

# Influence of a large dam on the longitudinal patterns of fish assemblages in Qingyi Stream

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**Abstract:** Using seasonally collected data (2009–2010) from 15 sampling sites that represent first- to fifth-order streams within the Qingyi watershed, we examined the spatio-temporal patterns of fish assemblages along two longitudinal gradients to explore the effects of a large dam on fish assemblages at the watershed scale. No significant variation was observed in either species richness or assemblage structure across seasons. Species richness significantly varied according to stream order and gradient. Dam construction appeared to decrease species richness upstream substantially, while a significant decrease between gradients only occurred within fourth-order streams. Along the gradient without the large dam, fish assemblage structures presented distinct separation between two neighboring stream orders, with the exception of fourth-order versus fifth-order streams. However, the gradient disrupted by a large dam displayed the opposite pattern in the spatial variation of fish assemblages related with stream orders. Significant between-gradient differences in fish assemblage structures were only observed within fourth-order streams. Species distributions were determined by local habitat environmental factors, including elevation, substrate, water depth, current discharge, wetted width, and conductivity. Our results suggested that dam construction might alter the longitudinal pattern in fish species richness and assemblage structure in Qingyi Stream, despite the localized nature of the ecological effect of dams.

**Keywords:** Fish assemblage; Species richness; Spatiotemporal pattern; Longitudinal gradient; Dam building

Stream fish assemblages are structured by abiotic factors, biotic interactions, and historical processes (Hoeinghaus et al, 2007). The physicochemical stream environment exhibits spatial heterogeneity and temporal variability, and may cause spatiotemporal variations in fish assemblages (Meador & Matthews, 1992). Typically, among the multiple spatial factors affecting fish assemblages, longitudinal-gradient variations in environmental conditions substantially influence the distribution and abundance of stream fishes (Araújo et al, 2009; Inoue & Nunokawa, 2002; Taniguchi et al, 1998; Vannote et al, 1980). From headwaters to downstream, fish species richness generally increases due to increases in stream size (Matthews, 1986), habitat diversity (Gorman & Karr, 1978), and shelter availability (da Silva Abes & Agostinho, 2001), and the different rates of fish immigration and extinction (Power et al, 1988). Concurrently,

fish species composition may vary longitudinally by species addition and/or species replacement (Boys & Thoms, 2006; Gorman & Karr, 1978; Roberts & Hitt, 2010). The River Continuum Concept (RCC) describes the changes in community structure and species richness of organisms from headwaters to mouth waters and relates these changes to flow regime, water temperature, food availability, and substrate conditions (Vannote et al, 1980). However, due to various human activities (e.g., damming, pollution, erosion), few riverine ecosystems remain free-flowing over their entire course. Overlaying

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Received: 17 December 2013; Accepted: 12 May 2014

Foundation items: This study was financially supported by the National Basic Research Program of China (2009CB119200) and the Natural Science Foundation of China (31071900, 31172120)

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this pattern displayed by the RCC, the Serial Discontinuity Concept (SDC) claims that regulation by dams disrupts the underlying continuum and produces a series of lentic and lotic reaches, thereafter causing longitudinal shifts in abiotic and biotic parameters and processes (Ward & Stanford, 1983).

Dams impact stream fishes and invertebrates in diverse ways, such as blocking migratory pathways (March et al, 2003), fragmentizing habitats (Travnichek et al, 1993), altering natural flow regimes (Bonner & Wilde, 2000) and food webs (Power et al, 1996), decreasing water temperature downstream (Clarkson & Childs, 2000) and current velocity upstream (Bennett et al, 2002), disrupting riparian plant communities (Nilsson et al, 1997), and shifting water chemistry (Humborg et al, 1997). The extent to which stream fishes and invertebrates are affected by dams may be associated with the characteristics of dams (e.g., location, purpose, and management) and fauna (Cumming, 2004; March et al, 2003). For example, large dams without spillways are impermeable barriers for migratory organisms and may extirpate all native migratory fish from upstream habitat (Holmquist et al, 1998). In contrast, large dams with spillways provide a possible passage for some native fishes. To date, investigations have primarily identified the effects of dams on lotic reaches directly below dams, mainstream reservoirs directly above dams, and lotic reaches upstream of impoundments (Clarkson & Child, 2000; Cumming, 2004; Santucci et al, 2005; Travnichek et al, 1993). However, little attention has been paid to the effects of dams at the watershed scale.

Stream ecosystems in China are experiencing massive ecological perturbation due to diverse human activities, such as extensive agricultural and industrial production, urbanization, development, and hydraulic engineering construction, all of which threaten freshwater fish (Chen, 2005). Based on data collected from first- to fifth-order streams, representing two longitudinal gradients (one disrupted by a large dam and the other not) within a tributary (Qingyi Stream) of the lower reaches of the Yangtze River, the spatial and temporal patterns of fish assemblages were examined. Totally, our three key goals were to: (1) to determine how fish assemblage patterns vary longitudinally from first- to fifth-order streams; (2) to identify the correlations between local habitat and fish assemblages; and (3) to assess how a large dam affects the longitudinal patterns of fish assemblages at the watershed scale.

## MATERIALS AND METHODS

### Study area

Qingyi Stream originates from the northern portion of Huangshan Mountain, and flows northeast toward its confluence with the lower reaches of the Yangtze River. This watershed is approximately 309 km long and covers an area of 7195 km<sup>2</sup>. Due to the subtropical monsoon climate, temperature and precipitation in this area are quite asymmetric across seasons. Annual air temperature ranges from -2.1 °C (January) to 27.5 °C (July), with a mean of 17.8 °C. Annual precipitation is high (approximating 2000 mm/year), with most rainfall (79%) occurring in spring and summer (April to September) and only minor rainfall (less than 5%) occurring in the cold, dry winter (December to February) (Yan et al, 2011).

Chencun Hydropower Station was constructed at the mid-reaches of the Qingyi mainstream in the 1950s. It is the largest station along the lower reaches of the Yangtze River, with 119 m deep impoundment and covering an area of 88.6 km<sup>2</sup>. Derived from Anhui Province topographic maps (1:300 000 scale), the Qingyi Stream is categorized as fifth-order (Strahler, 1957) at its mainstream. A total of 75 first-order, 34 second-order, 12 third-order, 4 fourth-order, and 1 fifth-order stream are included in this watershed. Among the fourth-order streams, the Qingxi, Shuxi, and Machuan streams flow into an artificial reservoir (i.e., Taiping Lake) formed by the impoundment of Chencun Hydropower Station, while Huishui Stream directly flows into the mainstream with its confluence downstream of the station (Figure 1).

### Fish sampling

A total of 15 segments representing first- to fifth-order streams were surveyed seasonally during April, August, and October 2009, and January 2010. The sampling segments were derived from two longitudinal gradients. One gradient (A) was set from the headwaters of Qingxi and Shuxi streams to the lower reaches of the mainstream, representing the gradient disrupted by Chencun Hydropower Station, and the other gradient (B) was set from the headwaters of Huishui Stream to the mainstream, representing the gradient not disrupted by a station. Each surveyed segment was set on the topographic map based on their stream orders. Four segments ranging from first- to fourth-order streams were selected within Qingxi, Shuxi, and Huishui streams, respectively. Three other segments representing fifth-order streams were set at the mainstream (Figure 1). Sampling

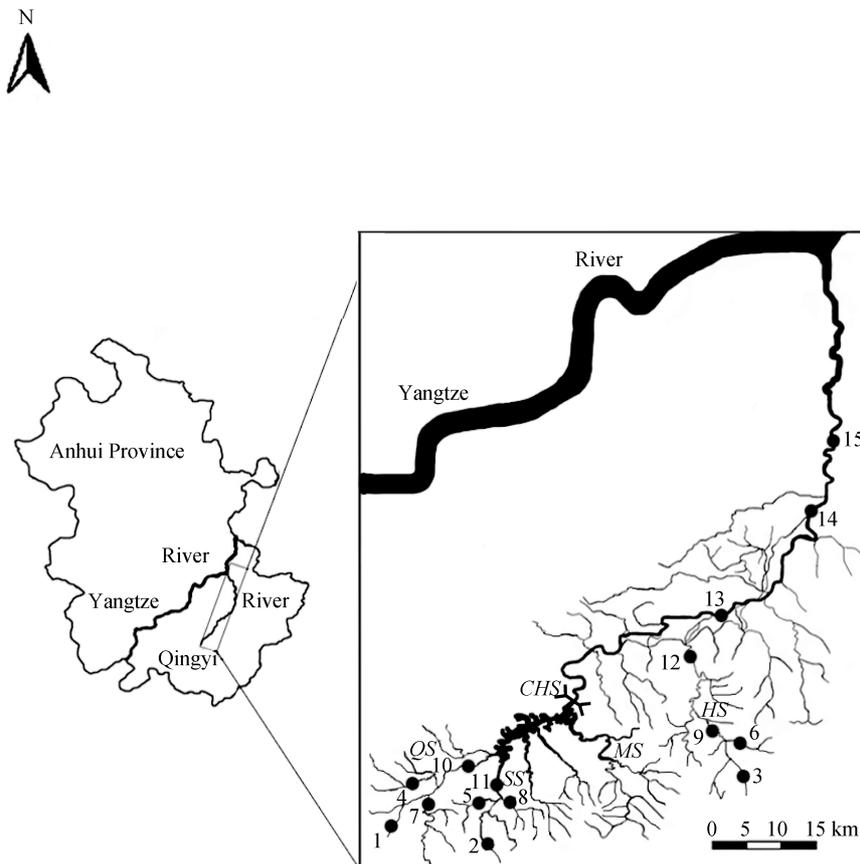


Figure 1 Map of the Qingyi Stream watershed in Anhui Province, China

Solid circles mark the 15 sampling sites. Sites 1–3, 4–6, 7–9, 10–12, and 13–15 represent first-, second-, third-, fourth-, and fifth-order streams, respectively. Sites 1, 2, and 3 are located at Qingxi (QS), Shuxi (SS), and Huishui Streams (HS), respectively.  $\times$  shows Chencun Hydropower Station.

sites were selected in the field based on habitat representativeness and accessibility. Each shallow-water (<1.0 m depth) site of first-, second-, and third-order streams was sampled using backpack electro-fishing by wading in two passes. Each site encompassed at least two mesohabitat units (pool and riffle). Each deep-water (>1.0 m depth) site of fourth- and fifth-order streams was sampled twice using boat electro-fishing along both riversides. Sampling sites were far (>1.0 km distance) from conspicuous human disturbance, such as dam, farmland, and urban land, and each sampling was conducted with comparable effort (i.e., 100 m long and approximately 40 min). Fish were identified to species level (except for *Ctenogobius* due to the deficiency in identifying tools), counted, and returned to sampling sites if alive. Voucher specimens were placed in 8% formaldehyde solution for further identification.

#### Environmental survey

Each sampling site was characterized using 10 variables to describe local habitat: elevation (m), wetted

width (m), water depth (m), water temperature ( $^{\circ}\text{C}$ ), pH, conductivity (mS/cm), dissolved oxygen (mg/L), current velocity (m/s), discharge ( $\text{m}^3/\text{s}$ ), and substrate. Elevation was determined by a portable GPS receiver. Wetted width was measured along five transects, regularly spaced across the stream channel. Water depth, temperature, dissolved oxygen, pH, and conductivity were surveyed at four equal-interval points along each transect. Water depths <1.0 m were measured using a graduated wading rod, and depths >1.0 m were measured using a supersonic echo sounder. Current velocity was taken at 60% of water depth at each point of each transect. Discharge of each channel was determined at the transect that yielded the most accurate measurement (smooth bottom and laminar flow). Along each transect, the proportion of substrate categories (particle size 1=0–1 mm; 2=1–5 mm; 3=5–25 mm; 4=25–50 mm; 5=50–100 mm; 6=100–500 mm; 7=500–1 000 mm; 8=>1 000 mm) was visually estimated, and an index of substrate coarseness ranging from 1 to 8 was derived for each site

following Bain et al (1985).

### Data analysis

Each fish species collected in this study was examined for frequency of occurrence ( $F$ ) and relative abundance ( $RA$ ), estimated from  $F_i=100(S_i/S)\%$  and  $P_i=100(n_i/n)\%$ , respectively, where  $S_i$  and  $S$  are the abundance of the samplings of which species  $i$  were collected and of total samplings, respectively, and  $n_i$  and  $n$  are the individual numbers of species  $i$  and total fish species, respectively. The above  $F$  and  $P$  values were determined independently for three groups of sampling segments, i.e., first- to fourth-order streams along gradient A and B and fifth-order streams, respectively. Species richness and fish abundance were analyzed using a separate three-way ANOVA model with stream order (first- to fifth-order), season (January, April, August, October), and dam (gradient A and B) as factors. One-way ANOVA was used to test differences in species richness across stream orders along gradients A and B, respectively. The Newman-Keuls test was used for post-hoc comparisons after ANOVA. Independent sample  $t$ -tests were used to compare species richness within the same ordered streams between the two gradients. All data were log-transformed to meet the assumptions of normality and homogeneity of variances.

Discrete spatial patterns in fish assemblages were identified using PRIMER 5 (Primer-E Ltd., 2001). Following a Bray-Curtis similarity matrix calculation, an analysis of similarity (ANOSIM) was used to test variations in fish assemblages across stream orders, seasons, and gradients. Firstly, variations associated with stream orders and seasons were analyzed separately for gradients A (two-way crossed ANOSIM) and B (one-way ANOSIM due to no replication), respectively. Secondly, variations associated with gradients and seasons were analyzed separately for each stream order using two-way crossed ANOSIM. The relationships among assemblages from each site and season were graphically presented using non-metric multi-dimensional scaling (NMS) analysis. The contribution of each species to differences among assemblage groups was identified using similarity percentages analysis (SIMPER) (Clarke & Warwick, 2001). The variability in fish assemblages in relation to local habitat environment was evaluated by canonical correspondence analysis (CCA) using CANOCA 4.5. All variables entered the CCA after a forward-selection procedure, showing their importance in explaining total

variability in species composition. The significance ( $P<0.05$ ) of the CCA gradients was assessed by Monte Carlo permutation tests, and their importance measured by the eigenvalues of the first two axes (ter Braak & Verdonschot, 1995). All variables of fish assemblages (i.e., species richness and abundance) and habitat environment were  $\log(X+1)$  transformed to meet assumptions of multivariate normality and to moderate the influence of extreme data. Species that occurred in less than two sites were excluded from the above analysis to avoid negligible weighting (Gauch, 1982).

## RESULTS

### Overview of species diversity

A total of 13 647 fish were captured throughout this study, representing 57 species, 15 families, and 5 orders. Species of family Cyprinidae comprised on average 59.6% of total species richness. Species richness per sampling site amounted to  $11.9\pm 6.6$  (mean $\pm$ SD) species, and abundance per site was  $227.6\pm 205.5$  specimens. A total of 16, 24, 24, 47, and 44 species were collected in first- to fifth-order streams, respectively. *Cyprinus carpio*, *Mylopharyngodon piceus*, *Hemiculter leucisculus*, *Sarcocheilichthys sinensis*, *Abbottina obtusirostris*, *Macropodus chinensis*, *Mystus macropterus* and *Hyporhamphus intermedius* were only collected within fifth-order streams. Within the first- to fourth-order streams, 18 species were only collected from streams along gradient B, including *Distoechoodon tumirostris*, *Elopichthys bambusa*, and *Spinibarbus hollandi*. *Saurogobio dabryi* was a unique species occurring in gradient A but not gradient B. *Zacco platypus*, *Acrossocheilus fasciatus*, *Pseudogobio vaillanti*, *Vanmanenia stenosoma* and *Ctenogobius* sp. were common ( $>40\%$  of  $F$ ) and relatively abundant ( $>1\%$  of  $P$ ) within both gradients. In addition, *Acheilognathus barbatulus*, *A. chankaensis*, *Rhodeus ocellatus*, *Squalidus argentatus* and *Misgurnus anguillicaudatus* were more frequent and abundant within gradient A, while *Opsariichthys bidens*, *Hemiculter bleekeri*, *Sarcocheilichthys parvus*, *Parabotia fasciata*, *Siniperca chuatsi*, *Odontobutis obscurus*, *Silurus asotus* and *Pseudobagrus albomarginatus* were more frequent and abundant in gradient B (Table 1).

### Local species richness

Fish species richness significantly varied according to stream order and gradient, but not season (Table 2).

**Table 1** Frequency of occurrence (%; left of dash) and relative abundance (%; right of dash) of fish collected within Qingyi Stream

Species	Code	First to fourth-order		Fifth-order
		Gradient A	Gradient B	
<b>Cypriniformes</b>				
<i>Abbottina rivularis</i>	ABR	50.0/1.7	31.3/2.3	83.3/2.9
<i>Abbottina tafangensis</i>	ABT*	3.1/<0.1	6.3/0.1	
<i>Abbottina obtusirostris</i>	ABO*			16.7/0.2
<i>Acheilognathus barbatulus</i>	ACB	53.1/3.9	12.5/0.3	58.3/0.8
<i>Acheilognathus chankaensis</i>	ACC	18.8/0.9	6.3/0.3	41.7/0.5
<i>Acrossocheilus fasciatus</i>	ACF	68.8/7.7	87.5/10.1	25.0/0.3
<i>Carassius auratus</i>	CAA	28.1/1.8	31.3/2.1	91.7/5.8
<i>Cobitis rarus</i>	COR	53.1/5.6	37.5/2.2	
<i>Cobitis sinensis</i>	COS	28.1/0.6	18.8/1.3	8.3/<0.1
<i>Cyprinus carpio</i>	CYC*			16.7/0.1
<i>Culter erythropterus</i>	CUE*		6.3/<0.1	
<i>Distoechodon tumirostris</i>	DIT*		6.3/0.1	
<i>Elopichthys bambusa</i>	ELB*		6.3/<0.1	
<i>Erythroculter ilishaeformis</i>	ERI		6.3/0.2	41.7/2.3
<i>Gnathopogon taeniellus</i>	GNT	18.8/0.6	25.0/0.4	
<i>Gobiobotia tungi</i>	GOT*		12.5/0.1	
<i>Hemiculter leucisculus</i>	HEL			75.0/7.9
<i>Hemiculter bleekeri</i>	HEB	6.3/0.2	31.3/4.3	58.3/1.2
<i>Hemibarbus labeo</i>	HEL		18.8/0.4	
<i>Hemibarbus maculatus</i>	HEM		31.3/0.7	16.7/0.1
<i>Misgurnus anguillicaudatus</i>	MIA	37.5/1.1	18.8/0.4	8.3/<0.1
<i>Mylopharyngodon piceus</i>	MYP			41.7/0.8
<i>Opsariichthys bidens</i>	OPB	21.9/1.0	56.3/1.6	66.7/2.1
<i>Phoxinus oxycephalus</i>	PHO	12.5/0.2	18.8/3.8	
<i>Pseudobrama simoni</i>	PSS		18.8/1.6	58.3/3.8
<i>Rhodeus ocellatus</i>	RHO	65.6/13.9	31.3/2.3	66.7/3.8
<i>Spinibarbus hollandi</i>	SPH*		12.5/0.1	
<i>Zacco platypus</i>	ZAP	100/34.7	93.8/26.0	58.3/5.5
<i>Parabramis pekinensis</i>	PAP		6.3/0.1	16.7/0.1
<i>Parabotia fasciata</i>	PAF	18.8/0.6	31.3/2.0	33.3/5.0
<i>Pseudorasbora parva</i>	PSP	15.6/0.6	25.0/2.7	50.0/2.2
<i>Pseudogobio vaillanti</i>	PSV	43.8/2.5	43.8/4.8	33.3/0.5
<i>Sarcocheilichthys sinensis</i>	SAS*			8.3/<0.1
<i>Sarcocheilichthys parvus</i>	SAP	3.1/0.1	25.0/2.9	66.7/2.8
<i>Sarcocheilichthys nigripinnis</i>	SAN		25.0/4.0	75.0/2.3
<i>Squalidus argentatus</i>	SQA	34.4/1.2	12.5/0.7	33.3/1.0
<i>Saurogobio dabryi</i>	SAD	6.3/0.1		8.3/<0.1
<i>Varicorhinus barbatulus</i>	VAB*		12.5/0.2	
<i>Vanmanenia stenosoma</i>	VAS	65.6/5.2	50.0/3.9	25.0/1.1
<b>Perciformes</b>				
<i>Channa argus</i>	CHA		18.8/1.4	91.7/6.1

(Continued)

Species	Code	First to fourth-order		Fifth-order
		Gradient A	Gradient B	
<i>Channa asiatica</i>	CHA*		6.3/0.1	8.3/0.1
<i>Siniperea roulei</i>	COR		12.5/0.3	33.3/0.3
<i>Ctenogobius</i> sp.	CTS	93.8/12.6	68.8/4.4	25.0/2.0
<i>Hypseleotris swinhonis</i>	HYS		12.5/0.2	9.3/0.1
<i>Mastacembelus aculeatus</i>	MAA	21.9/0.6	6.3/0.2	
<i>Macropodus chinensis</i>	MAC*			16.7/<0.1
<i>Odontobutis obscurus</i>	ODO	12.5/0.9	37.5/2.7	91.7/7.9
<i>Siniperca chuatsi</i>	SIC	3.1/<0.1	25.0/1.2	75.0/2.4
<i>Siniperca obscura</i>	SIO		6.3/0.2	50.0/0.6
<b>Siluriformes</b>				
<i>Glyptothorax fukiensis</i>	GLF*		6.3/0.9	
<i>Liobagrus styani</i>	LIS	31.3/1.0	31.3/0.6	
<i>Mystus macropterus</i>	MYM*			8.3/0.1
<i>Pelteobagrus fulvidraco</i>	PEF		25.0/3.9	100.0/21.1
<i>Pseudobagrus albomarginatus</i>	PSA	3.1/<0.1	37.5/0.9	66.7/4.1
<i>Silurus asotus</i>	SIA	3.1/0.1	25.0/0.5	41.7/0.7
<b>Synbranchiformes</b>				
<i>Monopterus albus</i>	MOA	31.3/0.5	18.8/0.4	33.3/0.9
<b>Beloniformes</b>				
<i>Hyporhamphus intermedius</i>	HEI*			8.3/0.9

\*: Rare species occurring in less than two sites, not included in statistical analysis.

**Table 2 Three-way ANOVA results of the spatial and temporal variations in fish species richness within Qingyi Stream**

Factors	df	SS	MS	F	P	Student-Newman-Keuls
Stream orders	4	2.3	0.6	38.9	**	1st<2nd=3rd<4th<5th
Seasons	3	0.1	0.02	1.9	ns	
Gradients	1	0.1	0.1	4.0	*	
Orders×seasons	12	0.2	0.01	0.9	ns	
Seasons×gradients	3	0.02	0.01	0.5	ns	A<B
Orders×gradients	4	0.6	0.1	9.5	**	
Orders×seasons×gradients	12	0.1	0.01	0.8	ns	

Factors are stream orders (first–fifth), seasons (January, April, July, October) and gradient (A, B; with and without the effect of a large dam, respectively).

\*:  $P < 0.05$ , \*\*:  $P < 0.01$ , ns  $P > 0.05$ . Student-Newman-Keuls test:  $P < 0.05$ .

Species richness significantly increased with stream orders, with the exception of no significant difference between second- and third-order streams. Gradient B had more species than that of Gradient A. A significant interaction effect was observed for stream order by gradient (Table 2). Within Gradient A, the lowest and highest species richness occurred in first-order and fifth-order streams, respectively, and species richness did not vary significantly among second-, third- and fourth-order streams. Within Gradient B,

however, the highest species richness was observed in fourth-order streams, while first-, second- and third-order streams were not significantly different in species richness (Figure 2). When comparing species richness within the same-order streams between the two gradients, significant differences were only observed in fourth-order streams ( $t$ -test,  $F=0.23$ ,  $P < 0.01$ ), but not in first- ( $F=0.4$ ,  $P=0.54$ ), second- ( $F=1.5$ ,  $P=0.21$ ), or third-order streams ( $F=7.2$ ,  $P=0.19$ ) streams.

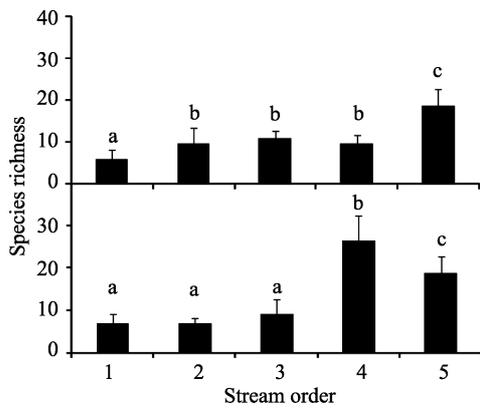


Figure 2 Fish species richness along two longitudinal gradients by stream orders within Qingyi Stream (upper: gradient A; lower: gradient B)

Different lowercases represent significant differences in species richness (One-way ANOVA,  $P < 0.05$ ).

### Fish assemblages

The two-way crossed ANOSIM results suggested that fish assemblages significantly differed across stream orders but not seasons, and were uniform for both longitudinal gradients of A and B (Table 3). Within gradient B, significant differences in inter-order fish assemblages were almost exclusively observed, with the exception of fourth- vs. fifth-order. Whereas, fish assemblages in fourth-order streams were similar with those in

Table 3  $R$ -values and their significance levels ( $P$ ) for comparisons of fish assemblages among stream orders and seasons using ANOSIM

	Gradient A		Gradient B	
	$R$	$P$	$R$	$P$
<b>Order</b>	0.50	<b>0.001</b>	0.66	<b>0.001</b>
1st vs. 2nd*	0.06	0.440	0.60	<b>0.029</b>
1st vs. 3rd	0.38	<b>0.012</b>	0.42	<b>0.036</b>
1st vs. 4th	0.29	<b>0.049</b>	1.00	<b>0.029</b>
1st vs. 5th	1.00	<b>0.001</b>	0.99	<b>0.001</b>
2nd vs. 3rd*	0.06	0.420	0.80	<b>0.029</b>
2nd vs. 4th*	0.06	0.370	1.00	<b>0.029</b>
2nd vs. 5th	0.98	<b>0.001</b>	0.96	<b>0.002</b>
3rd vs. 4th*	0.19	0.296	1.00	<b>0.029</b>
3rd vs. 5th	0.90	<b>0.001</b>	0.93	<b>0.002</b>
4th vs. 5th*	0.85	<b>0.002</b>	0.06	0.310
<b>Season</b>	-0.25	0.988	-0.10	0.971

One-way ANOSIM was conducted for gradient (B) without the effect of Chencun Hydropower Station, two-way crossed ANOSIM was conducted for gradient (A) disrupted by the station and both gradients (Both). Significance level was accepted at  $P < 0.05$  (in bold). \*: opposite significance level occurring between the two gradients.

second- and third-order but not fifth-order streams within gradient A (Table 3). For fish assemblages within the same-order streams, significant between-gradient differences were observed in fourth-order streams, but not in first-, second, and third-order streams (Table 4).

Table 4  $R$ -values and their significance levels for comparisons of fish assemblages among seasons and between two gradients disrupted by a large dam or not using ANOSIM

	$R$		$P$	
	Season	Gradient	Season	Gradient
1st-order	-0.33	-0.25	0.876	0.815
2nd-order	-0.04	0.00	0.562	0.617
3rd-order	-0.31	-0.73	0.800	0.988
4th-order	-0.38	0.75	0.790	<b>0.020</b>
5th-order	-0.19		0.872	

Two-way crossed ANOSIM was conducted for first- to fourth-order streams, one-way ANOSIM was conducted for fifth-order streams. Significance level was accepted at  $P < 0.05$  (in bold).

Based on NMS analysis, fish assemblages within gradient B varied substantially from headwaters to main-stream, despite the overlap between fourth- and fifth-order streams (Figure 3). In contrast, within gradient A, substantial overlaps were observed between neighboring orders from first- to fourth-order streams, while fish assemblages in fourth-order streams were distinct from those in fifth-order streams.

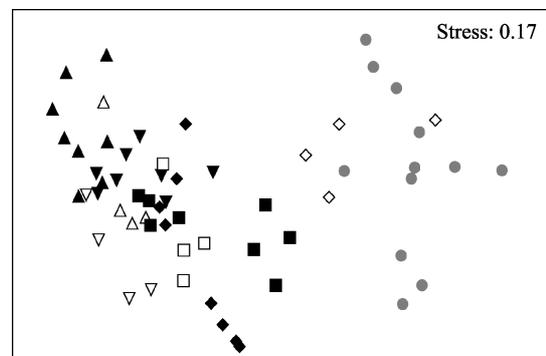


Figure 3 Non-metric multi-dimensional scaling (NMS) by stream orders and dams for fish assemblage data in Qingyi Stream. Black symbols, gradient disrupted by Chencun Hydropower Station; Open symbols, gradient without damming; Grey symbols, mutual part of both gradients. Normal triangle, reverse triangle, square, diamond, and rotundity, fish assemblages from first- to fifth-order streams, respectively.

SIMPER analysis revealed that *Z. platypus* was more abundant in first-, second- and third-order streams and less in fourth- and fifth-order streams within gradient B. The occurrence and abundance of *C. rarus*, *P. fasciata*,

*R. ocellatus*, and *S. nigripinnis* determined how fish assemblages varied substantially from first- to fourth-order streams. *Ctenogobius* sp. and *C. argus* contri-

buted most to the divergence in fish assemblages between fourth- and fifth-order streams within Gradient A (Table 5).

**Table 5** Diagnostic species by SIMPER analysis for first- to fifth-order streams along gradients A and B within Qingyi Streams

	Gradient A			Gradient B		
	AvAbu.	AvSim.	Contri (%)	AvAbu.	AvSim.	Contri (%)
<b>1st-order</b>		AvSim., 46.3%			AvSim., 44.1%	
<i>Zacco platypus</i>	60.9	18.5	40.0	167.3	19.4	30.2
<i>Acrossocheilus fasciatus</i>	39.6	10.2	22.1	17.3	11.5	17.9
<i>Vanmanenia stenosoma</i>	16.3	5.1	11.0			
<i>Cobitis rarus</i>				23.5	12.4	19.3
<b>2nd-order</b>		AvSim., 51.6%			AvSim., 52.9%	
<i>Zacco platypus</i>	63.1	16.8	32.5	37.0	17.7	33.5
<i>Acrossocheilus fasciatus</i>	15.3	9.7	18.9	15.0	13.1	24.7
<i>Ctenogobius</i> sp.	14.4	7.4	14.4			
<i>Parabotia fasciata</i>				16.0	7.6	14.4
<b>3rd-order</b>		AvSim., 48.6%			AvSim., 57.8%	
<i>Zacco platypus</i>	44.8	11.9	24.6	95.8	15.9	27.6
<i>Rhodeus ocellatus</i>	22.1	9.9	20.5	69.7	11.4	19.7
<i>Ctenogobius</i> sp.	28.5	6.6	13.6	28.8	8.4	14.6
<b>4th-order</b>		AvSim., 51.0%			AvSim., 64.3%	
<i>Ctenogobius</i> sp.	24.6	11.9	23.4			
<i>Zacco platypus</i>	46.1	8.5	16.8			
<i>Acrossocheilus fasciatus</i>	12.6	6.1	11.9	51.8	5.2	8.1
<i>Sarcocheilichthys nigripinnis</i>				36.5	5.7	8.8
<i>Abbottina rivularis</i>				20.3	4.8	7.5
<b>5th-order</b>		AvSim., 52.9%			AvSim., 52.9%	
<i>Pseudobagrus albomarginatus</i>	58.0	7.0	15.1	58.0	7.0	15.1
<i>Channa argus</i>	16.8	4.5	9.2	16.8	4.5	9.2
<i>Carassius auratus</i>	15.8	3.4	7.3	15.8	3.4	7.3

The first three species contributing most to the average similarity within each order are shown. AvSim., average similarity (%); AvAbu., average abundance; Contri., contribution.

### Relationships between species and environment

The first and second axes of the CCA ordination accounted for 49.7% and 12.4% of total variance in species richness and abundance among sampling sites, and for 54.7% and 13.6% of variance in species data and environmental relationship, respectively. From CCA, gradient A separated fish assemblages based on elevation, substrate, and flow velocity on the right, and wet width, water depth, discharge, and conductivity on the left. The species related to this gradient were *E. ilishaeformis*, *P. pekinensis*, *S. nigripinnis*, *H. labeo*, *C. rarus*, *C. argus*, *S. chuatsi*, *P. parva*, *C. auratus*, *A. chankaensis*, *R. ocellatus*, *C. sinensis*, *Ctenogobius* sp., *A. fasciatus*, and *Z. platypus* (left to right). Gradient B was caused by

water temperature and dissolved oxygen on the top and pH on the bottom, along which *P. oxycephalus*, *P. fasciata*, *A. chankaensis*, *P. vaillanti*, *M. albus*, *G. taeniellus*, and *S. argentatus* were distributed from top to bottom (Figure 4).

### DISCUSSION

Our results showed that along a longitudinal gradient without the direct effect of a large dam, fish species richness was highest in fourth-order streams and showed no significant difference among first- to third-order streams. Following the increase in stream size and habitat diversity from headwaters to downstream, fish

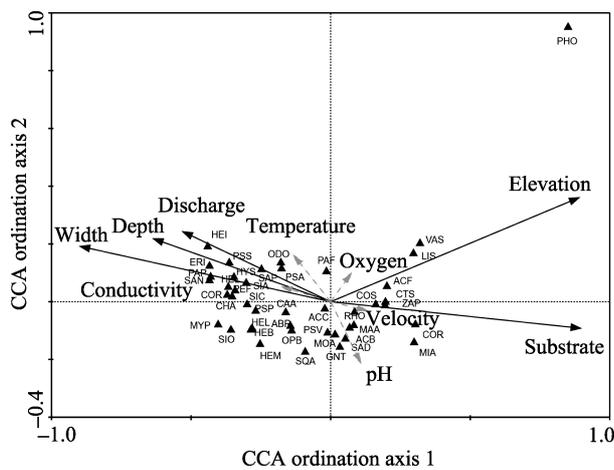


Figure 4 Canonical correspondence analysis (CCA) diagrams for environmental variables and fish assemblages in Qingyi Stream

Black arrows indicate the most important factors and grey arrows show the other factors. Species codes as in Table 1.

species richness generally increases downstream (Gorman & Karr, 1978; Matthews, 1986). Based on fish specimens collected from 89 shallow (first- to third-order) tributaries within the Qingyi watershed, Yan et al. (2011) discovered that local species richness was determined by local habitat variables (e.g., wetted width and water temperature) but not tributary spatial variables (e.g., stream order and link magnitude). Yan et al (2010) also revealed that stream order was not the optimal framework explaining spatial variation in fish assemblages within Puxi Stream, a tributary above Chencun Reservoir in the Qingyi watershed. The results in our study that fish species richness showed no substantial variation across first- to third-order streams appears to support fish species responding to local habitat features but not to stream classification schemes of humans (Matthews, 1998). In addition, our findings that the highest species richness occurred in fourth-order, not fifth-order, streams is consistent with the river continuum concept (RCC) claiming that maximum species diversity often occurs in mid-sized, not large, streams. Oberdorff et al (1993) also found a decline in fish species richness in the lower reaches of the Seine River, which was explained by anthropogenic disturbances decreasing habitat diversity.

In addition to species richness, fish also exhibit an alteration in zonation along the upstream-downstream gradient (Lasne et al, 2007; Miranda & Raborn, 2000). One of the most recognized theoretical classifications dividing running waters based on fish is longitudinal fish zonation proposed by Huet (1959); the brown trout,

grayling, barbel and bream zones exhibit alteration, in turn, from headwaters to lower reaches. However, associated with continuous, not abrupt, variation in the natural environments of many streams, fish assemblages vary by “addition” rather than by “replacement” (Matthews, 1998), which suggests a deficiency in the application of this zonation concept within these streams. In our results, despite some species only being collected in one ordered stream (e.g., *P. oxycephalus* and *C. molitorella* in first-order streams, *C. carpio*, *M. piceus*, and *H. leucisculus* in fifth-order streams), most fish species were distributed in at least two different ordered streams. Based on our SIMPER analysis, along the longitudinal gradient without the effects of a large dam, changes in the relative abundances of *Z. platypus*, *C. rarus*, *P. fasciata*, *R. ocellatus*, and *S. nigripinnis* contributed most to longitudinal species replacement. Our results suggest that “addition”, not “replacement”, was the main underlying mechanism explaining species distributions from upstream to downstream in Qingyi Stream. This spatial variation in species distributions could be explained by the relationship between species and the local habitat environment based on CCA. The spatial distributions of fish species in this study were affected by a series of local habitat environmental factors, such as elevation, substrate, water depth, current discharge, wetted width, and conductivity. At the watershed scale, Yan et al (2011) reported that fish assemblage structure in this study area was related to the combined effects of local habitat (i.e., elevation, substrate, and water depth) and spatial stream position (i.e., magnitude link and confluence link), suggesting that fish species distribution was associated with their ecological requirements, such as habitat preference and trophic ecology.

In Qingyi Stream, fish assemblages presented different patterns in their spatial variations between the two longitudinal gradients, which could be viewed as the effect of Chencun Hydropower Station. Fish showed significantly lower species richness and different species composition within the gradient disrupted by the dam compared with the gradient without the large dam. However, the substantial variations in fish assemblages between gradients were only observed in fourth-order streams. Numerous studies have revealed that dams may impact stream fish by blocking migratory pathways (March et al, 2003), decreasing current velocity upstream (Bennett et al, 2002), altering natural flow regime (Bonner & Wilde, 2000), and decreasing water temp-

erature downstream (Clarkson & Childs, 2000). In this study, when considering first- to fourth-order streams within the two gradients independently, a total of 18 fish species (e.g., *D. tumirostris*, *E. bambusa*, *S. hollandi*) were collected in gradient A only, and eight species (e.g., *O. bidens*, *H. bleekeri*, *S. parvus*) were more frequent and abundant in gradient A than in gradient B. This may be explained by two causes resulting from the effects of large dams on fish assemblages. Firstly, most of the 18 species only occurring in gradient A, including *H. bleekeri*, *E. ilishaeformis*, *H. maculatus*, and *S. roulei*, inhabited the lower reaches of the streams. The Chencun Hydropower Station may play a role in constraining their upstream movements, resulting in the local extinction of these fish in areas above the station. Secondly, dams may modify local habitat conditions upstream and

downstream (Bennett et al, 2002; Bonner & Wilde, 2000; Clarkson & Childs, 2000), which may decrease the fitness of endemic fish to naturally adapt to lotic conditions, eventually resulting in a decline in their abundance (Scott & Helfman, 2001). This may explain why some fish (e.g., *O. bidens*, *H. bleekeri*, *S. parvus*) showed lower abundance within the gradient disrupted by the dam. However, the influence of impoundment by dams on stream fish assemblage structure upstream was highly localized, which means that this influence was partially determined by proximity to impoundments (Falke & Gido, 2006a, b). Our results that significant between-gradient differences in fish assemblages only occurred in fourth-order, not lower-order, streams may support the findings of Falke & Gido (2006a, b), though some additional analyses may be necessary.

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