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Spatial and temporal variation of fish assemblages in a subtropical small stream of the Huangshan Mountain

Yunzhi YAN[1*], Shan HE[1], Ling CHU[1], Xiuying XIANG[1], Yanju JIA[2], Juan TAO[3], Yifeng CHEN[3]

[1] College of Life Sciences, Anhui Normal University; Provincial Key Laboratory of Biotic Environment and Ecological Safety in Anhui, Wuhu 241000, Anhui, China

[2] College of Biological Science and Engineering, Hebei University of Economics and Business, Shijiazhuang 050061, China

[3] Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan 430072, China

Abstract Spatial and temporal variation of fish assemblages were investigated seasonally from May 2007 to February 2008 across 11 study sites in a subtropical small stream, the Puxi Stream, of the Huangshan Mountain. Along the longitudinal gradient from headwater to downstream, fish species richness and abundance increased gradually, but then decreased significantly at the lower reaches. The highest species richness and abundance were observed in August and the lowest in February. Based on analysis of similarities (ANOSIM), fish assemblages were significantly different in spatial variation but not in temporal variation. Although differences were observed both among sites and among stream orders, the lower *R* value in order-variation suggested stream order was not the optimal factor explaining the spatial variation of fish assemblages. In addition, dam construction did not significantly alter fish assemblages in the sites adjacent to and immediately downstream to dams. Using cluster analysis and non-metric Multi Dimensional Scaling analysis (NMS), assemblages were separated into three groups at a Bray-Curtis similarity value of 42%: the upper, middle and lower groups. Following analysis of similarity percentages of species contributions (SIMPER), shifts in occurrence or abundance of *S. curriculus*, *Z. platypus*, *R. bitterling* and *A. fasciatus* contributed most to the differences amongst the three groups. Standard Deviation Redundancy Analysis (RDA) suggested that habitat structure (such as elevation, substrate, and flow velocity) contributed to the spatial and temporal pattern of fish assemblages in the Puxi Stream. In conclusion, the fish assemblages in Puxi Stream presented significant spatial but not temporal variation. Human disturbance has perhaps induced the decrease in species diversity in the lower reaches. However, no significant change was observed for fish assemblages in sites far from and immediately downstream from low-head dams [*Current Zoology* 56 (6): 670–677, 2010].

Key words Assemblage structure, Low-head dam, Stream fish, Spatial-temporal pattern

Maintaining species diversity of stream-dwelling fishes is one of the ecological functions of streams. The identification of patterns of variation in stream-dwelling fish assemblages, and their potential causal mechanisms, is a central theme in stream ecology (Matthews, 1998). Much research has shown that factors influencing fish assemblages involve the physiochemical environment, which is spatially heterogeneous and temporally variable, and biotic interactions such as competition and predation (Gorman, 1988; Harvey and Stewart, 1991; Grossman et al., 1998; Dauwalter et al., 2008). Along the headwater-downstream longitudinal gradient, fish assemblages often experience an increase in species richness and abundance, mainly resulting from an increase in habitat complexity and diversity, variation in the rate of fish immigration, and extinction (reviewed in Matthews, 1986). However, an asymptote or a decrease in species richness is also observed in the lower reaches of some streams, which could be due to greater pollution levels (e.g., Oberdorff et al., 1993). Small streams also represent an ecological gradient along which upstream assemblages are relatively variable but downstream assemblages relatively stable. This is associated with the general pattern of upstream environments being physically variable and structurally simple while downstream environments are the opposite (Grossman et al., 1990). The above spatial-temporal patterns have been tested almost exclusively in mid-western streams of the United States and Mediterranean streams in Europe, but their generality remains unknown (Erős and Grossman, 2005), especially in subtropical areas where annual changes in temperature and precipitation are quite different from temperate or Mediterranean areas. Recently, some topics regarding stream fish assemblages in sub-

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* Corresponding author. E-mail: yanyunzhi7677@126.com; yanyunzhi1976@yahoo.com.cn

tropical areas have been reported, such as: the effect of selective timber extraction (Martin-Smith, 1998) and seasonal typhoons (Tew et al., 2002) on fish assemblages; the assessment of habitat quality by an index of biotic integrity based on stream fish assemblages (Bozzetti and Schulz, 2004); and the trophic structure of fish along an environmental gradient (Kartharina et al., 2008). To date, the spatio-temporal pattern of subtropical stream fish assemblages remains relatively unknown.

Huangshan Mountain is located in the southern part of Anhui Province, China, and is characterized by a subtropical monsoon climate. A total of 122 fish species, diversified in their ecological behavior, have been observed in this area (Diao and Shen, 1981). Impacts including habitat destruction, water pollution and overfishing have caused fish species diversity to severely decline in some small streams of Huangshan Mountain (Yan et al., 2007). Here, we investigated spatial and temporal variation and causal mechanisms of fish assemblages in the Puxi Stream, one of the four major streams at the northern part of the Huangshan Mountain, seasonally over a one-year period. Our aims were: 1) to determine spatio-temporal patterns in fish assemblages in the Puxi Stream, and 2) to identify whether low-head dams affect fish assemblages in sites adjacent to and immediately downstream from dams.

1 Materials and Methods

1.1 Study area

The subtropical monsoon climate of Huangshan Mountain is characterized by asymmetrical seasonal temperatures and precipitation. Mean temperatures range from –22.1°C in January to 27.5°C in July, with an annual mean of 17.8°C. Annual rainfall is plentiful (approximately 2400 mm/year), with 79% of rainfall during spring and summer (April–September) and less than 5% during the cold dry winter. The Puxi Stream originates from the Lion Apex and inflows into the Taiping Lake, which then flows into the Qingyi River, a tributary of the lower reach of the Yangtze River. With a total length of 30 km and a catchment area of 158 km^2, it is one of the four major streams in the northern part of the Huangshan Mountain. The flow regime in the Puxi Stream varies seasonally, with almost no flow during winter and high flow in spring and summer. The minimum water temperature (close to 0°C) occurs in January, and the maximum (approximately 25°C) in July. Many low-head dams, less than two meters, were built during the late 20th century for the purpose of irrigation and domestic consumption. Due to the large number of residents near the middle reach of this stream, the water quality downstream is worse than upstream.

1.2 Fish sampling

Fish were sampled at 11 sites in the Puxi Stream (Fig. 1). Altitude, stream order, adjacent to dam or not, and height of the dam for the 11 sites were shown in Table 1. Each site was sampled seasonally during May, August, and November of 2007, and February of 2008. Fish sampling was standardized by stream length and time. A sample reach of 100 m was fished for 30 min at every site, using electro-fishing (CWB-2000 P, China; 12 V, 100 HZ) by single pass, operated by the same person with netters that followed a zigzag route across each site. Fish were identified to species level (*Rhinogobius* sp. only to genus level), counted and returned to the site where they were captured.

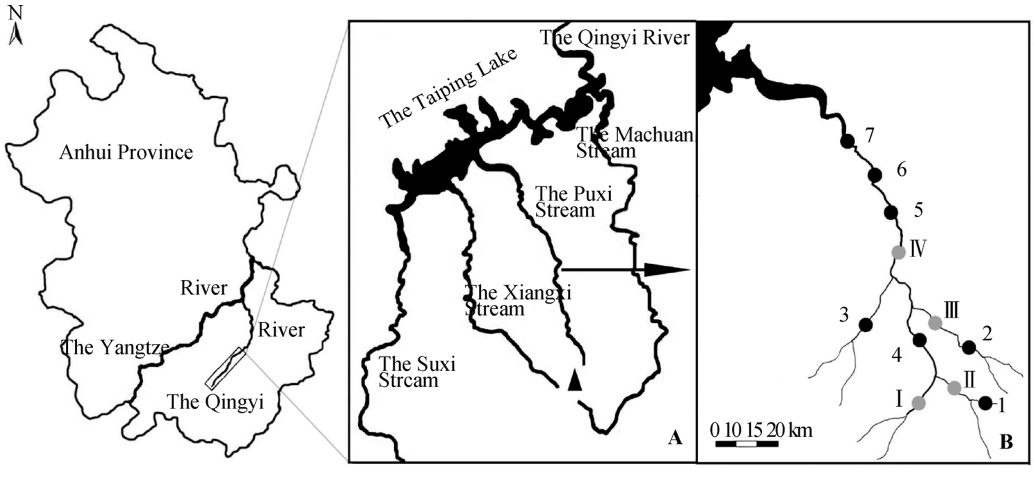


Fig. 1 Sampling sites for our study on fish assemblages in the Puxi Stream of the Huangshan Mountain
A. The geographical position of the Puxi Stream at the northern of Huangshan Mountain, ▲ showing the Huangshan Mountain. **B**. The sampling sites on the Puxi Stream, 1–7 showing the sites not adjacent to dams, I–IV showing the sites adjacent to dams.

Table 1 Altitude, stream order, adjacent to dam (yes or no), and dam height of the 11 study sites on the Puxi Stream

Site	1	2	3	4	5	6	7	I	II	III	IV
Altitude (m)	281	198	195	194	172	149	110	226	237	182	177
Stream order	1	2	2	3	3	3	3	2	2	2	3
Adjacent to dam (Y/N)	N	N	N	N	N	N	N	Y	Y	Y	Y
Dam height (m)	/	/	/	/	/	/	/	1.24	1.85	0.66	1.37

1.3 Environmental characterization

Habitat at each sampling site was described using ten variables: elevation, wetted width, water depth, current velocity, discharge, water temperature, dissolved oxygen, pH, conductivity, and substrate size. Elevation was measured using GPS. Stream width was measured along four transects, regularly spaced across the stream channel. Water depth, dissolved oxygen, pH and conductivity were measured at four equal-interval points for each transect. Current velocity was taken at 60% of stream depth at the points of each transect. 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 = 500–1000 mm, 8 = >1000 mm) was estimated visually, following Bain et al. (1985).

1.4 Data analysis

Analysis focused on quantifying the spatial and temporal variations in species richness and abundance, and identification of environmental variables explaining variations across the 11 study sites. Since the sampling effort was similar across sites and seasons, species richness and abundance were used directly in the analysis. Species that occurred at less than two sites were excluded from the analysis to avoid negligible weighting. Species dominance was assessed by the importance value index (IVI) as proposed by Krebs (1989), using the frequency of occurrence and relative abundance of a species. One-way ANOVA was used to test the differences in species richness and abundance across sites during four seasonal sampling, and significant main effects were further analyzed using Fisher's LSD when appropriate. SPSS 5.0 (SPSS Inc., Chicago, USA) was used to perform statistical analyses and alpha was set at $P < 0.05$.

Discrete temporal and spatial patterns in fish assemblages were identified using PRIMER (v.5; Primer-E Ltd. 2001). Richness and abundance data collected were log(x+1) transformed to meet assumptions of multivariate normality and to moderate the influence of extremes in richness and abundance. Transformed sample data were then used to create a Bray-Curtis similarity matrix calculated for all pair-wise sample comparisons (Bray and Curtis, 1957). An analysis of similarities (ANOSIM) was used to compare fish assemblages from the 11 sites across four seasons. A two-way ANOSIM without replication was used to test for site and season effects, since fish at each site were sampled once, not repeatedly, in every season. A two-way nested ANOSIM (stream order and season nested with dam, respectively) was used to test for dam effect, after the first order being deleted from analysis for no dam within this order. The relationships amongst assemblages from each site are graphically represented using cluster analysis and a non-metric Multi Dimensional Scaling analysis (NMS) (Clarke and Warwick 2001). The contribution of each species to the differences among assemblage groups was identified using SIMPER (Clarke and Warwick 2001).

A Detrended Correspondence Analysis (DCA) was performed to identify the strongest gradient of assemblage composition independent of the environmental variables. Since the length of gradient in DCA was lower than 4, standard Deviation Redundancy Analysis (RDA) was selected for the evaluation of the variability in assemblage structure in relation to the measured environmental factors. The multivariate statistical analysis was performed using CANOCO version 4.5 (ter Braak and Šmilauer 2002). All sample data (except pH) were log(x+1) transformed to minimize the effect of extreme values.

2 Results

2.1 Species diversity

A total of 13,593 fish were captured in the Puxi Stream, representing 24 species (not including *Rhinogobius* sp.), 10 families and 4 orders; Cyprinidae was the most numerous family with 13 species (Yan et al, unpublished). Species richness per sample amounted to 7.7 ± 3.5 species, and abundance 303 ± 244 specimens. Pale chub, *Zacco platypus*, was the most common (occurrence in all samples) and the most dominant (2 898% of IVI) fish. *Rhodeus bitterling*, *Rhinogobius* sp., *Acrossocheilus fascitus*, *Cobitis sinensis*, *Abbottian rivularis*, *Misgurnus anguillicaudatus*, *Pseudogobio vaillanti*, *Vanmanenia stenosoma* and *Liobagrus styani* were also common (> 40% of samples) and dominant

(>100% of IVI) species. Whereas, *C. rarus*, *Sarcocheilichys parvus*, *Opsarrichthys bidens*, *Acheilongnathus chankaensis*, *Pseudobagrus truncates*, *Squaliobarbus curriculus*, *Squalidus argentatus* and *Mastacembelus aculeatus* were restricted (<40% of samples) but relatively important (>10% of IVI) species. Another seven fish were rare species (<10% of IVI): *Carassius auratus*, *Parbotia fasciata*, *Pseudorasbora parva*, *Monopterus alba*, *Ophicephalus argus*, *Silurus asotus*, *Sa. Kiangsiensis*.

Species richness gradually increased from site 1–5, but decreased in sites 6–7 (Fig. 2). A significant difference was observed in species richness among the seven sampling sites far from dams (One-way ANOVA, $F_{6, 21}$ =22.37, P<0.05). The species richness of site 1 was significantly lower than the other six sites (P<0.05). In addition, the species richness of sties 4 and 5 (not significantly different between the two sites, P>0.05) were significantly higher than sites 1, 2, 3 and 7 (P<0.05). However, no significant difference was observed in species richness among the four sites adjacent to dams (One-way ANOVA, $F_{3, 12}$ =2.24, P>0.05). Fish abundance also varied among the 11 sites (Fig. 2). Overall, species richness and abundance was lowest in February (richness: 5.27±2.79; abundance: 124.82±142.15) and highest in August (richness: 9.18±3.09; abundance: 385.24±316.30). Fish richness in November (9.06±3.37) was greater than in May (8.54±3.83), but the opposite was observed in fish abundance (November, 314.18±19.37; May, 389.09±239.52).

2.2 Fish assemblages

Two-way ANOSIM without replication testing for both spatial and temporal variations in fish assemblages suggested that there was a significant difference in spatial variation (R=0.68, P<0.01) but no significant difference in seasonal variation (R=0.17, P>0.05). Two-way nested ANOSIM testing for dam and stream order effects showed that order significantly influenced fish assemblages (R=0.58, P<0.01), but no significant effect was found for dam (R < 0.01, P > 0.05). This ANOSIM testing for dam and season order effects suggested that the two factors did not significant affect assemblages (both R<0.01, P>0.05). Although fish assemblages were significantly different among stream orders and study sites, the R value detected by order was lower than for site.

The Cluster analysis showed that fish assemblages were clearly separated into two groups at a Bray-Curtis similarity value of 11% (Fig. 3): the first branch representing the assemblages of site 1, and the second branch consisting of the other ten sites. Subsequent groupings within the second branch were slightly more difficult to

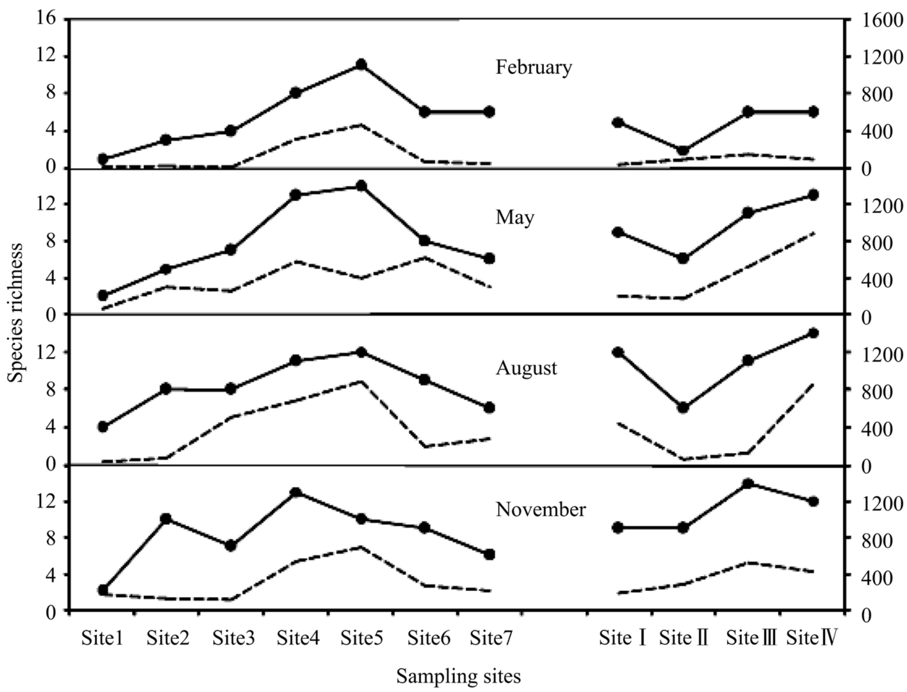


Fig. 2 Species richness (left axis; filled circles) and individual abundance (right axis; dashed line) for the 11 sites sampled seasonally along the Puxi Stream through May 2007 and February 2008

1–7 sites are far from dams; I–IV sites are adjacent to dams.

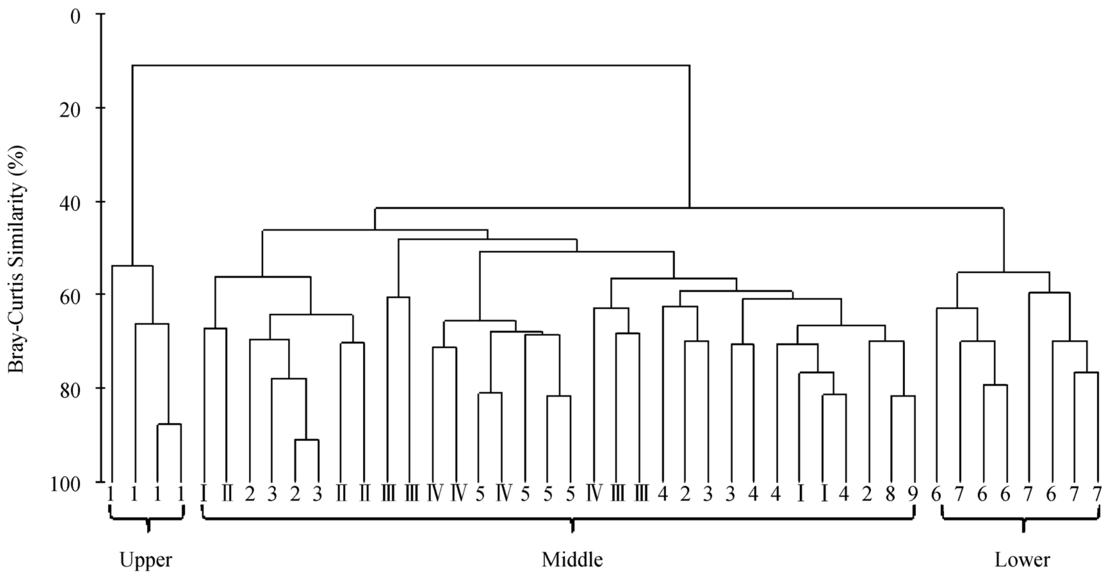


Fig. 3 Cluster analysis of all season-site data for the Puxi Stream using a Bray-Curtis similarity matrix
Season-site combinations delineated into three groups indicated by brackets and labels.

identify, but a further split was observed at a Bray-Curtis similarity of 42% (Fig. 3), with one branch representing the assemblages of sites 6 and 7, and the remaining sites in the other branch. Based on the spatial pattern in fish assemblages, the Puxi Stream could be roughly defined by the following three reaches: the upper (site 1), middle (sites 2–5 and I–IV) and lower (sites 6 and 7) reaches. Similarly, NMS plots, overlain with the similarity values that correspond to the groups identified in the cluster analysis, also supported these spatial assemblage groupings. The entire fish assemblage was split into two and three groups at a Bray-Curtis similarity value of 11% and 42%, respectively (Fig. 4).

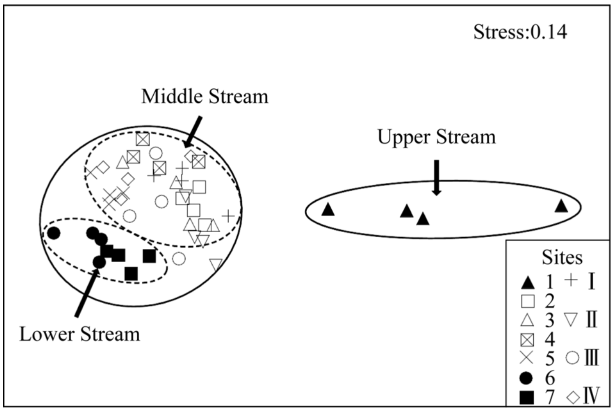


Fig. 4 Non-metric Multi Dimensional Scaling analysis for the fish assemblage data in Puxi Stream, including assemblage identification boundaries at Bray-Curtis similarity levels of 11% (solid) and 42% (dashed).

The SIMPER procedure provided information on overall assemblage and species-specific contributions to the differences among the three assemblage groups previously identified by calculating dissimilarity values from the Bray-Curtis similarity matrix. Dissimilarity values showed that the relative abundances of ten of the dominant species contributed over 70% of the differences among the three identified groups (Table 2). Shifts in abundance of *Z. platypus* and the occurrence of *S. curriculus* contributed most to the differences between the upper stream and middle stream groups, and shifts in abundances of *Z. platypus* and *R. bitterling* and the occurrence of *S. curriculus* contributed most to the differences between the upper and lower groups, and the abundances of *R. bitterling* and *A. fasciatus* contributed to the majority of differences observed between the middle and lower groups.

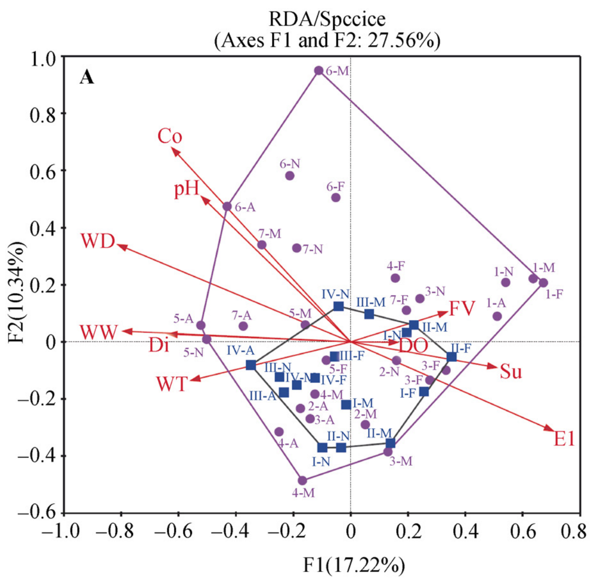
2.3 Relationship between species and environment

The first and second axes of the RDA accounted for 27.56% of the total variance (17.22% on the first axis and 10.34% on the second). The RDA biplot indicated the relationship between species, sites in each season, and environmental variables (Fig. 5). The first axis explained a gradient associated with elevation, flow velocity, water width, depth, and substrate. The sites with the highest values for these variables were site 5 on the left and sites 1, II and IV on the right. The species associated with these sites were *A. rivularis*, *M. anguillicaudatus*, *S. argentatus*, *Z. platypus*, *S. parvus*, *M. aculeatus*, while *S. curriculus* was in the opposite direction. The

Table 2 Species specific contributions to differences among assemblage groups

Species	Relative abundance (Mean ± *SD*)			Mean dissimilarity / contribution (%)		
	Upper (U)	Middle (M)	Lower (L)	U *vs* M	U *vs* L	M *vs* L
Z. platypus	6.16 ± 3.65	27.91 ± 2.35	41.14 ± 18.30	**14.49 / 16.57**	**19.06 / 20.04**	2.49 / 4.26
S. curriculus	76.05 ± 17.47	–	–	**13.16 / 15.04**	**16.72 / 17.58**	–
R. bitterling	–	18.90 ± 2.33	25.00 ± 11.76	3.94 / 4.50	**14.74 / 15.50**	**7.31 / 12.10**
R. sp.	3.85 ± 7.69	6.39 ± 3.09	8.70 ± 7.38	7.16 / 8.18	8.77 / 9.22	3.87 / 6.63
C. sinensis	–	8.99 ± 1.11	0.11 ± 0.08	5.56 / 6.35	–	4.19 / 7.17
A. rivularis	–	6.89 ± 3.76	3.52 ± 2.58	4.16 / 4.75	7.53 / 7.92	4.23 / 7.24
M. anguillicaudatus	–	3.392 ± 2.35	2.09 ± 1.78	–	4.93 / 5.18	3.95 / 6.75
A. fascitus	7.58 ± 7.17	5.61 ± 4.29	0.20 ± 0.40	4.36 / 4.99	5.92 / 6.22	**6.32 / 10.10**
P. vaillanti	–	3.73 ± 2.56	–	5.53 / 6.32	–	3.96 / 6.78
V. stenosoma	2.56 ± 5.13	3.56 ± 1.83	2.25 ± 4.51	5.14 / 5.88	–	3.97 / 6.80

Bold represents contributions more than 10%



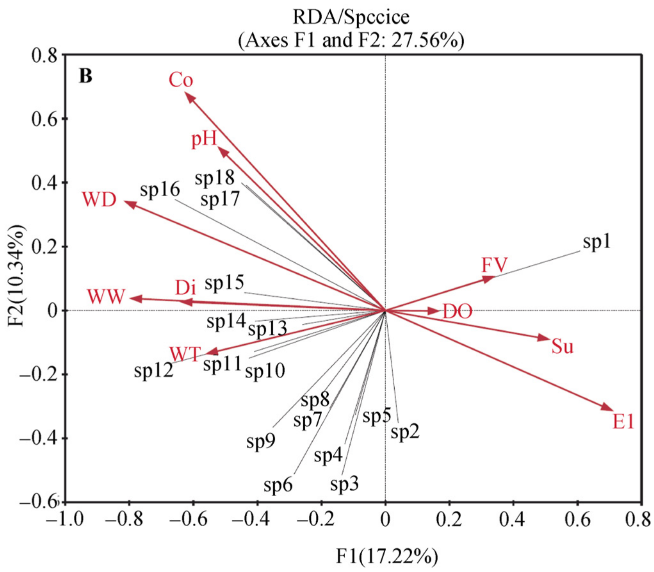


Fig. 5 Biplots from redundancy analysis (RDA) for the fish assemblages in the Puxi Stream

A. Sites and environmental variables. El=elevation; Su=substrate; FV=flow velocity; DO=dissolved oxygen; WT=water temperature; Di=Discharge; WD=water depth; Co=conductivity; WW=water width. Letters represent the study sites (1–7; I–IV) and sampling month: F=February; M=May; A=August; N=November. Purple and blue frames representing sites far from and adjacent to dams. **B**. Environmental variables and fish species. Species (sp) numbered 1–18 representing *S. curriculus, P. vaillanti, A. fascitus, C. sinensis, C. rarus, L. styani, P. trancatus, R. spp, V. stenosoma, M. anguillicaudatus, S. parvus, Z. platypus,S. argentatus, M. aculeatus, A. rivularis, R. bitterling, A chankaensis,* and *O. bidens*.

second axis showed the variables of conductivity and pH. Sites 2, 3, 4, I and III were at the bottom of axis 2, but sites 6 and 7 are at the top. The species found at these sites included *A. fasciatus*, *P. truncates*, *L. styani*, *P. vaillanti*, *C. sinensis* and *C. rarus*. In addition, habitat environmental conditions of the sites adjacent to dams played were larger role than sites far from dams (Fig. 5b), so dam did not significantly alter habitat structure downstream.

3 Discussion

Fish assemblages in the Puxi Stream display a gradual increase in species richness and abundance along a longitudinal gradient from headwater to downstream. However, species diversity is reduced at the lower reach of the main stream. This spatial variation of fish diversity observed in our study is also found in other streams (Fausch et al., 1984; Osborne and Wieley, 1992). Fish assemblages often increase in species diversity with an increase in habitat complexity, the increment in the relative abundance of food supply and the variation in the rate of immigration and emigration of fishes, which reflects the progression of the longitudinal gradient downstream (Schlosser, 1982; Paller, 1994; Inoue and Nunokawa, 2002). However, a threshold or decrease is often observed in fish diversity at the lower reach of some streams, which may be due to more intensive human disturbance downstream (Fausch et al., 1984; Osborne and Wieley, 1992). This interpretation may explain the decrease in fish diversity observed at the lower reach of the Puxi Stream, where local people congregate and municipal waste is deposited.

Based on our ANOSIM fish assemblages in the Puxi Stream differ in spatial variation but not in temporal variation. Although differences are observed for fish assemblages across both sampling sites and stream orders, the R value for site-variation (0.68) is larger than for order-variation (0.58), which suggests that stream order is not the major factor in the spatial variation in fish assemblages in the Puxi Stream. In addition, fish assemblages at sites immediately downstream from dams are not significantly changed, which is shown by the relatively low R (0.01) and high P (> 0.05) values in ANOSIM, for assemblages between sites far from and adjacent to dams.

Community composition varies temporally in response to internal interactions and external factors (Belyea and Lancaster, 1999). In streams where environmental conditions are often extremely dynamic and are affected strongly by periodic hydrological events such as floods and droughts, fish assemblages are structured more by external factors than by internal interactions, and their temporal variations result mostly from these hydrological events (Grossman et al., 1990). Although no distinct difference was found for temporal variation of fish assemblages in the Puxi Stream, species richness and abundance differed over time. The lowest level of fish diversity observed in February could have resulted from the relatively harsh environmental conditions of winter such as low water temperature and low flowing discharge, while the highest observed fish diversity level in August is associated with the relatively high temperature and water discharge in summer. In addition, stream fishes often spawn synchronously during the local flood season because of the increase in breeding habitat and food supply (Alkins-Koo, 2000). An example is *Acrossocheilus fasciatus* which spawns from May to August in the Puxi Stream (Yan et al., 2009), and is almost synchronous with flood events (from April to September). Therefore, numerous recruit stocks could be responsible for the relatively high abundance in August.

Dam construction can reduce upstream fish richness by eliminating or reducing fish movement (Holmquist et al., 1998; March et al., 2003). Dam construction can also alter the natural flow regime of species that complete their life cycles depending on seasonal flow, thus reducing their abundance (Bonner and Wilde, 2000; Minckley et al., 2003). Dams can replace native warm water assemblages with non-native coldwater assemblages by decreasing downstream water temperature (Quinn and Kwak, 2003). However, in our study, the extremely low R value found within our two-way nested ANOSIM indicates that fish assemblages far from dams were not significantly different from those immediately downstream from dams. In addition, the RDA biplot of sampling sites and environment indicate that low-head dams do not significantly alter habitat structure immediately downstream from dams. According to Dodd et al. (2003), low-head dams induce variation in habitat environment but not in fish assemblages. Gillette et al. (2005) found low-head dams alter both habitat and fish assemblage, and the effects appear quite localized as opposed to the widespread effects of hydroelectric dams. To standardize sampling efforts, a reach of 100 m, including pools and riffles, was fished at each site during our study. Due to the localized effect proposed by Gillette et al. (2005) for low-head dams, we hypothesize that low-head dams may influence fish assemblages and habitat in pools immediately downstream from dams, but not in the riffles adjacent to these pools in the Puxi Stream. Therefore, the unitary analysis of fish assemblages from these pools and riffles perhaps hides the effect of low-head dams, which should be validated by the comparison of fish assemblages between pools far from dams and immediately downstream from dams.

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