similarity = 22.34%), by *S. prenanti*, *A. obtusirostris* and *R. sinensis* in summer (average similarity = 22.88%), by *Z. platypus*, *A. obtusirostris* and *P. nudiventris* in autumn (average similarity = 28.78%), and by *R. sinensis* and *P. parva* in winter (average similarity = 33.76%).

3.4. Correlation between fish assemblage structure and environmental factors

Seven of the selected physicochemical parameters (water temperature, dissolved oxygen, channel width, water velocity, water depth, altitude, and total phosphorus) showed significant differences between the three river reaches in summer (ANOVA: $F = 4.263$, $p = 0.034$; $F = 3.840$, $p = 0.045$; $F = 6.054$, $p = 0.012$; $F = 16.26$, $p < 0.001$; $F = 6.008$, $p = 0.012$; $F = 35.332$, $p < 0.001$; $F = 16.938$, $p < 0.001$, respectively) (Table 9). pH, electrical conductivity and TDS did not significantly differ between the three river reaches (ANOVA: all $p > 0.05$). In general, water temperature, dissolved oxygen, electrical conductivity, total dissolved solids, channel width and water depth increased downstream along the longitudinal gradient, while water velocity and altitude decreased from upstream to downstream.

Three physicochemical parameters out of ten were retained in the final CCA model by the forward selection procedure ($p < 0.10$; Monte Carlo permutation). Water velocity explained the most variance (21.77%; $p = 0.002$), followed by TP (18.37%; $p = 0.016$), water depth (12.93%; $p = 0.078$), DO (6.80%; $p = 0.204$), altitude (6.12%; $p = 0.420$) and T (6.12%; $p = 0.604$). CCA1 and CCA2 accounted for 36.3% and 29.7% for the total variance in fish species abundances (species with fish individuals less than 10 were omitted) during the summer season, respectively (Fig. 6). CCA1 was positively correlated to water velocity (canonical coefficient, $r = 0.882$), whereas it was negatively correlated to water depth ($r = -0.433$) and total phosphorus ($r = -0.420$). Total phosphorus ($r = 0.817$) and water depth ($r = 0.452$) were positively correlated with CCA2. The presence of *T. bleekeri,* dominant in the upstream reaches, was positively associated with increasing water velocity. *S. prenanti*, *R. sinensis*, *Platysmacheilus nudiventris* and *Saurogobio dabryi* were mainly distributed in the downstream reaches and preferred deeper water. The remaining fish species including *Z. platypus*, *A. obtusirostris*, *P. parva*, *C. auratus* and *G. imberbis* were mainly scattered around the center of the CCA diagram, indicating the species were adapted to a range of environmental conditions.

4. Discussion

4.1. Fish composition

The dominance of Cypriniformes, followed by Siluriformes and Perciformes, observed in this study is consistent with the broad patterns of Chinese freshwater fish diversity. Although there are differences in fish composition, richness and abundance, the fish fauna is similar at the order level to that of other investigated Chinese rivers. The Zhougong River was dominated by small-sized fishes, which is likely to have been caused by frequent fishing that targets the more commercially valuable large and medium-sized species. The species richness, fish abundance and Shannon-Wiener diversity of the river were low, which may be linked to the overall poor habitat quality of the Zhougong River. The main driving factors of poor habitat quality in the river

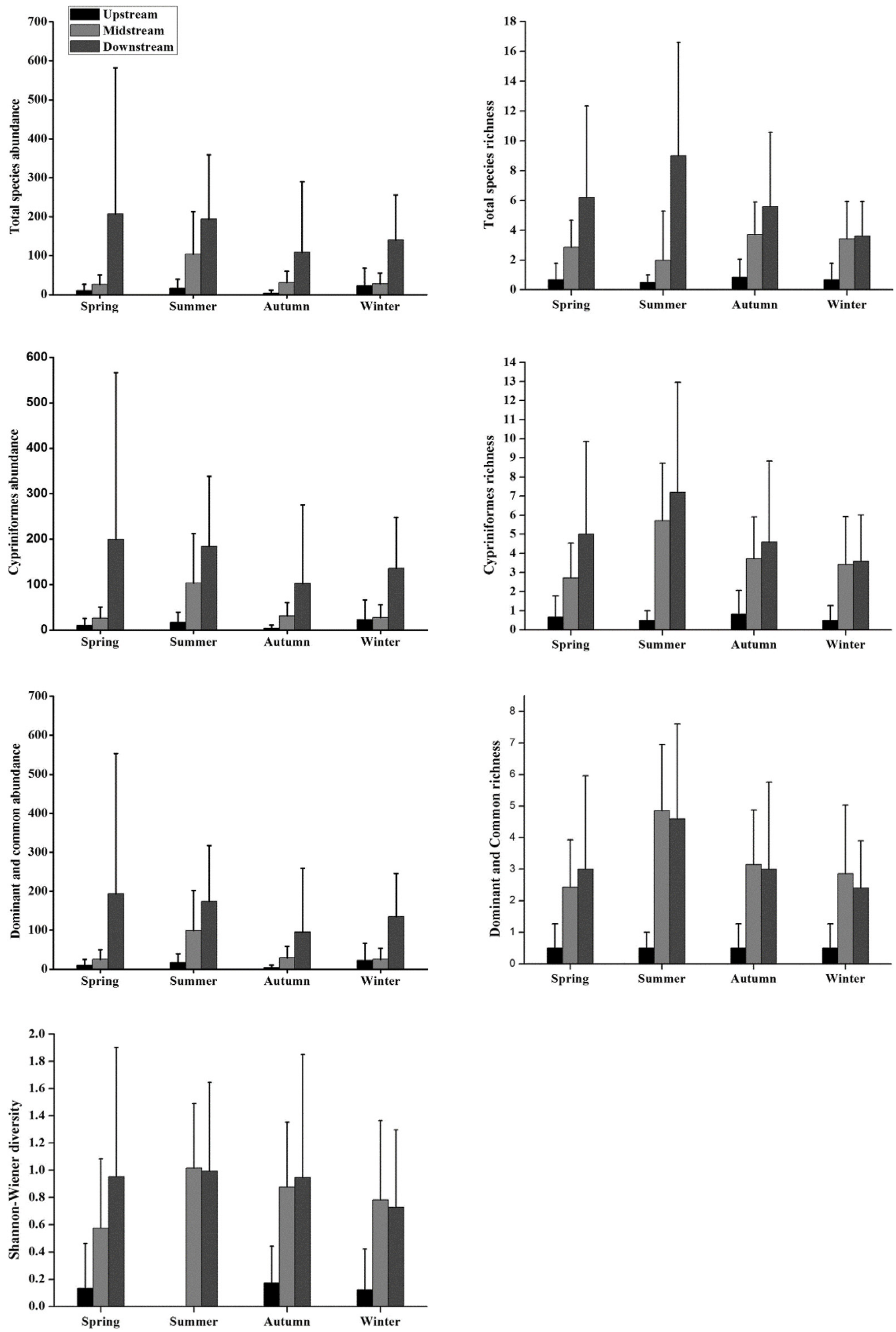

Fig. 4. Mean value and standard deviation (SD) of the total fish abundance, total species richness, Cypriniformes abundance, Cypriniformes richness, dominant and common abundance, dominant and common richness, and Shannon-Wiener diversity among the three reaches (upstream, midstream and downstream) in four seasons (spring, summer, autumn and winter).

include cascade dam structures and blockages, river channel modification driven by sand extraction from the river bed for construction purposes, the existence of commercial, subsistence and recreational fishing, and deforestation of upland and riparian vegetation.

Based on the River Continuum Concept (RCC) (Vannote et al., 1980), the upstream fish assemblage was expected to be dominated by herbivore, insectivore and frugivore fish since food sources are primarily from riparian vegetation and its associated insect community. In contrast, downstream fishes were predicted to belong to omnivorous, detritivorous, invertivorous and piscivorous trophic guilds. However, the whole Zhougong River watershed was dominated by omnivorous fishes. We also found that there was only one herbivorous and one invertivorous trophic guild in the upstream. The herbivores were abundant in the downstream. Consequently, our results on feeding

Table 6
PERMANOVA results of the fish assemblages. Significant p-values (< 0.05) are indicated in bold.

Source	df	SS	MS	pseudo-F	p (perm)	Unique perms
Reaches	2	31130	15565	4.6715	**0.0001**	9916
Season	3	9941.6	3313.9	0.9946	0.4365	9892
Reaches × Season	6	10898	1816.3	0.54512	0.9948	9860
Residual	60	199910	3331.9			
Total	71	251630				

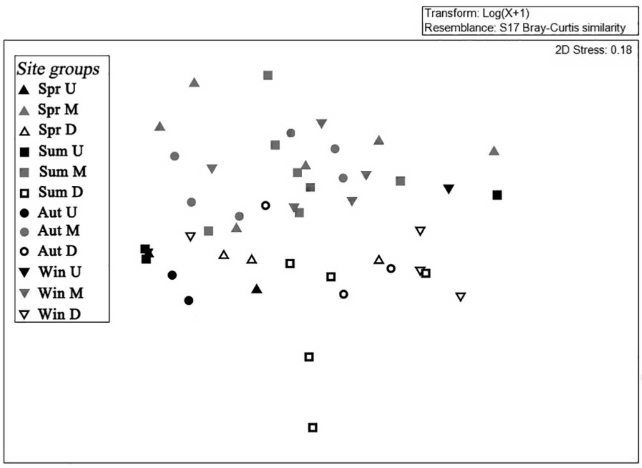

Fig. 5. Non-metric multi-dimensional scaling (NMDS) by river reaches (upstream, midstream and downstream) and seasons (spring, summer, autumn and winter) for the fish abundance data of Zhougong River. Spr: Spring, Sum: Summer, Aut: Autumn, Win: Winter; U: Upstream, M: Midstream, D: Downstream.

Table 7
One-way ANOSIM test for pair-wise comparisons of fish assemblage structure between sampling locations. See Fig. 1 for detailed information of the sampling locations, *p < 0.05.

The relationship between sampling locations and the dams	Fish assemblage structure between sampling locations being compared	Global *R*
Sampling sites located above and below the dams	ZG6 vs. ZG7	0.646*
	ZG8 vs. ZG11	0.708*
	ZG13 vs. ZG15	0.948*
	ZG13 vs. ZG14	0.489*
	ZG16 vs. ZG17	0.420*
Sampling sites located within the dams	ZG7 vs. ZG8	0.542*
	ZG12 vs. ZG13	−0.099
	ZG14 vs. ZG15	0.205
	ZG14 vs. ZG16	−0.167
	ZG15 vs. ZG16	−0.056

guild structures of the fish communities of the Zhougong River were incongruent with the RCC predictions. The reason for this inconsistency may be that the construction of cascade dams in the Zhougong River and other human disturbances have caused physicochemical changes and the trophic generalists like omnivores are more likely to succeed.

4.2. Effects of cascade dams on fish assemblage structure

Vannote et al. (1980) (i.e., RCC) proposed that fish species distribution and communities change in response to a river's physiochemical longitudinal gradient. The RCC is an ideal reference model of the natural river systems that are undisturbed by human activities. However, most rivers have been impacted by anthropogenic perturbations in some way, including the Zhougong River that has been dammed, polluted and its banks eroded. Considering this, the Serial Discontinuity Concept (SDC) predicts that any alteration in the river continuum (e.g., dams or other anthropogenic activities) results in significant longitudinal changes in abiotic and biotic parameters and processes (Stanford and Ward, 2001). Hence, if the observed longitudinal variations do not fit the predicted results of the RCC (e.g., feeding habits), and notable differences of fish communities occur in the river channels into which dams divide the river, we can apply the predictions of SDC being at least partially applied (Araújo et al., 2009). We found that fish communities were significantly different between the three reaches of the river and the composition and dominance of omnivores was unexpected. Thus, we conclude that the cascade dams have partially altered Zhougong River's longitudinal biotic gradient, resulting in the observed significant differences in fish assemblages and unexpected dominance of omnivores. Due to the lack of reference information regarding fish community composition and human disturbance before the construction of hydroelectric stations in the Zhougong River, we are unable to rigorously test the predictions of SDC. Therefore, there is a real need for more researches on how cascade dams have impacted the fish assemblages in the Zhougong River.

We assume that the sampling locations that were close to each other should have the same fish community composition in an unregulated river due to river connectivity, taking no account of other human-induced activities. However, we found that the adjacent sampling sites located above and below the hydroelectric dams had significantly different assemblages, therefore, dams across the river channels have led to detrimental effects on both upstream and downstream fish communities. It is assumed that if dams did not impact upon fish communities, the difference between upstream and downstream would be insignificant, as it would be if the dams were not built. We only found that one pair-wise comparison of fish assemblages between sampling sites located within the dams was significantly different. The sampling locations of ZG7 and ZG8 had distinct habitat types (riffle and reservoir, respectively) mainly due to dam obstruction. Fish species upstream of the dam inhabit different environments like reservoirs, lotic tributaries and free-flowing stretches upstream dependent on their preferences, which results in distinct differences in fish community composition and distribution. The sampling locations of ZG12 and ZG13 showed insignificant variation in fish assemblages since they possessed similar upstream riffle habitats. Although ZG14, ZG15 and ZG16 had different habitat types (pool, riffle and reservoir, respectively), *R. sinensis*, *P. parva*, *S. prenanti* and *Rhinogobius giurinus* were the dominant species at the three sampling locations influencing pair-wise comparisons. The observed homogenization of fish assemblages may be related to overfishing, water pollution and sand extraction from the river bed. Consequently, the variations in fish assemblages located above and below the hydroelectric dams were more significant compared to that located within the dams. The construction of cascade hydropower dams caused abiotic changes (e.g., dissolved oxygen, thermal stress, water depth, velocity, flow discharge and physical habitat) upstream and downstream of the dams, resulting in the observed differences in fish assemblages of paired locations. It is also likely that overfishing, water pollution and sand extraction from the river bed has altered fish community dynamics upstream of the dams, thus leading to overall community homogeneity.

No significant seasonal variations in fish assemblages were observed in the three river reaches, which indicated that fish assemblages in the Zhougong River did not vary with time. Possible explanations for this result are that: (1) Cascade dam presence has contributed to fish assemblage homogenization because the seasonal migration routes of fishes were disrupted (Freeman and Bowerman, 2002). Although we found no long-distance migratory fish in the Zhougong River, most species had the short-distance migration habits such as, spawning, foraging and overwintering. Due to the construction of cascade dams, fishes were blocked in specific areas and could not move upstream through the dams. (2) Many studies have shown that seasonal floods and droughts have a strong impact on the stability and availability of

Table 8
Results of SIMPER analysis identifying the contribution of fish species to differences among the three reaches (upstream, midstream and downstream) in four seasons (spring, summer, autumn and winter) in the Zhougong River.

Reaches	Four seasons Av. Sim.	Av. Abu.	Spring Av. Sim.	Av. Abu.	Summer Av. Sim.	Av. Abu.	Autumn Av. Sim.	Av. Abu.	Winter Av. Sim.	Av. Abu.
Upstream	44.78%		57.21%		26.29%		56.76%			
Triplophysa bleekeri	40.65%	2.34	57.21%	3.13	26.29%	2.29	56.76%	2.48		
Midstream	31.22%		17.19%		32.97%		33.32%		38.12%	
Pseudorasbora parva			5.14%	0.65						
Triplophysa bleekeri	4.50%	1.10	4.54%	0.96	3.87%	1.00	5.31%	1.11		
Abbottina obtusirostris	8.22%	1.64	2.45%	0.93	6.87%	1.89	5.67%	1.47	20.42%	2.35
Zacco platypus	9.35%	1.74			12.68%	2.64	15.34%	1.82	6.77%	1.23
Downstream	25.45%		22.34%		22.88%		28.78%		33.76%	
Zacco platypus	2.80%	1.40	10.31%	2.73			3.17%	1.48		
Triplophysa bleekeri	2.39%	1.09	6.44%	1.79						
Schizothorax prenanti	3.53%	1.30			13.82%	2.37				
Abbottina obtusirostris	4.26%	2.03			1.90%	1.90	12.35%	2.31		
Rhodeus sinensis	3.90%	2.26			1.24%	1.61			14.74%	3.57
Platysmacheilus nudiventris							5.72%	1.87		
Pseudorasbora parva	3.28%	1.92							11.51%	2.84

Av. Sim.: average similarity (%); Av. Abu.: average abundance (species individuals in each sample). Cut-off for low contributions: 70%. Due to ubiquitous nature of some species within sites, a cut-off criterion was applied to allow for the identification of a subset of species whose cumulative percentage contribution reached 70% of the similarity value.

fish habitats, causing cyclic variations in many fish populations (Grossman et al., 1982; Matthews, 1986). However, the cascade dams decrease the seasonal dynamics of fish populations through changing flow regime, perturbing rhythm of natural disturbances such as flood, drought and rainfall, and reducing downstream water flows (Tallent-Halsell and Walker, 2002). Therefore, we believe that no seasonal change in fish community may be related to the cascade hydroelectric dams because damming in the mainstream of the Zhougong River not only blocked the seasonal migration routes of fishes, but also decreased the seasonal dynamics of fish populations.

4.3. Key environmental factors influencing on fish assemblage structure

The CCA results showed that spatial variations of fish community in the Zhougonng River during the summer season were significantly correlated to the water velocity, total phosphorus and water depth. TP was highest in the downstream, which indicated intense human disturbance in the downstream like contaminants from industrial and domestic sewage, and agriculture activities, has severely affected the water quality of the river. This situation has also been exacerbated due to the obstruction by cascade dams in the downstream. EC and TDS were higher in downstream compared to the upstream and midstream reaches. Various ions are inputted into the aquatic ecosystem primarily due to contaminants from industrial and domestic sewage and surface run off, which augment the dissolved solids and conductivity of water (Yousafzai et al., 2013). The gills of fish would be damaged if conductivity exceeds the allowable limit (Yousafzai et al., 2013). Furthermore, high concentration of total dissolved solids reduces the light penetration in water, and thus influences the primary productivity of

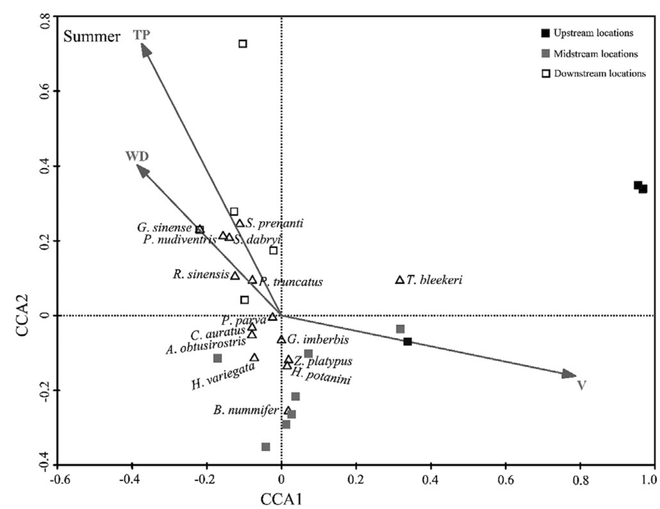

Fig. 6. Canonical correspondence analysis diagram showing the relationship among environmental factors, sampling locations and fish species from three river reaches (upstream, midstream and downstream) during summer season. V: Water velocity, TP: Total phosphorus and WD: Water depth.

Table 9
Longitudinal variations in environmental factors of the Zhougong River during the summer season determined by one-way ANOVA. The p-values < 0.05 are in bold.

Factors	Season	River reaches: Upstream	Midstream	Downstream	Spatial variations: One-way ANOVA F	p	LSD test p (Up-Mi)	p (Up-Do)	p (Mi-Do)
T (°C)	Summer	17.87 ± 1.76	18.77 ± 1.66	21.10 ± 1.75	4.263	**0.034**	0.362	0.012	0.056
pH	Summer	8.95 ± 0.05	8.97 ± 0.11	8.97 ± 0.29	0.016	0.984	0.864	0.906	0.967
DO (mg/L)	Summer	8.20 ± 0.32	8.62 ± 0.35	11.27 ± 3.55	3.84	**0.045**	0.589	0.019	0.044
EC (μS/cm)	Summer	178.17 ± 47.87	182.00 ± 34.24	245.40 ± 35.78	3.432	0.059	0.771	0.029	0.043
TDS (mg/L)	Summer	85.71 ± 21.02	88.43 ± 14.86	118.52 ± 14.72	3.201	0.072	0.703	0.031	0.052
CW (m)	Summer	20.98 ± 9.95	31.39 ± 20.23	81.76 ± 35.4	6.054	**0.012**	0.397	0.004	0.018
V (m/s)	Summer	1.72 ± 0.58	0.71 ± 0.24	0.21 ± 0.24	16.26	< **0.001**	0.001	< 0.001	0.08
WD (m)	Summer	0.45 ± 0.11	1.48 ± 2.21	3.70 ± 2.54	6.008	**0.012**	0.21	0.004	0.036
Altitude (m)	Summer	1083.33 ± 154.27	748.43 ± 61.45	606.80 ± 25.9	35.332	< **0.001**	< 0.001	< 0.001	0.008
TP (mg/L)	Summer	0.0256 ± 0.0110	0.0221 ± 0.0034	0.0528 ± 0.0115	16.938	< **0.001**	0.554	< 0.001	< 0.001

the aquatic ecosystem (Nazeer et al., 2016). However, EC and TDS did not significantly impact the fish assemblage structure during the summer season ($p = 0.735$, $p = 0.586$, respectively), which may result from the strong self-purification ability.

Incongruent with studies in other mountain stream systems (e.g., Jaramillo-Villa et al., 2010; He et al., 2017), dissolved oxygen and water temperature did not significantly affect the distribution of fish assemblages. The insignificant effect may be attributed to the relatively high and uniform dissolved oxygen (7.90–12.27 mg L^{-1}), and slightly varied water temperature (16.00–24.10 °C). Flow velocity and water depth were identified as important predictors of several fish species in the Zhougong River during the summer season. In particular, *T. bleekeri* preferred lotic characteristics with shallow water in the upstream reaches, while *A. obtusirostris*, *R. sinensis*, *S. dabryi* and *P. nudiventris* mainly inhabited slow flowing water. Seven cascade dams in the mainstream of the Zhougong River have significantly changed the natural flow regime especially in dry season, which can result in habitat homogenization and decline in diversity of aquatic species (Helms et al., 2009). Water depth has been found to be vital predictor associated with fish community composition in stream and river ecosystems (Bhagat et al., 2011). Changes in water depth can lead to the alteration of some physicochemical factors such as dissolved oxygen and water temperature, which can indirectly affect the fish community characteristics.

In this study, we found no significant seasonal variation in fish assemblage in the three river reaches since the hydrological regime was altered by the presence of the cascade dams (i.e., flow velocities and water depth). Meanwhile, the CCA results also showed that spatial variations of fish community in the Zhougonng River during summer were significantly correlated to the water velocity and water depth. The other three seasons had similar hydrological regime to summer due to dam obstruction. Thus, it is reasonable to speculate that water velocity and water depth may likewise have significant impacts on fish assemblages in spring, autumn, and winter seasons. It is necessary to verify this prediction in further studies.

4.4. Implications for conservation and management

Our findings indicate that anthropogenic perturbations, especially cascade hydropower dams and subsequent altered environmental factors such as total phosphorus and hydrological regime, have significantly affected the longitudinal patterns of fish assemblages in the Zhougong River. In addition, it is likely overfishing has affected the fish assemblages as well according to the analysis of the fishery catches. Therefore, managers should consider the following measures to reduce adverse impacts: (1) Prevent water pollution: The government should prevent discharge of sewage waste particularly industrial and domestic sewage directly into the river. (2) Partial removal of dam infrastructure: The cascade dams have accentuated the deterioration of water quality and significantly changed the natural flow regime. Dam removal can rehabilitate aquatic ecosystems and associated riparian areas, and therefore is growingly becoming an important part of river restoration (Magilligan et al., 2016). Therefore, the cascade dams within the mainstream should be removed to re-establish the longitudinal connectivity and to restore the fish habitat. (3) Modify dam ecological operations: Flow velocities and water depths immediately downstream of dams were reduced to exceedingly low levels especially in the dry season, which affected the survival and reproduction of fish resulting in spatial variations of fish community. Therefore, prior to dam removal, it is recommended that peak flows be increased by modifying dam ecological operations to meet the hydrological needs of various species during the breeding season. (4) Control fishery activity: The government should control fishery activities by imposing spatial restrictions (e.g., prohibit locations where fishes are more vulnerable), season restrictions (e.g., prohibit fishing during the spawning season), size restrictions (e.g., release any larval and juvenile individuals caught), limits on licenses (e.g., provided by the Fishery Department and needed for both professional and recreational fishermen), fishing gear (e.g., prohibit fishing tools with low selectivity and that capture a lot of fish) and methods (e.g., prohibit the use of explosives, poisons and electricity in fishing).

5. Conclusion

The findings have demonstrated that fish assemblages fluctuated longitudinally and there was no evidence of expected seasonal migration, partially attributable to the effects of damming over the past few decades. Spatial variations in river fish assemblages appeared to be influenced by total phosphorus, water velocity and water depth, while these water parameters were altered by water pollution and obstruction of cascade dams. Understanding the dynamics of fish communities in space and time and how human disturbance has contributed to these changes is of great significance to formulate successful management policy. Future studies should undertake a more widespread investigation of the relationship between abiotic factors (e.g., substratum type, total nitrogen, NH_3-N, turbidity and total suspended solids) and fish assemblages in the Zhougong River. Nevertheless, the findings indicate that fish assemblages have been impacted mainly by damming, water pollution and overfishing and we have made several recommendations to mitigate impacts on fish and should also benefit the health of the entire river.

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