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Effects of anthropogenic disturbances on α and β diversity of fish assemblages and their longitudinal patterns in subtropical streams, China

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Abstract

Identifying the spatial patterns of α and β diversity of biotics is an important yet little-understood area of basic and applied ecological research. Although the upstream–downstream patterns of α diversity of stream fishes are numerously reported, β diversity has received less attention. In this study, we surveyed fishes along the upstream–downstream gradients in three headwater streams of the Qingyi River, China, which were affected by different extents of human activities. We aimed to assess how anthropogenic disturbances affect α and β diversity of stream fishes and their upstream–downstream patterns. We found that, compared with that in the Shuxi Stream disturbed less, endemic species decreased and cosmopolitan species increased in the Maxi and Puxi Stream disturbed heavily. The streams disturbed heavily showed lower α diversity and higher β diversity than that in the stream disturbed less. This among-stream variations in fish diversity only occurred at the mid-downstream, not upstream segments. α diversity increased downstream and β diversity decreased downstream from headwaters to mouth in the stream disturbed less, whereas this upstream–downstream pattern in fish diversity shifted in the streams disturbed heavily, in which both α and β diversity showed the quadratic distributions with the hump-shape for α diversity and the U-shape for β diversity respectively. Our results suggest that anthropogenic disturbances cause some cosmopolitan fishes replacing many endemic fishes in upland streams. This replacement processes result in α diversity decreasing and β diversity increasing, and shift the spatial patterns in fish diversity along the upstream–downstream gradient.

KEYWORDS

anthropogenic disturbance, headwater stream, upstream–downstream pattern, α and β diversity

1 | INTRODUCTION

Fluvial ecosystems show high spatial heterogeneity and frequent temporal dynamic in environmental factors (Poff & Ward, 1990). Along the upstream–downstream gradient, various environmental factors gradually vary downstream, such as energy production and consume (Vannote, Minshall, Cummins, Sedell, & Cushing, 1980), habitat volume and diversity (Schlosser, 1982), environmental stability (Taylor & Warren, 2001) and so on. The longitudinal patterns of how fish assemblages vary along this gradient have been substantially surveyed till now (e.g., Chu, Wang, Yan et al., 2015; Mazzoni & Lobón-Cerviá, 2000; Oberdorff, Guilbert, & Lucchetta, 1993; Suvarnaraksha, Lek, Lek-Ang, & Jutagate, 2012; Torgersen, Baxter, Li, & Mcintosh, 2006). Many researchers have found that local species richness of stream fishes increase downstream, obtain the maximum at the middle reaches and decrease at the lower reaches of streams (e.g., Minshall et al., 1985;

Oberdorff et al., 1993; Sui, Lu, Yan, Chen, & Jia, 2014). This hump-shaped distribution of fish species richness can be explained by the river continuum concept (Vannote et al., 1980), mid-domain effect (Dunn, Colwell, & Nilsson, 2006), habitat complexity (Minshall et al., 1985) and anthropogenic disturbances (Oberdorff et al., 1993). Also, species composition varies downstream through species gain and/or loss (Matthews, 1998). Over large spatial extents, streams may cross some geographic boundaries characterised by sharp physical and chemical habitat transitions, which can lead to extensive species replacement (including both species gain and loss) and community turnover (Leprieur et al., 2011; Matthews, 1998; McGarvey & Hughes, 2008). However, at small spatial scale (e.g., from small-sized to medium-sized wadeable streams), physical and chemical habitat may vary continuously downstream, which can allow for species addition (i.e., species gain) and some degree of community nestedness (McGarvey & Hughes, 2008; Taylor & Warren, 2001; Wang et al., 2013).

Comparing α and β diversity at local and landscape scales is an important yet little-understood area of basic and applied ecological research (Kessler et al., 2009). However, most studies on the spatial distributions of stream fish diversity focused on α diversity (i.e., within-community diversity), whereas fewer studies have investigated β diversity (i.e., between-community diversity) (Johnson & Angeler, 2014; Tisseuil, Leprieur, Grenouillet, Vrac, & Lek, 2013). Only Jaramillo-Villa, Maldonado-Ocampo, and Escobar (2010) and Tisseuil et al. (2013) have reported the longitudinal pattern of β diversity of stream fishes. Jaramillo-Villa et al. (2010) found that, at the Colombian Andes, β diversity decrease with elevation decreasing from 1,750 to 1,000 m. Tisseuil et al. (2013) discovered an overall pattern of decreasing β diversity along the upstream–downstream river gradient at the Adour-Garonne basin (France). However, it is not clear that whether the discovered longitudinal patterns of β diversity of stream fishes are consistent with other unstudied regions or not.

Anthropogenic disturbances, such as urbanisation, agricultural activities and deforestation, have modified habitat conditions, decrease resource availability and threatened stream fishes world widely (Allan, 2004; Wang, Lyons, Kanehl, & Bannerman, 2001; Zhang et al., 2015). Following with habitat destruction, many endemic intolerant species are replaced by cosmopolitan tolerant species (Allan, 2004; Chu, Wang, Yan et al., 2015; Wang et al., 2001). From this perspective, the change in local species richness largely depends on the numbers of both endemic species lost and cosmopolitan species introduced. In addition, this process of species loss and/or gain resulted from anthropogenic activities can increase the dissimilarity of fish assemblages between disturbed and undisturbed segments/streams, which will modify the spatial pattern of β diversity of fishes in headwater streams. In this study, we investigated fish assemblages along the upstream–downstream gradient from three headwater streams within the Qingyi River, a tributary at the lower reach of the Yangzi River, China. The three study streams were influenced by different extents of anthropogenic activities, which allowed us to assess the effects of anthropogenic disturbance on fish assemblages by comparing their among-stream variation. This study was aimed to (i) determine the among-stream variations in both α and β diversity of fishes, by which to assess how anthropogenic disturbance affected the mean α and β diversity in streams; and (ii) to examine the among-stream variations in the "diversity–distance from headwaters" relationship, by which to assess the effects of anthropogenic disturbance on the "upstream–downstream" patterns in both α and β diversity. The processes of endemic species losing and cosmopolitan species gaining resulted from human activities may increase the between-community dissimilarity between disturbed and undisturbed segments. Therefore, we hypothesised that the mean β diversity of fishes in the stream(s) heavily disturbed may be higher than that in the stream(s) disturbed less. Also, we hypothesised that α diversity of fishes in stream(s) disturbed less may increase downstream as stated by Roberts and Hitt (2010) and β diversity may decrease downstream as supported by Tisseuil et al. (2013), whereas this upstream–downstream pattern in fish diversity may change in stream(s) disturbed heavily, because the species loss and gain resulted from human activities can alter both the within-assemblage diversity and the between-assemblage dissimilarity of fishes.

2 | MATERIALS AND METHODS

2.1 | Study area

The Qingyi River originates in the northern portion of the Huangshan Mountain and flows northeast towards its confluence with the lower Yangtze River, China. Due to the influence of subtropical monsoon climate, this basin is characterised by asymmetric seasonal temperature and precipitation distributions. Average annual temperature is 17.8°C, with monthly mean temperature ranging from −2.1°C in January to 27.5°C in July. Annual rainfall is approximately 2,000 mm/year, of which 71% rainfall occurs from April to September. In the mid-late 20th century, the Chencun Hydropower Station was built at the middle reach of the Qingyi River (Chu, Wang, Zhu et al., 2015; Li et al., 2016).

The streams flowing into the Chencun Reservoir include the Qingxi, Shuxi, Yangxi, Maxi and Puxi Stream. The Maxi and Puxi Stream are heavily polluted by human activities. The pollution emitted yearly into the Maxi and Puxi Stream is approximately twice as much that emitted into the other three streams (Li et al., 2014). Also, these streams are different in the proportion of land use. The proportion of land use is the highest in the Puxi Stream (9.32% of urban land and 11.12% of farmland land respectively), the medium in the Yangxi (1.26% urban and 7.28% farmland) and Maxi Stream (3.13% urban and 8.08% farmland), and the lowest in the Shuxi and Qingxi Streams (<1% urban and <5% farmland) (Lu et al., 2014). We collected fishes from the Shuxi, Puxi and Maxi Stream, among which the Shuxi is disturbed less by human activities, and the Maxi and Puxi Stream are heavily disturbed.

2.2 | Field survey

Within each study stream, we set sampling sites continuously with an interval of 2–3 km from headwaters to downstream segments. Sampling sites were selected in the field based on habitat representativeness and accessibility. Each site was wadeable (<1 m depth) and encompassed at least two common habitat-patches such as pools and riffles. A total of 14 sites were sampled in both the Shuxi and Maxi Stream, whereas 11 sites were sampled in the Puxi Stream because of multiple dams that uplifted water level and lessened wadeable segments (Figure 1).

During May and October 2011, fish were collected from each site using a backpack electro-fishing unit (CWB-2000 P, China; 12 V import, 250 V export) by wading in two passes without blocking nets. Each fish collection was operated with a uniform sampling effort (approximately 30-min sampling time for each 50-m sampling segment) by the same three persons, one operating the electro-fishing unit and the other two capturing fishes. Fishes were identified in the field to species, counted and returned to the sampling sites if alive.

We characterised the physical habitat of each sampling site by six habitat variables, including wetted width (m), water depth (m), current velocity (m/s), and substrate coarseness and heterogeneity. Wetted width was measured along five transects equally spacing across the stream channel. Water depth was measured at four equal interval points along each transect. Current velocity was taken at 60% of water depth at each point (FP111, USA). Substrate was quantified with a 1-m lead core divided into 10-cm sections, using the frequency size-class method of Bain (1999). Mean and standard deviation of dominant substrate values were regarded as indices of substrate coarseness and heterogeneity respectively.

2.3 | Diversity index calculation

Diversity index of fishes used in this study included α diversity and β diversity. According to the fishes collected twice (during May and October) at each sampling site, we determined the overall species composition and species richness for each site. Local species richness was regarded as α diversity, which measures the within-community diversity of fishes. β diversity was estimated by the Sørensen similarity index: $\beta = (b + c)/(2a + b + c)$, where a is the number of species shared by the two assemblages, and b and c are the number of species unique to each assemblage. β diversity was calculated independently for each study stream. Because one aim of this study was to determine how β diversity varied along the upstream–downstream gradient, we used the mean Sørensen index between one specific assemblage and all other assemblages as the mean β diversity of this specific assemblage.

2.4 | Data analysis

We used Pearson's correlation to test the linear correlation between physical habitat and distance from headwaters, which was calculated from the Anhui Province land-use data sets of 1:100,000 scales in 2010. Mean of each habitat variable collected twice (during May and October) was used to describe the habitat characteristic of each site. Because both α and β diversity of fishes varied along the upstream–stream gradient, we classified all sampling sites within each study stream into three groups of segments according to the distance from headwaters, including the upper (0–20 km of distance), middle (20–30 km) and lower segments (30–40 km). Then, we used One-way ANOVA to test the among-stream variation in both α and β diversity for the three segments independently. The Student-Newman-Keuls test was used for post hoc comparisons after ANOVA. To determine the spatial variations in both α and β diversity along the upstream–downstream gradient, we examined

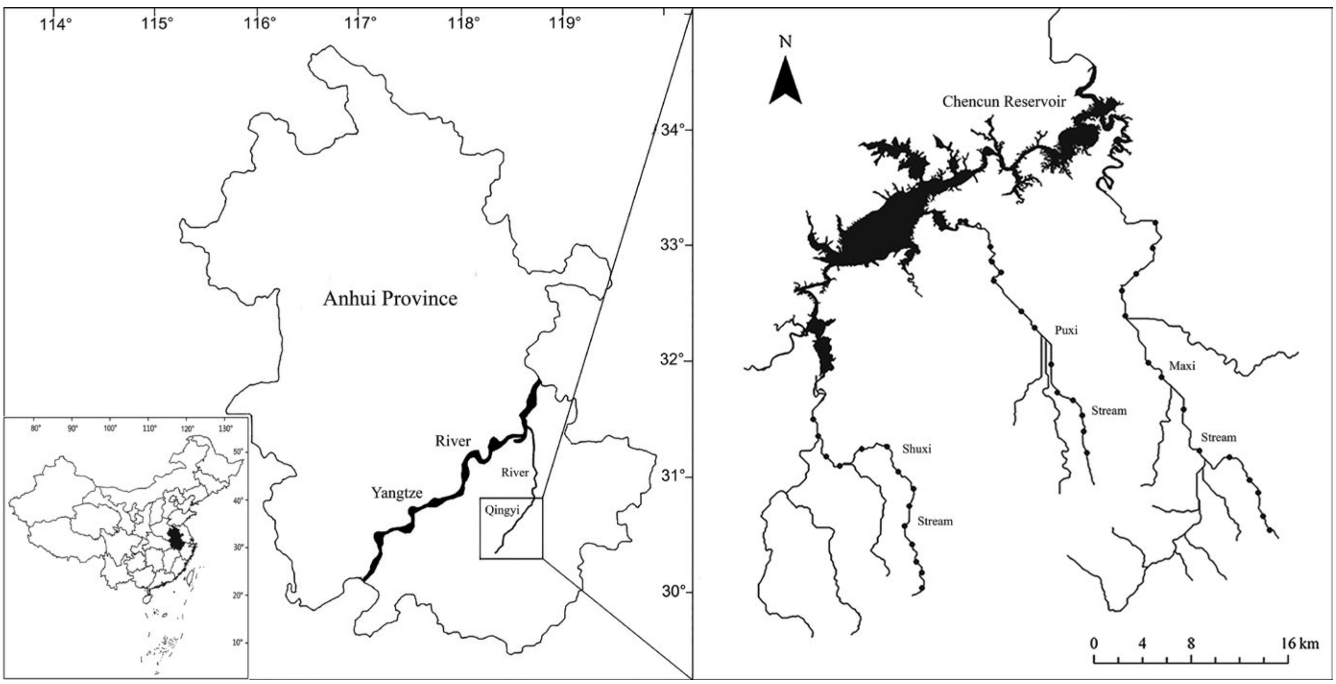

FIGURE 1 Map of the headwater streams upper the Chencun Reservoir of the Huangshan Mountain (black circles indicated the sampling sites)

the correlation between diversity index and the distance from headwaters. First, we expected to use the simple linear model to describe the "diversity–distance" relationship. Pearson's correlation was used to test this diversity–distance relationship, of which statistical significance was accepted at $p < .05$. Second, if the "diversity–distance" relationship was not significant, we used curve estimation to test how diversity index vary with distance data. According to R value of each model, we determined the optimal model that explained the most spatial variation of diversity index. Independent and dependent variables were all $\log_{10}^{(X+1)}$ transformed to meet assumptions of multivariate normality and to moderate the influence of outliers. The SPSS 22.0 statistics package (SPSS Inc., Chicago, IL, USA) was used to perform the statistical analysis.

3 | RESULTS

3.1 | Environmental characteristics

From headwaters to mouth, some habitat variables including wetted width and substrate heterogeneity increased significantly, and others significantly decreased downstream, such as current velocity (with an exception of that in the Puxi Stream) and substrate coarseness. But water depth and canopy (except for in the Maxi Stream) showed no significant correlation with the distance from headwaters (Figure 2). At the lower reaches of the study streams, the Shuxi Stream showed higher wetted width, substrate coarseness and heterogeneity than that in the Maxi and Puxi Stream (Figure 2).

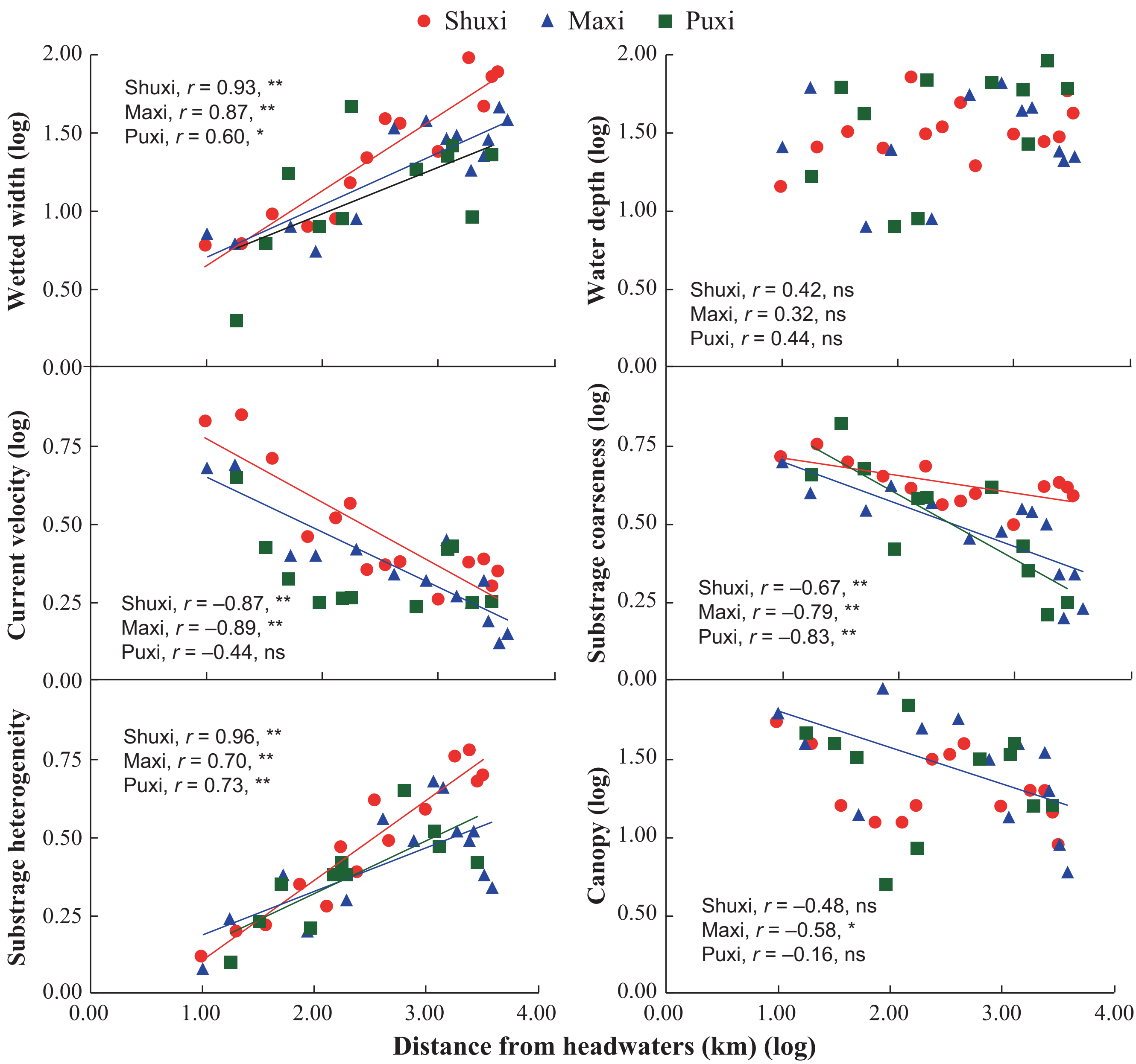

FIGURE 2 Relationship between physical habitat and distance from headwaters in the Shuxi, Maxi and Puxi Stream

3.2 | Overview of species composition

A total of 30 species were collected in this study, representing 10 families and four orders. Species of family Cyprinidae comprised, on average, 57.1% of total species richness; 26, 25 and 23 species were collected from the Shuxi, Maxi and Puxi Stream respectively. The 30 species differed in their habitat preference. Fifteen species were the native fishes preferring lotic conditions in the upland headwater streams, such as *Zacco platypus*, *Acrossocheilus fasciatus* and *Vanmanenia stenosoma*. Other 15 species often preferred lentic conditions at the lowland areas, such as *Carassius auratus*, *Abbottina rivularis* and *Pseudorasbora parva*, which was defined as the "native invader" by Chu, Wang, Zhu et al. (2015); 15, 11 and 10 native species were collected in the Shuxi, Maxi and Puxi Stream, and 11, 14 and 13 invasive species were collected in the Shuxi, Maxi and Puxi Stream respectively. In overall, most native species showed relatively higher frequency of occurrence in the Shuxi Stream and some invasive species were more frequent in the Maxi and Puxi Stream (Table 1).

3.3 | α diversity

The mean α diversity was 8.0 ± 1.0 (mean ± *SD*) species (Shuxi), 7.0 ± 1.1 species (Maxi) and 7.5 ± 1.1 (Puxi). After dividing each stream surveyed into the upper, middle and lower segments, we found that α diversity did not show significant among-stream variation at upper (One-way ANOVA, $F = 0.67$, $p > .05$) and middle segments ($F = 0.89$, $p > .05$), but differed significantly at the lower segments ($F = 5.27$, $p < .05$), of which α diversity in the Shuxi Stream was higher than that in the Maxi and Puxi Stream ($p < .05$).

Pearson's correlation analysis showed that linear "α diversity–distance from headwaters" relationship was significant in the Shuxi Stream ($R^2 = .56$, $p < .01$), of which α diversity increased downstream significantly (Figure 3). However, this linear diversity–distance correlation was not significant in the Maxi and Puxi Stream ($p > .05$). After curve estimation, we found that the quadratic model explained the most variation in α diversity in the Maxi ($R^2 = .89$, $p < .01$) and Puxi Stream ($R^2 = .87$, $p < .01$). α diversity increased downstream, obtained its maximum at the middle reach and decreased in the lower reach (Figure 3).

3.4 | β diversity

The mean β diversity was 0.48 ± 0.03 in the Shuxi Stream, 0.67 ± 0.05 in the Maxi Stream and 0.62 ± 0.04 in the Puxi Stream respectively. β diversity showed significant among-stream variation at the middle (One-way ANOVA, $F = 13.17$, $p < .01$) and lower segments ($F = 16.07$, $p < .01$), not at the upper segment ($F = 1.52$, $p > .05$). β diversity was lower in the Shuxi Stream than that in the Maxi and Puxi Stream ($p < .05$).

According to Pearson's correlation analysis, linear "β diversity–distance from headwaters" relationship was significant in the Shuxi Stream, of which β diversity decreased downstream significantly ($R^2 = .52$, $p < .05$) (Figure 3). However, this linear relationship was not

TABLE 1 The frequency of occurrence of fishes collected in the Shuxi, Maxi and Puxi Stream

Species/family/order	Shuxi	Maxi	Puxi
Cypriniformes			
Cyprinidae			
Zacco platypus[a]	92.86	78.57	90.91
Carassius auratus	7.14	14.29	27.27
Opsarrichthys bidens[a]	28.57	7.14	36.36
Phoxinus oxycephalus[a]	21.42	14.29	/
Rhodeus ocellatus	42.86	50.00	45.45
Acheilognathus barbatulus[a]	28.57	21.43	/
Acrossocheilus fasciatus[a]	85.71	14.29	63.64
Pseudorasbora parva	21.43	28.57	45.45
Sarcocheilichthys parvus	7.14	14.29	9.09
Squalidus argentatus	28.57	14.29	36.36
Abbottina rivularis	7.14	21.43	18.18
Hemiculter leucisculus	14.29	7.14	/
Pseudohemiculter dispar	/	7.14	/
Pseudogobio vaillanti[a]	35.71	28.57	27.27
Onychostoma barbatulum[a]	7.14	/	9.09
Parasinilabeo assimilis[a]	14.29	/	/
Cobitidae			
Cobitis sinensis[a]	42.86	14.29	54.46
Cobitis rarus[a]	57.14	14.29	9.09
Misgurnus anguillicaudatus	50.00	57.14	54.55
Leptobotia guiiinensis[a]	21.42	21.43	36.36
Homalopteridae			
Vanmanenia stenosoma[a]	85.71	28.57	/
Perciformes			
Mastacembelidae			
Mastacembelus aculeatus	14.29	28.57	27.27
Channidae			
Channa argus	/	/	18.18
Electridae			
Odontobutis obscura	/	50.00	9.09
Hypseleotris swinhonis	/	7.14	9.09
Gobiidae			
Ctenogobius sp.[a]	100.00	71.43	81.82
Siuriformes			
Amblycipitidae			
Liobagrus styani[a]	35.71	/	/
Bagridae			
Pseudobagrus truncates[a]	14.29	/	18.18
Pelteobagrus fulvidraco	/	14.29	18.18
Synbranchiformes			
Synbranchidae			
Monopterus albus	14.29	21.43	9.09

[a]The species preferring lotic conditions in upland headwater streams. Other fishes were the species often preferring lentic conditions in lowland areas, and these species were defined as the "native invader" by Chu, Wang, Zhu et al. (2015).

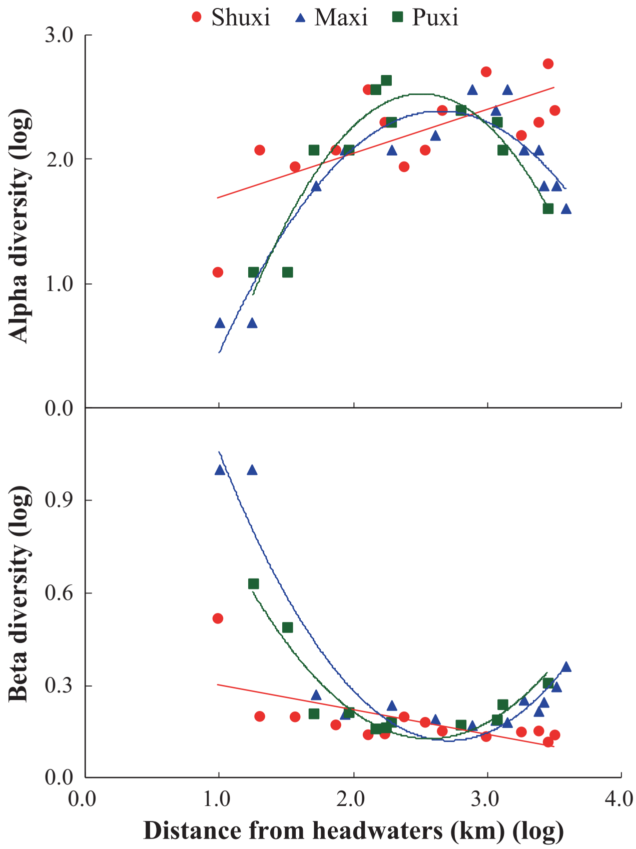

FIGURE 3 Relationship between fish diversity and distance from headwaters in the Shuxi, Maxi and Puxi Stream

observed in the Maxi and Puxi Stream ($p > .05$). The curve estimation showed that quadratic model agreed to the "β diversity–distance" relationship in the Maxi ($R^2 = .81$, $p < .01$) and Puxi Stream ($R^2 = .84$, $p < .01$). β diversity decreased downstream and obtained its minimum at the middle, not the lower segments in the Maxi and Puxi Stream (Figure 3).

4 | DISCUSSION

Abiotic and biotic factors and their ecological processes in streams substantially vary along the upstream–downstream (Vannote et al., 1980). At least in wadable headwater streams, local species richness of fishes often increase downstream, which is due to that stream size, habitat diversity and complexity generally increase downstream (Matthews, 1998; Roberts & Hitt, 2010). We found that, in the Shuxi Stream disturbed less, wetted width and substrate heterogeneity increased downstream, and current velocity and substrate coarseness decreased from headwaters to mouth. Also, we found that α diversity of fishes positively related to distance from headwaters, which supported our hypothesis that α diversity of fishes increase downstream along the "upstream–downstream" gradient in a stream disturbed less.

Different to α diversity (i.e., with-community diversity), β diversity quantify the degree to which species compositions vary from one community to another (Kessler et al., 2009; Whittaker, 1972). Therefore, α diversity and β diversity may show different spatial pattern (Tylianakis, Klein, & Tscharntke, 2005). Jaramillo-Villa et al. (2010) found β diversity of stream fishes positively relate to elevation ranging from 1,750 to 1,000 m at the Colombian Andes. Tisseuil et al. (2013) discovered an overall pattern of decreasing beta diversity along the upstream–downstream river gradient in the Adour-Garonne basin. We found that β diversity of fishes in the Shuxi Stream showed negatively correlation with the distance from headwater, which supported our hypothesis that β diversity of fishes decrease downstream along the "upstream–downstream" gradient in a stream disturbed less. Compared with fishes distributed at the lower reaches of streams, fishes upstream are characterised by simple composition and high endemism, suggesting a pattern of low α diversity but high β diversity of fish assemblages upstream (Meyer et al., 2007; Scott & Helfman, 2001). For example, in the Qingyi watershed, *Phoxinus oxycephalus* and *Onychostoma barbatulum* are the cold-water species, only distributed at stream headwaters with high elevation (Chu, Wang, Zhu et al., 2015; Wang et al., 2013; Yan, Xiang, Chu, Zhan, & Fu, 2011). In this study, the two species were only collected at two sampling sites at headwaters of the Shuxi Stream, which can increase the rate of species turnover from upstream assemblages to midstream and/or downstream assemblages, and can further result in a relatively higher β diversity of upstream assemblages.

Anthropogenic activities, such as urbanisation, agriculture and river regulation, may alter hydrologic rhythm, flowing and thermal regimes, nutrient and sediment input, physical and chemical conditions (Allan, 2004; Diana, Allan, & Infante, 2006; Paul & Meyer, 2001; Strayer et al., 2003). Following habitat modification, many endemic species are replaced by some cosmopolitan species of fishes (Allan, 2004; Chu, Wang, Yan et al., 2015; Li et al., 2016; Morgan & Cushman, 2005; Wang et al., 2001; Yan, Wang, Zhu, Chu, & Chen, 2013). This species loss and gain may modify α diversity of local assemblages (Mckinney, 2002). In this study area, the Maxi and Puxi Stream are heavily polluted by COD, NH_3-N and TP. The amounts of these pollutants are approximately twice as much that emitted in the Shuxi Stream (Li et al., 2014). In addition, the three streams show different proportions in land use of urbanisation and agriculture. The proportions of urban land and farmland are the highest in the Puxi Stream (9.32% urban land and 11.12% farmland), the medium in the Maxi Stream (3.13% urban land and 8.08% farmland) and the lowest in the Shuxi Stream (0.63% urban land and 3.67% farmland) (Lu et al., 2014). We found that the Shuxi Stream had more native fishes (15 species) and less invasive fishes (11 species), but the Maxi and Puxi Stream showed less native fishes (11 species, Maxi; 10 species, Puxi) and more invasive fishes (14 species, Maxi; 13 species, Puxi). Because of native species loss outnumbering invasive species gain, anthropogenic activities lead to the decrease in the overall and mean α diversity of fishes in the streams disturbed heavily. Also, we found that the two streams disturbed heavily showed higher mean β diversity than that in the stream disturbed less, which is due to that the processes of endemic species losing and cosmopolitan species gaining may alter the rate of species turnover from place to place (Tisseuil et al., 2013).

However, the above among-stream variation in both α and β diversity occurred only at the mid-downstream, not the upstream segments of these study streams, which may be associated with two causes, at least, as follows. First, Lu et al. (2014) have reported that the proportions of urban and farm lands within the basins of the Shuxi, Maxi and Puxi Stream increase gradually following slope decreasing. For example, the relative area of urban land in the Puxi Stream is 0.08% (>25° slope), 0.37% (15–25°), 1.53% (6–15°) and 7.33% (<6°) respectively (Lu et al., 2014). We believe that anthropogenic disturbance may be too less to induce the replacement of endemic species by cosmopolitan species at the upstream segments. But this replacement can occur at the mid-downstream segments due to relatively heavy disturbance. Second, the invasive fishes collected in this study, named the "native invader" by Chu, Wang, Zhu et al. (2015), are from the lower reach of this study basin (i.e., the Qingyi River), especially from the Chencun Reservoir, into which the Shuxi, Maxi and Puxi Stream flow (Chu, Wang, Zhu et al. 2015). Therefore, we consider that it is difficult for the invasive fishes to pass through some geographic obstacles, such as steep segment with high slope and even waterfalls, and to invade the upstream segments. This may also explain why no obvious replacement of endemic species by cosmopolitan species occurs in assemblages upstream, whereas, because of no obvious geographic obstacle constraining the movements of fishes, it is easy for the invasive fishes to immigrate from stream mouth to the mid-downstream segments, at which invasive species will replace endemic species. This replacement process increases the mean between-assemblage dissimilarity and β diversity of fishes at mid-downstream segments. Also, because endemic species losing outnumbers cosmopolitan species gaining, this replacement process decreases local species richness and α diversity of fishes at downstream segments. Furthermore, this sharp decrease in α diversity and sharp increase in β diversity at the lower segments will alter the upstream–downstream patterns of both α and β diversity, which supports our hypothesis that the spatial patterns of α and β diversity may shift from their natural patterns in the streams disturbed heavily.

It has been well established that local fish assemblages in streams are not only determined by abiotic factors and historical events (Hoeinghaus, Winemiller, & Birnbaum, 2007), but also influenced by fish movement, such as fish immigration and/or emigration (Taylor & Warren, 2001). At a watershed scale, a stream can be viewed as a dendritic ecological network, among which the abiotic and biotic factors and their ecological processes are often spatially autocorrelated due to between-segment continuity (Campbell-Grant, Lowe, & Fagan, 2007). Many researchers do not account for spatial and/or temporal dependence, and use tradition statistical tests, such as ANOVA and correlation analysis used in this study, to determine the spatial and/or temporal variations in fish assemblages in streams. However, a simplifying but necessary component in the derivation of many traditional statistical tests is that the data being analysed are independent, and the statistical consequences of not accounting for spatial/temporal dependence can be severe (Carroll & Pearson, 2000). If the data are positively, spatially autocorrelated, the variance estimates are often biased downward (Underwood, 1997), and the coefficient of determination in regression analysis is biased upward (Haining, 1990). In this study, we used a common ANOVA to test the among-stream variation in fish diversity, and used linear correlation and curve estimation to examine the "fish diversity–distance from headwaters" relationship. Therefore, the among-stream variations in both α and β diversity may be biased downward (Underwood, 1997), and the correlation coefficient and significance of "diversity–distance" relationship may be biased upward (Haining, 1990). One aim of this study was to determine the among-stream variations in fish diversity and to assess how anthropogenic disturbance affected fish diversity in streams. We found the significant variation in fish diversity in the heavily disturbed segments compared to that in the less disturbed segments. Given that the traditional statistical test (i.e., ANOVA) will bias downward the variance estimation, potential larger among-stream variation in diversity may occur in this study area. However, this potential bias does not conflict with our conclusion that anthropogenic disturbance decreases α diversity but increases β diversity of fishes in streams. The other aim of this study was to determine the "upstream–downstream" pattern in fish diversity and to assess the effect of anthropogenic disturbance on the longitudinal distribution of fish diversity in streams. We found that the linear "diversity–distance from headwaters" relationship in the less disturbed stream is replaced by the quadratic distribution in the heavily disturbed streams. In future research, geostatistical techniques (e.g., correlogram, variogram and kriging model) may provide further insights into the dependence of the data on fish assemblages collected in field and spatial and/or temporal variations of fish assemblages in streams.

In conclusion, we found that α diversity gradually increase downstream and β diversity decrease downstream along the upstream–downstream gradient in a stream disturbed less, which suggests the different spatial patterns between α diversity and β diversity along the environmental gradient. Anthropogenic activities cause that many endemic fishes are replaced by cosmopolitan fishes in streams disturbed heavily. This replacement alters the rate of species turnover of fishes from place to place, and substantially increases the between-assemblage dissimilarity of fishes. Because of endemic species loss outnumbering cosmopolitan species, this replacement substantially decreases α diversity in these streams. Also, associated with the spatial heterogeneity in anthropogenic disturbance along the longitudinal gradient in streams and the spatial accessibility for native-invasive fishes to immigrate, this replacement mainly occurs only at the mid-downstream, not upstream reaches of streams. As a result, we can observe α diversity decreasing and β diversity increasing at the mid-downstream reaches, which may further alters the upstream–downstream patterns of α diversity and β diversity in streams disturbed heavily.

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