Differences in stream fish assemblages subjected to different levels of anthropogenic pressure in the Taizi River catchment, China

Article *in* Ichthyological Research · February 2015

DOI: 10.1007/s10228-015-0459-6

Sen Ding
Chinese Research Academy of Environmental Sciences

Wei Meng
Shanxi University

Ichthyol Res (2015) 62:450–462
DOI 10.1007/s10228-015-0459-6

FULL PAPER

Differences in stream fish assemblages subjected to different levels of anthropogenic pressure in the Taizi River catchment, China

Yuan Zhang · Sen Ding · Catherine N. Bentsen · Shuqin Ma · Xiaobo Jia · Wei Meng

Received: 10 April 2014 / Revised: 26 November 2014 / Accepted: 12 January 2015 / Published online: 5 February 2015

Abstract This study was conducted in the Taizi River catchment, located in northeastern China. Six representative streams in three regions (upper mountains, middle hills, lower plains) with different levels of anthropogenic disturbances were surveyed to describe the structure of fish assemblages and their relationship to environmental parameters. The results showed that the fish assemblages were significantly different among the three regions in the Taizi River catchment. Indicator species analysis found ten representative fish species in the Taizi River catchment and four species in the upper, four species in the middle, and two species in the lower regions. The ecological traits of the representative fish species were generally in agreement with the physiochemical features of the streams located within different regions. Multivariate analysis indicated that altitude, water temperature, and total nitrogen were the three most significant environmental parameters influencing the fish assemblage structure in the Taizi River catchment. Based on the different environmental features and fish assemblages found in each region, fish management and conservation strategies should be tailored to the specific characteristics of each region.

Y. Zhang · S. Ding (✉) · C. N. Bentsen · S. Ma · X. Jia · W. Meng
State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
e-mail: dingsen@craes.org.cn

Y. Zhang · S. Ding · C. N. Bentsen · S. Ma · X. Jia
Laboratory of Riverine Ecological Conservation and Technology, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

Keywords Fish assemblage · Stream · Anthropogenic pressure · Water quality · Taizi River

Introduction

The study of the distribution of organisms, including freshwater fishes, within the landscape has a long history (Frimpong and Angermeier 2010), but has become increasingly important in recent years in light of global declines in freshwater biodiversity (Vörösmarty et al. 2010) linked to habitat loss and degradation, pollution, flow modification, fishery exploitation, and invasive species (Dudgeon et al. 2006; Strayer and Dudgeon 2010). Fish play an important role for the ecological functioning of the river system by cycling nutrients, altering food web and trophic dynamics, and providing linkages both within aquatic systems and between aquatic and terrestrial systems (Nakano and Murakami 2001). Fish also provide ecosystem services through the provision of food, medicine, and recreation (Holmlund and Hammer 1999). For these reasons, fish are often used as a component of biomonitoring programs (Barbour et al. 1999), especially because of their ability to integrate stressors over long-term temporal scales and different spatial scales (Karr 1981; Oberdorff et al. 2002; Resh 2008).

Several conceptual frameworks exist (e.g., Vannote et al. 1980; Frissell et al. 1986) that illustrate the spatial organization and hierarchical nature of river networks. This hierarchy has also been described as a set of filters, or screens, that act to limit the biological community through the preconditions presented at each level (Smith and Powell 1971; Poff 1997; Jackson et al. 2001; Quist et al. 2005). At the catchment scale, biogeography, climate, geology, topography, soils, and vegetation act as the main overarching factors that affect the stream system (Frissell et al. 1986). Some frameworks also include hydrology (Snelder and Biggs 2002), for which variables such as flow regulation and river connectivity (i.e., fragmentation) influence the ability of fish communities to disperse, migrate, and spawn (Hering et al. 2006). Within this broader scale, environmental factors on each subsequent nested level influence the organization of the biotic community on increasingly localized spatial scales. Natural factors that interact with historical, biogeographical, and evolutionary conditions act to constrain the full suite of species to a regional pool of those species potentially present within a certain geographical range (Jackson et al. 2001).

Land use and anthropogenic disturbances at the catchment scale have significant effects on fish assemblages (Wang et al. 2001; Allan 2004). Agricultural land has been implicated in lower fish biotic condition (Roth et al. 1996; Walser and Bart 1999), likely in response to high levels of nutrients and pesticides (Cuffney et al. 2000), sediments (Diana et al. 2006), and altered thermal and hydrological regimes (Strayer et al. 2003). The detrimental effects of urban land on fish communities have also been documented. Urbanization is linked to increased surface runoff, which scours the stream channel and increases nutrient, sediment, and contaminant loads to the system (Paul and Meyer 2001; Allan 2004; Walsh et al. 2005). Fish in urban streams have lower biotic integrity, generally characterized by lower species richness and lack of sensitive species (Klein 1979; Lenat and Crawford 1994; Wang et al. 2001; Morgan and Cushman 2005). Conversely, forest and wetland coverage have positive relationships with fish integrity (Roth et al. 1996; Wang et al. 1997; Walters et al. 2009). Since geomorphology and available resources also influence the type of land use suited to that area (Slaymaker et al. 2009), anthropogenic disturbances become regionalized, with different patterns in the extent of degradation of the freshwater ecosystem (Stein et al. 2002).

On a finer scale, local abiotic and biotic factors further affect fish assemblage structure (Grossman et al. 1998; Hawkins et al. 2000; Jackson et al. 2001; Valério et al. 2007). Water quality and habitat structure are essential local factors for determining fish distribution (Pinto et al. 2009). Fish have been shown to be sensitive indicators of water quality (Chalar et al. 2013); community condition is variously associated with water quality parameters, such as water temperature, dissolved oxygen, pH, total dissolved solids, nitrogen, and phosphorus (Meador and Goldstein 2003; Hering et al. 2006; Pinto et al. 2009). Fish also respond negatively to heavy metal concentrations, either dissolved or within sediments, and total suspended solids (Griffith et al. 2005). Based upon these responses, measurements of fish community structure are commonly used to assess river condition (e.g., Karr 1981; Friberg et al. 2011). Habitat quality and availability exert another influence on fish distribution, with different fish species showing distinct preferences for different habitat structures (Martin-Smith 1998), including depth, velocity, substrate, and pool availability (Lammert and Allan 1999; Mueller and Pyron 2010). Large woody debris and submerged aquatic vegetation add structural complexity that can create habitat conditions conducive to some fish species (Quist et al. 2005). In addition, Perna et al. (2012) found the removal of floating weed improved the quality of physical habitat and led to the re-establishment of many native fish species. Biotic factors of predation and competition further act to filter fish assemblage structure through the processes of niche segregation and resource partitioning (Jackson et al. 2001). This includes interactions with non-native fish, which can outcompete and replace native species of similar trophic status, such as piscivores (Quist et al. 2005).

Increasingly, researchers have focused on the relative contributions from different spatial scales in determining fish assemblages (Marsh-Matthews and Matthews 2000; Strayer et al. 2003). Several studies have shown that local environmental factors play a greater role on small spatial scales, while regional factors play a greater role on broad scales (Allan et al. 1997; Poff 1997; Jackson et al. 2001; Lammert and Allan 1999; Wang et al. 2001; Wang et al. 2006). As a result, comparison of the fish assemblage structure among or within regions with different history and characteristics of anthropogenic disturbance, and in relation with local factors, can provide greater understanding of the specific mechanisms of degradation, as well as aid in the establishment of management priorities aimed at the conservation and restoration of fish communities in these disturbed ecosystems.

We chose the Taizi River in Liaoning Province, northeastern China, as the study site, since the catchment contains regional variation in the degree and type of anthropogenic disturbance. The main aim of this study was to assess the variation in fish community features with different levels of human disturbance and identify the main environmental variables influencing fish assemblage in this region. With the development of the regional economy, the aquatic ecosystem is under a huge amount of pressure, but the laws and management plans for fish protection and conservation are deficient in this drainage. The second aim of this study was to supply some basic information for fish protection in the Taizi River catchment.

Materials and methods

Study area. The Taizi River, which drains approximately 13,880 km^2, flows through one of the most important economic regions in China. The Taizi River catchment has been spatially delineated into three ecoregions based on natural landscape factors, of which altitude and precipitation were the most important (Kong et al. 2013). These factors also influence the spatial patterns of land use and anthropogenic disturbance found within the catchment. The upper Taizi River is classified as a mountainous forest region consisting mainly of broadleaf deciduous forest. The land cover is predominantly forest, and development is broadly restricted for the purpose of tourism. The middle reach of the Taizi River is located in the hilly region, which has large-scale agricultural development. The lower Taizi River flows through the economically developed plain region, in which there are several important industrial cities. In addition, there is a high population within the middle and lower reaches of the Taizi River, especially concentrated in the cities of the lower plain region. The environmental characteristics and land use statistics for each ecoregion are shown in Table 1.

This study was carried out on six tributaries of the Taizi River: Taizi South (length: 84.3 km), Xiaotang (53.8 km), Tang (77.4 km), Lan (49.9 km), Nansha (55.2 km), and Beisha (93.9 km). Taizi South and Xiaotang tributaries are located in the upper mountainous region; Tang and Lan tributaries are located in the middle hilly region; and Nansha and Beisha tributaries are located in the lower plain region. In total, 91 sites—25 sites in the upper mountainous region, 45 sites in the middle hilly region, and 21 sites in the lower plain region—were sampled during the autumn in October 2009 and the summer in August 2010 (Fig. 1). Human disturbances are shown in Table 1, and there is a huge difference in the population pressure and social economic pressure among the three regions. In this study, Taizi South and Xiaotang tributaries represented low human disturbances, whereas Tang and Lan tributaries, and Nansha and Beisha tributaries represented moderate and high human disturbances, respectively.

Environmental factors. At each site, we sampled environmental variables and fishes within a 300-m survey reach. Twelve environmental variables were measured for each site: altitude (m), mean depth (cm), mean velocity ($m\ s^{-1}$), water temperature (°C), pH, dissolved oxygen ($mg\ L^{-1}$), conductivity ($\mu s\ cm^{-1}$), total dissolved solids ($mg\ L^{-1}$), total nitrogen ($mg\ L^{-1}$), total phosphorus ($mg\ L^{-1}$), chemical oxygen demand ($mg\ L^{-1}$), and ammonia-nitrogen ($mg\ L^{-1}$). Altitude was obtained with a Trimble-Juno SB GPS receptor. We randomly chose three cross sections within each survey reach; at each cross section we took depth and velocity measurements at three equidistant points with a digital velocity meter (Global Water flow probe FP-201). Mean depth and velocity were calculated from the nine data points obtained from the three cross sections. Water temperature, pH, dissolved oxygen, conductivity, total dissolved solids, and ammonia-nitrogen were measured with a handheld YSI Pro 2030 multi-parameter instrument (Professional Plus) *in situ*. Total nitrogen, total phosphorus, and chemical oxygen demand were measured in the laboratory by the potassium persulfate oxidation method, the molybdenum–antimony anti-spectrophotometric method, and the potassium chromate method, respectively, according to the Chinese Standard Methods for Examination of Water and Wastewater (MEP 2002), respectively.

Fish collection. Fish were captured with a Smith-Root (Model 15 D) backpack electro-fisher for the sites of wadeable reach. Two workers walked along one side of the

Table 1 Environmental characteristics, land use and human disturbances statistics for each ecoregion of the Taizi River catchment

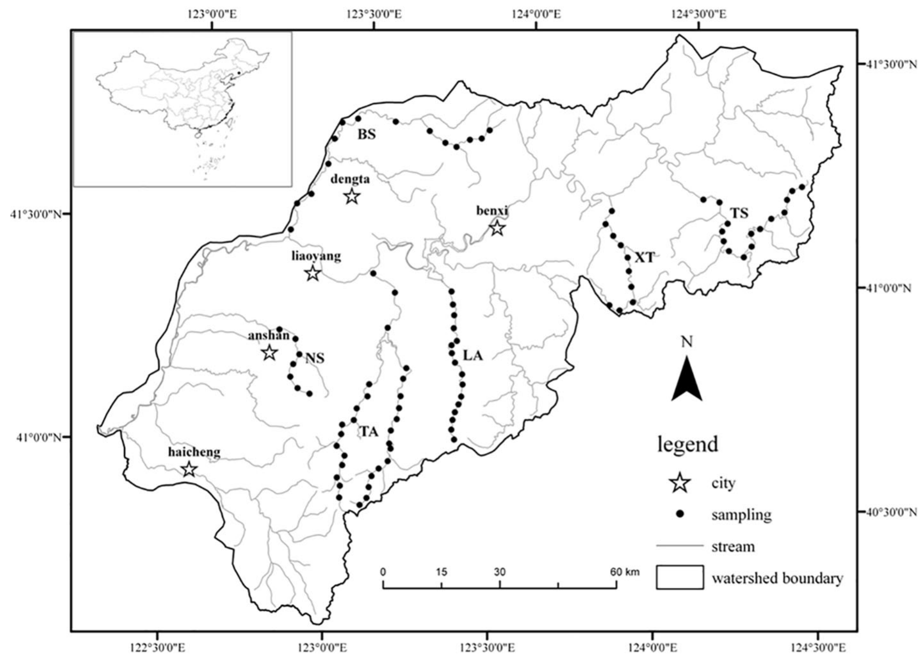
Background traits		Upper mountainous region	Middle hilly region	Lower plain region
Environmental characteristics	Drainage area (km^2)	4,557	3,896	4,749
	Altitude (m)	400–643	67–400	0–67
	Temperature, air (°C)	2.28–7.75	4.38–9.22	4.90–10.00
	Precipitation (mm)	786–954	717–868	653–775
Land use	Forest (%)	26.9	21.9	8.1
	Grassland (%)	0.3	0.4	0.3
	Agriculture (%)	4.5	5.5	20.2
	Urban/residential (%)	0.4	1.2	7.0
	Other (%)	0.9	1.1	1.2
Human disturbances	GDP (RMB)	8,810	52,830	231,930
	Population (ind.)	298,000	961,000	3,849,000

Drainage area and *land use data* were obtained from GIS works (unpublished data)

Air temperature and *precipitation data*, which represent 40-year average ranges, were obtained from Liaoning province bureau of meteorology

GDP and *population data* were obtained from the following website: http://wenku.baidu.com/view/81b367e8856a561252d36f93.html

Fig. 1 Location of the 91 sampling sites in the Taizi River catchment



river and went back along the other side to collect fish during a 300-m long (150 m along each bank) survey of the reach. Double-pass electrofishing was conducted for 30 min. All habitat types within the survey reach were sampled before the area was declared not occupied by fish. Gill nets (ca. 6 cm mesh) and the backpack electro-fisher were used together for the sites of non-wadeable portion of the reach. Gill nets were set for one hour for each site. Species identifications were conducted immediately after sampling. After identification, all fish were released back to the site, except for unknown species, which were taken back to the laboratory for further identification.

Statistical analyses. One-way analysis of similarity (ANOSIM) (Clarke 1993) was used to evaluate whether major differences existed in the fish assemblage structure among the three regions (upper mountainous region, middle hilly region, and lower plain region). The R-statistic value from ANOSIM represents the amount of similarity of fish assemblage structure among the three regions. An R-value close to zero means very similar composition, whereas a value close to one indicates little similarity (Clarke and Warwick 1994). ANOSIM was performed using PRIMER 5. We then used the non-metric multidimensional scaling (NMDS) technique to ordinate the fish assemblage similarities for sites within different regions. NMDS was performed using PC-ORD 5 (McCune and Mefford 1999), based on the Bray–Curtis distance measure and 50 runs with a maximum of 100 iterations per run. Prior to the NMDS analysis, fish abundance data were log (x + 1) transformed to reduce variation.

The representative species for each region were defined with indicator species analysis (Dufrêne and Legendre 1997). An indicator species occurs only in one group and should be faithful and exclusive to this group. For each species, an indicator value close to zero represents no indication, whereas that close to 100 means perfect indication (Keister and Peterson 2003). The significance test of the indicator species analysis was performed with a Monte Carlo randomization procedure with 1,000 permutations using PC-ORD 5. The ecological traits and functional groups (including habitat, flow preference, trophic guild, and reproduction) of indicator species were determined according to the descriptions of Xie (2007). Habitat was classified as either benthic or water column. Flow preference was determined based on whether fish inhabited fast-moving waters (rheophilic), slow waters (limnophilic), or had no preference (eurytopic). Trophic feeding habit categories were herbivore, invertivore, carnivore, or omnivore.

Principal components analysis (PCA) was used to detect major gradients and principal patterns of variation among the environmental variables. The remaining variables were then re-analyzed by PCA to obtain a few easily interpretable principal components. Component loadings >0.5 from PCA were used to identify latent variables (Pinto et al. 2009). PCA was performed using CANOCO for Windows Version 4.5 software (ter Braak and Šmilauer 2002).

Canonical correspondence analysis (CCA) was used to characterize the relationship between the fish assemblage and environmental variables (not including land use). Before CCA, the rare species occurring at only one site were excluded, and species abundances were logarithmically transformed [log (x + 1)] to reduce the variation of abundance. A preliminary forward selection CCA with all environmental variables was used to identify redundant variables, i.e., those with high variance inflation factor (>20) which were then deleted. CCA was also performed using CANOCO for Windows Version 4.5 software with the forward selection and Monte Carlo permutations analysis with 1,000 permutations to select a minimum set of environmental variables that had significant and independent effects on fish community distribution. Statistical significance of all analysis was accepted at $P < 0.05$.

Results

Fish assemblage structure. Fishes were represented by 32 species in nine families (Fig. 2). *Phoxinus lagowskii* was a widespread and dominant species and the abundance was the highest in the Taizi River catchment. *Odontobutis obscura*, *Nemacheilus nudus*, and *Carassius auratus* were the second most dominant species of the upper, middle, and lower regions, respectively. *Lampetra morii* was an endangered species and just ten individuals were found at six sampling sites. Fish community structure was significantly different among the three regions (Table 2). R-statistic values from ANOSIM showed that the fish assemblage structure in the upper mountainous region was more similar to the middle hilly region than the lower plain region. The fish assemblage structure changed gradually from the upper to the lower reaches. The sampling sites of the three regions were well separated in the biplot of NMDS (Fig. 3). Several sampling sites in the lower region of the stream had relatively good habitat conditions, which resulted in the fish community being more similar to that of the upper region.

Indicator species analysis. Ten species were identified as representative of the three different regions (Table 3).

Fig. 2 Number of fish collected in the Taizi River catchment: *U* upper mountainous region; *M* middle hilly region; *L* lower plain region; *asterisks* represent the dominant species of the specific region

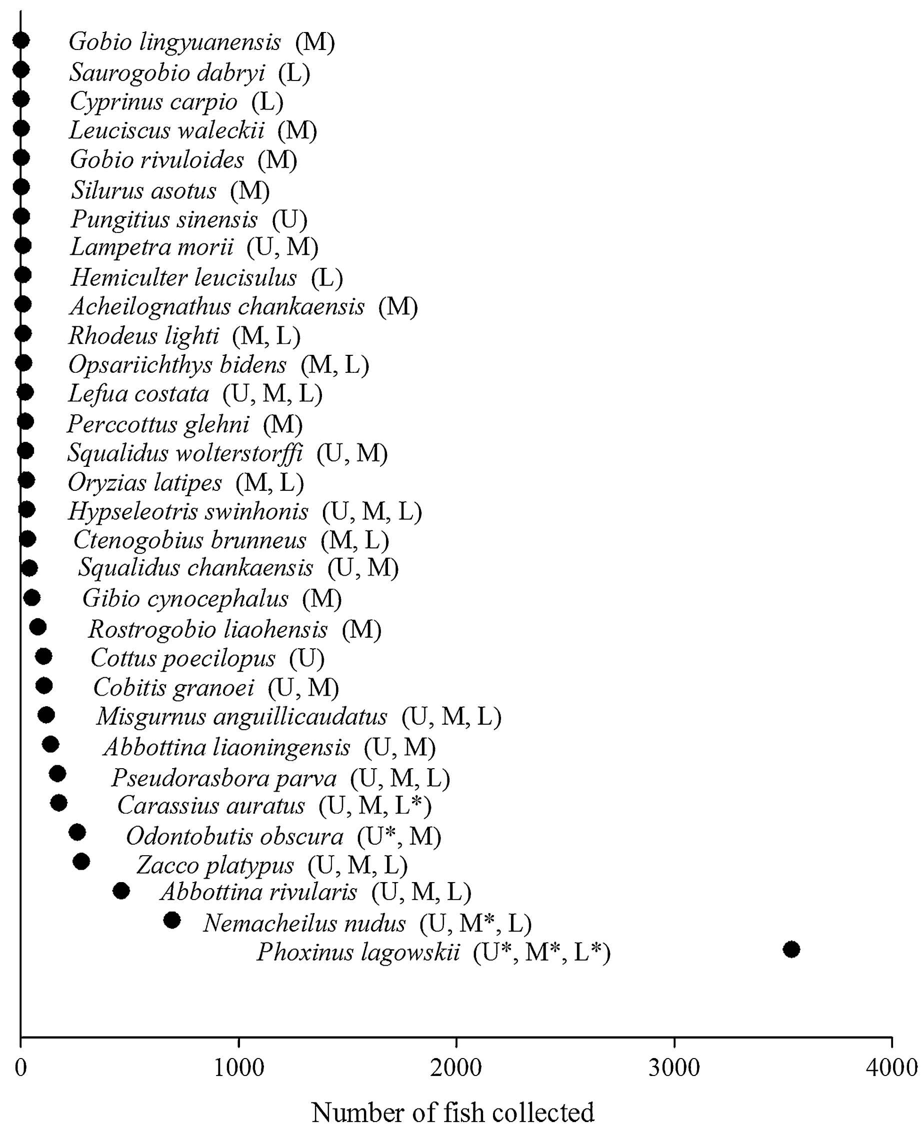


Table 2 Statistic results of ANOSIM and their significance levels (999 permutations) for pairwise comparisons of fish assemblage structure among the three regions

Regions	Global R	*P* level
U; M	0.17	0.001
U; L	0.61	0.001
M; L	0.49	0.001

U upper mountainous region; *M* middle hilly region; *L* lower plain region; ** $P < 0.01$

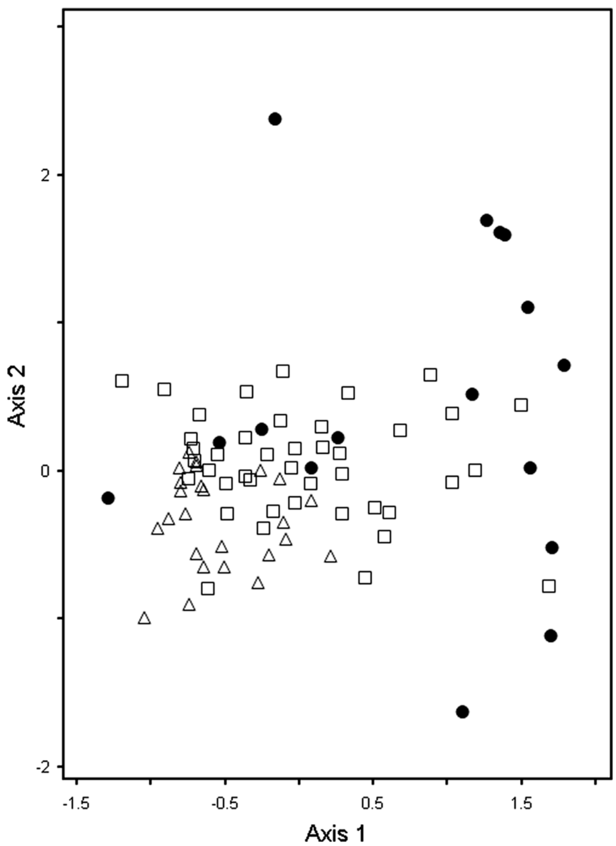


Fig. 3 Non-metric multidimensional scaling ordination of the fish assemblage for sites coded by region: *open triangles* upper mountainous region; *open squares* middle hilly region; *closed circles* lower plain region

The indicator species of the upper mountainous region were *Cottus poecilopus* ($P = 0.0002$), *Phoxinus lagowskii* ($P = 0.0002$), *Odontobutis yaluensis* ($P = 0.0006$), and *Squalidus wolterstorffi* ($P = 0.0306$). The indicator species for the middle hilly region were *Abbottina rivularis* ($P = 0.0008$), *A. liaoningensis* ($P = 0.0028$), *Gobio cynocephalus* ($P = 0.0186$), and *Cobitis granoei* ($P = 0.0354$). *Carassius auratus* ($P = 0.0004$) and *Opsariichthys bidens* ($P = 0.0492$) represented the lower plain region. These ten species were also classified based on ecological traits and functional guilds (Table 3). In general, the indicator species representing upper region sites were members of several families adapted to cool water and gravel sediment. Those species are rheophilic, prefer benthic habitat, and have small body size. On the other hand, species characterizing lower region sites belonged to the Cyprinidae. Those species prefer lotic conditions, utilize water column habitat, and have broad tolerance to environmental conditions.

Environmental variables. Table 4 shows the environmental variation for different regions of the Taizi River catchment. PCA axis 1 and PCA axis 2 explained 72.7 % and 8.1 % of the variance, respectively (Table 5). Axis 1 was positively correlated with total dissolved solids, conductivity, total nitrogen, chemical oxygen demand, ammonia-nitrogen, and water temperature, and negatively correlated with altitude and dissolved oxygen. Sites from the upper mountainous region are located on the left side of the PCA ordination diagram, reflecting high altitude and dissolved oxygen (Fig. 4). Conversely, sites from the lower plain region are located on the right side of the diagram, reflecting high temperature, conductivity, and nitrogen source pollution.

Fish assemblage and environmental relationships. The Monte Carlo permutation analysis found that altitude ($F = 7.33$, $P = 0.00$), total nitrogen ($F = 2.17$, $P = 0.01$), and water temperature ($F = 1.97$, $P = 0.02$) significantly affected the fish assemblage structure of all three regions. CCA analysis summarized the spatial trends of environmental variables in relation to the sites (Fig. 5) and characteristic species (Fig. 6). The first two axes of this analysis accounted for 84.6 % of the variance of environmental variables and fish species occurrence (Table 6).

Fig. 5 indicates that environmental gradients, as shown by sites coded by region, were evident. For sites of the upper mountainous region group, most are located in the left lower quadrant of Fig. 5, representing high altitude, low water temperature, and low nitrogen source pollution. On the other hand, nearly all sites of the lower plain region are located on the right side of the diagram, reflecting low altitude, high water temperature, and high nitrogen source pollution. Characteristic species groups also showed noticeable spatial differentiation (Fig. 6); those of the upper region are located on the left side of the diagram, whereas those of the lower region are located on the right side of the diagram in accordance with those differences observed among sites from different regions.

Discussion

The analyses presented in this study demonstrated significant differences of environmental quality among regions,

Table 3 Indicator species for different regions with associated ecological traits and functional groups, including habitat, flow preference, trophic guild, and reproduction

Species	Code	Region	P value	Habitat	Flow	Trophic guild	Notes
Phoxinus lagowskii	*sp1*	U	0.0002	B	E	O	Prefers clean and cool water
Squalidus wolterstorffi	*sp3*	U	0.0306	B	R	O	Prefers clean and cool water
Odontobutis yaluensis	*sp9*	U	0.0006	B	R	IC	Prefers gravel sediment and macrophyte habitat
Cottus poecilopus	*sp10*	U	0.0002	B	R	C	Prefers cool water and gravel sediment; egg-guarding behavior by male parent
Gobio cynocephalus	*sp4*	M	0.0186	B	R	IC	Prefers gravel sediment
Abbottina rivularis	*sp5*	M	0.0008	W	L	O	Prefers gravel sediment; egg-guarding behavior by male parent
Abbottina liaoningensis	*sp6*	M	0.0028	W	L	O	Prefers gravel sediment
Cobitis granoei	*sp8*	M	0.0354	B	L	O	Prefers riverbank
Opsariichthys bidens	*sp2*	L	0.0492	W	L	C	Prefers predation
Carassius auratus	*sp7*	L	0.0004	W	E	O	Tolerates pollution, eurythermic

Region: *U* upper mountainous region; *M* middle hilly region; *L* lower plain region

Habitat: *B* benthic; *W* water column

Flow: *R* rheophilic; *L* limnophilic; *E* eurytopic

Trophic guild: *H* herbivore; *O* omnivore; *I* invertivore; *C* carnivore

Table 4 The range of environmental variables for different regions

Environmental variables	U		M		L	
	minimum	maximum	minimum	maximum	minimum	maximum
Temperature, water (°C)	6.8	21.1	10.7	23.4	10.4	24
pH	8.09	10.12	8.2	9.67	8.25	9.8
Dissolved oxygen (mg L^{-1})	9.22	13.78	8.49	15.63	0.01	13.35
Conductivity (μS cm^{-1})	24.5	176.1	3.9	475.6	109	1431
Total dissolved solids (mg L^{-1})	22.1	139.1	14.95	352.95	98.8	968.5
Total nitrogen (mg L^{-1})	0.44	6.72	1.04	12.9	8.49	22.6
Total phosphorus (mg L^{-1})	0.01	0.36	0.01	0.94	0.01	0.51
Chemical oxygen demand (mg L^{-1})	0.5	3.7	0.7	12.5	1.8	6.8
Ammonia-nitrogen (mg L^{-1})	0.04	1.6	0.1	5.72	0.26	14.5
Mean depth (cm)	10	39.67	8.33	41.67	8.33	65
Mean velocity (m s^{-1})	0.03	0.67	0.02	0.83	0.03	0.65

Region: *U* upper mountainous region; *M* middle hilly region; *L* lower plain region

particularly between the upper mountainous region and lower plain region. As determined by PCA, the upper sites were characterized by high altitude, high dissolved oxygen, cold water, low conductivity and total dissolved solids, and low total nitrogen, chemical oxygen demand, and ammonia-nitrogen. In contrast, the sites located at lower altitudes had poor water quality, with low dissolved oxygen, high temperature, high conductivity and total dissolved solids, and high nitrogen source pollution. CCA analysis further isolated altitude, water temperature, and total nitrogen as the most important factors determining fish assemblages in the Taizi River.

Despite the correlation with altitude, water temperature and total nitrogen are affected by anthropogenic

Table 5 Factor loadings from principal components analysis on environmental variables for the first two axes

Variables	Axis 1	Axis 2
Altitude	**−0.87**	−0.36
Water temperature	**0.71**	−0.06
Mean depth	0.47	0.30
Mean velocity	0.17	−0.19
Dissolved oxygen	**−0.51**	−0.20
pH	−0.02	0.07
Conductivity	**0.93**	−0.31
Total dissolved solids	**0.95**	−0.20
Total nitrogen	**0.85**	0.16
Total phosphorus	0.31	0.09
Chemical oxygen demand	**0.81**	−0.02
Ammonia-nitrogen	**0.74**	0.45
Eigenvalues	0.73	0.08
% variance explained	72.7	8.1

Component loadings >0.5 are shown in *bold*

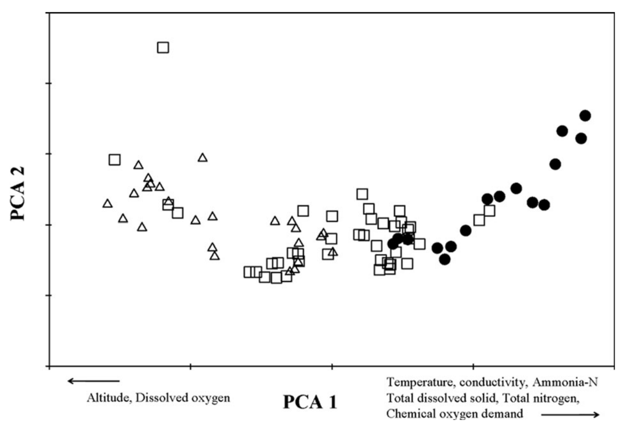


Fig. 4 Principal components analysis ordination for 8 environmental variables with sites coded by region: *open triangles* upper mountainous region; *open squares* middle hilly region; *closed circles* lower plain region

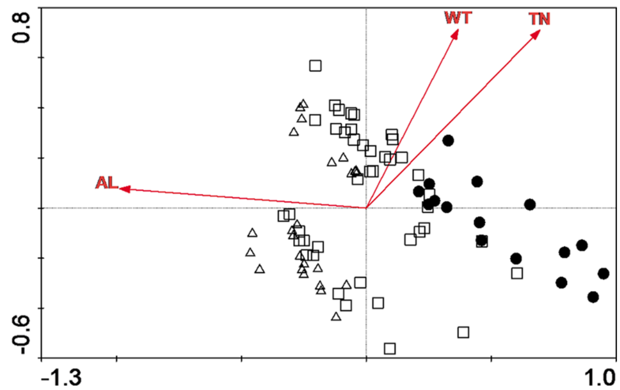


Fig. 5 Canonical correspondence analysis ordination diagram for environmental variables and sites coded by region: *AL* altitude; *WT* water temperature; *TN* total nitrogen; *open triangles* upper mountainous region; *open squares* middle hilly region; *closed circles* lower plain region

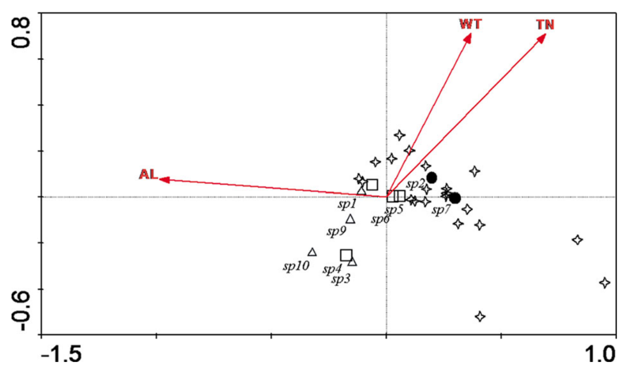


Fig. 6 Canonical correspondence analysis ordination diagram for environmental variables and representative species: *AL* altitude; *WT* water temperature; *TN* total nitrogen; *open triangles* representative species of upper mountainous region; *open squares* representative species of middle hilly region; *closed circles* representative species of lower plain region; *open stars* non-representative species. For species codes, see Table 3

disturbances. Water temperature is not only related to altitude, but also to shading by forest canopy cover that decreases naturally as the stream widens longitudinally (Vannote et al. 1980), although it can also decrease as a result of forest harvest (Johnson and Jones 2000) or as forest cover is displaced by other land use types, such as agriculture (Allan 2004). Janisch et al. (2012) contrasted the effect of clear-cut logging with two riparian buffer designs, a continuous buffer and a patch buffer, which indicated the stream average water temperature increased under all designs in a small forest headwater catchment in western Washington. Increases in water temperature (i.e., thermal pollution) have also been linked to aspects of urbanization that include discharge of industrial wastewater, runoff from impervious surfaces, and the urban heat island effect (Klein 1979; Paul and Meyer 2001; Pickett et al. 2001; Walsh et al. 2005). Similarly, total nitrogen is affected by the type of land use, as fertilizer runoff and sewage from agricultural and urbanized land contribute nutrient loads to the stream system. Sun et al. (2013) also found that human-induced land use factors, such as residential areas and road density, had the most significant effect on nitrogen concentration in the Haihe River, China. Both large-scale agriculture and urbanization are predominant in the lower region of the Taizi River, whereas the upper region is characterized by a greater extent of forest cover.

Although the quantitative effect was not analyzed in this study, the adverse impact of agriculture and

Table 6 Canonical correspondence analysis for the first two axes and environmental variables in the Taizi River tributaries during 2009 and 2010

Variables	Axis 1	Axis 2	Inflation factor
Total nitrogen	0.60	0.48	2.64
Water temperature	0.32	0.47	1.94
Altitude	−0.85	0.05	1.61
Eigenvalues	0.39	0.11	
Species–environment correlations	0.87	0.66	
Cumulative percentage variance of species–environment relation	66.1	84.6	

urbanization on fish assemblages should be of concern. Allan (2004) reported that agriculture occupied the largest fraction of land area and degraded the fish assemblage in many developed catchments. The development of agriculture not only increases water supply volume demands, but also increases nonpoint inputs of nutrients and particle materials, impacts riparian and channel habitat, alters flows (Allan 2004), and reduces the abundance of sensitive fish species (Wang et al. 1997). Fitzpatrick et al. (2001) found that the stream fish biotic integrated index declined when the area under agricultural development in Wisconsin was above 30 %. In some other studies of streams, agriculture showed a strong effect only when it exceeded 50 % at catchment scale (Wang et al. 1997, 2003). Compared to the upper and middle regions, the proportion of the area under agricultural development is much higher in the lower region (Table 1) and reaches 20 % of catchment scale. It is not hard to speculate that there may be another coupling influence acting upon fish assemblage structure here. In addition to agriculture, there are several industrial cities in the lower region, such as Liaoyang and Anshan. These urban areas are a major source of pollution to the Taizi River, with an estimated 861 million tons of domestic sewage, 42.3 million tons of industrial wastewater, and 482,000 tons of aquaculture wastewater discharged into the river in 2004 (Leigh et al. 2012). In the PCA analysis, total nitrogen, ammonia-nitrogen, and chemical oxygen demand were higher in the lower region sites, reflecting organic pollution potentially from wastewater discharges. Diffuse sources of urban runoff are other contributors to nutrient loads. Proximity of urban land to the stream has been found to be a main factor in explaining nitrogen and phosphorus concentrations (Gergel et al. 2002), and an impervious surface with a direct hydrologic connection to the stream better explains fish community degradation (Wang et al. 2001). Furthermore, since many industries (e.g., ferrous mining and smelting, paper production, chemical manufacturing, textiles, beverages, non-metallic mineral processing, etc.) are concentrated around the cities, heavy metals and other contaminants are likely also to be present in the Taizi River water and sediments (Bai et al. 2014; Lv et al. 2014), with potentially toxic effects upon its biota.

Based on the coupling of natural unchanged environment features and human-induced environmental factors, the ANOSIM and NMDS analyses performed on fish assemblages in this study showed that the fish assemblage structure changed gradually from the upper to the lower regions. Fish communities are thought to transition gradually along a longitudinal gradient as species are either replaced or added due to changes in environmental conditions and species requirements, rather than being separated into discrete zones defined by key species or distinct assemblages (Lasne et al. 2007). Schlosser (1990) found that flow regime, channel morphology, and physiochemistry were the primary environmental gradients that determined fish communities from upstream to downstream, with upstream communities more responsive to disturbance due to greater temporal variation in upstream reaches. Fish communities also respond to gradients of human-induced habitat loss and environmental degradation, as demonstrated by Habit et al. (2006) in the lower areas of the Biobío River catchment in Chile.

In this study, the species representing different regions had ecological characteristics specifically related to the type of anthropogenic degradation of environmental conditions. For the upper region, the indicator species *Squalidus wolterstorffi* and *Phoxinus lagowskii* require relatively good water quality, and *Odontobutis yaluensis* and *Cottus poecilopus* prefer low temperature and gravel sediment (Xie 2007). Less anthropogenic disturbance and more vegetation coverage were related with those preferred environmental characteristics in this area. Conversely, for the lower region, *Carassius auratus* is a relatively tolerant species and can be found in any waterbody in China (Xie 2007). During the process of field investigation, low riparian vegetation coverage and poor physical habitat and water quality were found in the lower region where there is higher human population density and more industrial development that did not support environmental conditions conducive to a good fish community with less tolerant species or without an unbalanced species assemblage. These results are supported by similar findings in other studies (McKinney 2001; Marchetti et al. 2006).

Although ecological characteristics essentially reflected the relationship between the fish species and the environment, not all characteristics were suitable for evaluation of river physiochemical conditions. Fish species were classified based on functional attributes that pertained to a variety of environmental guilds, including habitat, flow preference, and trophic status. While trophic guilds have historically provided the basis for many assessments of fish assemblages (starting with Karr 1981), feeding plasticity observed for many fish species (Frimpong and Angermeier 2010) has led to the inclusion of other functional metrics (Welcomme et al. 2006), such as habitat, flow preference, reproductive strategy, pollution tolerance, migration, and life history (Oberdorff et al. 2002; Pont et al. 2006; Lasne et al. 2007). This study found that there was an obvious gradient of water pollution from the upper to the lower regions (Fig. 4), and fish species assemblage also changed according to this gradient. Pollution tolerance, however, although used in some assessment frameworks, is not well defined (Frimpong and Angermeier 2010) and was omitted from this study because fish species were assessed in relation to measured physiochemical conditions.

Ecological classifications varied widely for the ten representative species. For qualitative habitat traits, fishes were generally differentiated by ecoregion. Fishes of the upper region were all classified as benthic species and those of the lower region were water column species, with the middle region a combination of both types. In contrast, flow preferences did not appear to be associated with ecoregion, as both rheophilic and limnophilic species were present across several ecoregions. This was also reflected in the quantitative analysis, as neither water depth nor water velocity was significantly related to species assemblages. The apparent lack of a relationship between flow preference and ecoregion could be an artifact of the spatial scale of analysis, however, as the local flow conditions of riffles and pools are discernible on a reach scale, but not on a regional scale. The trophic guilds of the ten representative species also were not related to the ecoregion; omnivores and carnivores or invertivores were found across regions. Other studies have shown that trophic guilds change longitudinally (Vannote et al. 1980) and with increasing degradation, such that species with specialized diets (e.g., carnivores, invertivores, herbivores) decrease, while those fish with generalized diets (i.e., omnivores) increase (Quist et al. 2005; Pont et al. 2006; Schmutz et al. 2007; Chalar et al. 2013). Goldstein and Meador (2004) found, however, that the high frequency of invertivores remained constant even as stream size increased, thus demonstrating the variability of trophic responses and the potential role of the flood-pulse concept in providing food sources to large floodplain rivers.

Protection of stream fishes should be conducted on the basis of understanding the fish community structure and its relationship to environmental conditions. In this study, we found that the characteristic species of the upper region were important endemic species that had rigorous habitat requirements of low temperature, gravel sediment, and high water quality. This information indicates that it is essential to maintain a high level of water quality and control human disturbances for fish conservation. The characteristics of serious human disturbances and poor water quality in the lower region show that attention should be paid to reducing pollutant loads, and especially nitrogen. More detailed analysis of the specific sources of pollution can help target where management strategies are needed most. Examples include reducing fertilizer application in agricultural areas or upgrading wastewater treatment systems in urban areas. Several fish species, such as *Leuciscus waleckii* and *Cottus poecilopus*, existed in only one region. Other species, such as *Rostrogobio liaohensis*, *Pungitius sinensis*, and *Perccottus glehni* are important endemic species, aquarium species, and economic species, respectively, and were found at only one site, as well. In addition, *Lampetra morii*, an endangered species recorded by Red Data Book of China, has suffered serious population declines because of habitat loss during the last several decades. Our study provides a list of fish species of concern for the Taizi River catchment in the future.

Conclusions

This study demonstrates that the fish species assemblage changes with the increase of human disturbances from the upper to lower regions of the Taizi River. The fish indicator species are also significantly different among the three regions in the catchment. The analysis of ecological characteristics of the indicator species indicated that there was consistency between these characteristics and water quality and habitat conditions. In addition, there were several rare species and endangered species which should be considered for protection in the Taizi River catchment. Our results revealed that there were three environmental factors which significantly affected the fish assemblage. These were altitude, water temperature, and total nitrogen. Water temperature is a human-induced factor but has a strong correlation with altitude, which is a geographic factor. Increased levels of total nitrogen results from human disturbances and is possibly related to human population size and social and industrial development in this catchment. It is obvious that the reduction of total nitrogen should be considered as an important outcome in any plan designed to control water pollution and afford protection to fish assemblages in this river and especially in its lower region.

Acknowledgements This study was supported by grants from the Major Science and Technology Program for Water Pollution Control and Treatment (2012ZX07501-001-04) and the National Natural Science Foundation of China (41401066). In addition, we thank Xianwei Huang and Tao Wen for their help with collecting fish samples. All experiments in this study comply with the current laws of the country in which they were performed.

References

Allan JD, Erickson DL, Fay J (1997) The influence of catchment land use on stream integrity across multiple spatial scales. Freshw Biol 37:149–161

Allan JD (2004) Landscapes and riverscapes: the influence of land use on stream ecosystems. Annu Rev Ecol Evol Syst 35:257–284

Bai Y, Meng W, Xu J, Zhang Y, Guo C (2014) Occurrence, distribution and bioaccumulation of antibiotics in the Liao River Basin in China. Environ Sci: Processes Impacts 16: 586-593

Barbour MT, Gerrisen J, Synder BD, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington D.C.

Chalar G, Delbene L, González-Bergonzoni I, Arocena R (2013) Fish assemblage changes along a trophic gradient induced by agricultural activities (Santa Lucía, Uruguay). Ecol Indic 24:582–588

Clarke KR (1993) Non-parametric multivariate analyses of changes in community structure. Aust J Ecol 18:117–143

Clarke KR, Warwick RM (1994) Change in marine communities: an approach to statistical analysis and interpretation. Natural Environment Research Council, Plymouth Marine Laboratories, Plymouth

Cuffney TF, Meador MR, Porter SD, Gurtz ME (2000) Responses of physical, chemical, and biological indicators of water quality to a gradient of agricultural land use in the Yakima River Basin, Washington. Environ Monit Assess 64:259–270

Diana M, Allan JD, Infante D (2006) The influence of physical habitat and land use on stream fish assemblages in southeastern Michigan. Am Fish Soc Symp 48:359–374

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-I, Knowler DJ, Lévêque C, Naiman RJ, Prieur-Richard A-H, Soto D, Stiassny MLJ, Sullivan CA (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biol Rev 81:163–182

Dufrêne M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol Monogr 67:345–366

Fitzpatrick FA, Scudder BC, Lenz BN, Sullivan DJ (2001) Effects of multi-scale environmental characteristics on agricultural stream biota in eastern Wisconsin. J Am Water Resour Assoc 37:1489–1507

Friberg N, Bonada N, Bradley DC, Dunbar MJ, Edwards FK, Grey J, Hayes RB, Hildrew AG, Lamouroux N, Trimmer M, Woodward G (2011) Biomonitoring of human impacts in freshwater ecosystems: the good, the bad and the ugly. Adv Ecol Res 44:1–68

Frimpong EA, Angermeier PL (2010) Trait-based approaches in the analysis of stream fish communities. Am Fish Soc Symp 73:109–136

Frissell CA, Liss WJ, Warren CE, Hurley MD (1986) A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environ Manage 10:199–214

Gergel SE, Turner MG, Miller JR, Melack JM, Stanley EH (2002) Landscape indicators of human impacts to riverine systems. Aquat Sci 64:118–128

Goldstein RM, Meador MR (2004) Comparisons of fish species traits from small streams to large rivers. Trans Am Fish Soc 133:971–983

Griffith MB, Hill BH, McCormick FH, Kaufmann PR, Herlihy AT, Selle AR (2005) Comparative application of indices of biotic integrity based on periphyton, macroinvertebrates, and fish to southern Rocky Mountain streams. Ecol Indic 5:117–136

Grossman GD, Ratajzak Jr. RE, Crawford M, Freeman MC (1998) Assemblage organization in stream fishes: effects of environmental variation and interspecific interactions. Ecol Monogr 68:395–420

Habit E, Belk MC, Tuckfield RC, Parra O (2006) Response of the fish community to human-induced changes in the Biobío River in Chile. Freshw Biol 51:1–11

Hawkins CP, Norris RH, Gerritsen J, Hughes RM, Jackson SK, Johnson RK, Stevenson RJ (2000) Evaluation of the use of landscape classifications for the prediction of freshwater biota: synthesis and recommendations. J North Am Benthol Soc 19:541–556

Hering D, Johnson RK, Kramm S, Schmutz S, Szoszkiewicz K, Verdonschot PFM (2006) Assessment of European streams with diatoms, macrophytes, macroinvertebrates and fish: a comparative metric-based analysis of organism response to stress. Freshw Biol 51:1757–1785

Holmlund CM, Hammer M (1999) Ecosystem services generated by fish populations. Ecol Econ 29:253–268

Jackson DA, Peres-Neto PR, Olden JD (2001) What controls who is where in freshwater fish communities—the roles of biotic, abiotic, and spatial factors. Can J Fish Aquat Sci 58:157–170

Janisch JE, Wondzell SM, Ehinger WJ (2012) Headwater stream temperature: interpreting response after logging, with and without riparian buffers, Washington, USA. Forest Ecol Manage 270: 302-313

Johnson SL, Jones JA (2000) Stream temperature responses to forest harvest and debris flows in western Cascades, Oregon. Can J Fish Aquat Sci 57:30–39

Karr JR (1981) Assessment of biotic integrity using fish communities. Fisheries 6:21–27

Keister JE, Peterson WT (2003) Zonal and seasonal variations in zooplankton community structure off the central Oregon coast, 1998–2000. Prog Oceanogr 57:341–361

Klein RD (1979) Urbanization and stream quality impairment. J Am Water Resour Assoc 15:948–963

Kong W, Meng W, Zhang Y, Gippel C, Qu X (2013) A freshwater ecoregion delineation approach based on freshwater macroinvertebrate community features and spatial environmental data in Taizi River Basin, northeastern China. Ecol Res 28:581–592

Lammert M, Allan JD (1999) Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates. J Environ Manage 23:257–270

Lasne E, Bergerot B, Lek S, Laffaille P (2007) Fish zonation and indicator species for the evaluation of the ecological status of rivers: example of the Loire basin (France). River Res Appl 23:877–890

Leigh C, Qu X, Zhang Y, Kong W, Meng W, Hanington P, Speed R, Gippel C, Bond N, Catford J, Bunn S, Close P (2012) Assessment of river health in the Liao River basin (Taizi subcatchment). International Water Centre, Brisbane

Lenat DR, Crawford JK (1994) Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294:185–199

Lv J, Xu J, Guo C, Zhang Y, Bai Y, Meng W (2014) Spatial and temporal distribution of polycyclic aromatic hydrocarbons (PAHs) in surface water from Liaohe River Basin, northeast China. Environ Sci Pollut Res 11:7088–7096

Marchetti MP, Lockwood JL, Light T (2006) Effects of urbanization on California's fish diversity: differentiation, homogenization and the influence of spatial scale. Biol Conserv 127:310–318

Marsh-Matthews E, Matthews WJ (2000) Geographic, terrestrial and aquatic factors: which most influence the structure of stream fish assemblages in the midwestern United States? Ecol Freshw Fish 9:9–21

Martin-Smith KM (1998) Relationship between fishes and habitat in rainforest streams in Sabah, Malaysia. J Fish Biol 52:458–482

McCune B, Mefford MJ (1999) PC-ORD. Multivariate Analysis of Ecological Data, Version 4. MjM Software Design, Oregon

McKinney ML (2001) Effects of human population, area, and time on non-native plant and fish diversity in the United States. Biol Conserv 100:243–252

Meador MR, Goldstein RM (2003) Assessing water quality at large geographic scales: relations among land use, water physicochemistry, riparian condition, and fish community structure. J Environ Manage 31:504–517

Ministry of Environmental Protection (MEP) (2002) Chinese Standard Methods for Examination of Water and Wastewater (4th edition). China Environmental Science Press, Beijing

Morgan RP, Cushman SF (2005) Urbanization effects on stream fish assemblages in Maryland, USA. J North Am Benthol Soc 24:643–655

Mueller Jr R, Pyron M (2010) Fish assemblages and substrates in the middle Wabash River, USA. Copeia 1:47–53

Nakano S, Murakami M (2001) Reciprocal subsidies: dynamic interdependence between terrestrial and aquatic food webs. Proc Natl Acad Sci USA 98:166–170

Oberdorff T, Pont D, Hugueny B, Porcher JP (2002) Development and validation of a fish-based index for the assessment of 'river health' in France. Freshw Biol 47:1720–1734

Paul MJ, Meyer JL (2001) Streams in the urban landscape. Annu Rev Ecol Syst 32:333–365

Perna CN, Cappo M, Pusey BJ, Burrows DW, Pearson RG (2012) Removal of aquatic weeds greatly enhances fish community richness and diversity: an example from the Burdekin River floodplain, tropical Australia. River Res Appl 28:1093–1104

Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat RV, Zipperer WC, Costanza R (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu Rev Ecol Syst 32:127–157

Pinto BCT, Araujo FG, Rodrigues VD, Hughes R (2009) Local and ecoregion effects on fish assemblage structure in tributaries of the Rio Paraíba do Sul, Brazil. Freshw Biol 54:2600–2615

Poff NL (1997) Landscape filters and species traits: towards mechanistic understanding and prediction in stream ecology. J North Am Benthol Soc 16:391–406

Pont D, Hugueny B, Beier U, Goffaux D, Melcher A, Noble R, Rogers C, Roset N, Schmutz S (2006) Assessing river biotic condition at a continental scale: a European approach using functional metrics and fish assemblages. J Appl Ecol 43:70–80

Quist MC, Rahel FJ, Hubert WA (2005) Hierarchical faunal filters: an approach to assessing effects of habitat and nonnative species on native fishes. Ecol Freshw Fish 14:24–39

Resh VH (2008) Which group is best? Attributes of different biological assemblages used in freshwater biomonitoring programs. Environ Monit Assess 38:131–138

Roth NE, Allan JD, Erickson DL (1996) Landscape influences on stream biotic integrity assessed at multiple spatial scales. Landsc Ecol 11:141–156

Schlosser IJ (1990) Environmental variation, life history attributes, and community structure in stream fishes: implications for environmental management and assessment. J Environ Manage 14:621–628

Schmutz S, Melcher A, Frangez C, Haidvogl G, Beier U, Böhmer J, Breine J, Simoens I, Caiola N, De Sostoa A, Ferreira MT, Oliveira J, Grenouillet G, Goffaux D, De Leeuw JJ, Noble RAA, Roset N, Virbikas T (2007) Spatially based methods to assess the ecological status of riverine fish assemblages in European ecoregions. Fish Manag Ecol 14:441–452

Slaymaker O, Spencer T, Embleton-Hamann C (2009) Geomorphology and Global Environmental Change. Cambridge University Press, London

Smith CL, Powell CR (1971) The summer fish communities of Brier Creek, Marshall County, Oklahoma. Am Mus Novit 2458:1–30

Snelder TH, Biggs BJF (2002) Multiscale river environment classification for water resources management. J Am Water Resour Assoc 38:1225–1239

Stein JL, Stein JA, Nix HA (2002) Spatial analysis of anthropogenic river disturbance at regional and continental scales: identifying the wild rivers of Australia. Landsc Urban Plan 60:1–25

Strayer DL, Beighley RE, Thompson LC, Brooks S, Nilsson C, Pinay G, Naiman RJ (2003) Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. Ecosystems 6:407–423

Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. J North Am Benthol Soc 29:344–358

Sun R, Chen L, Chen W, Ji Y (2013) Effect of land-use patterns on total nitrogen concentration in the upstream regions of the Haihe River basin, China. J Environ Manage 51: 45-58

ter Braak CJF, Šmilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide, software for canonical community ordination (Version 4.5). Microcomputer Power, New York

Valério SB, Súarez YR, Felipe TRA, Tondato KK, Ximenes LQL (2007) Organization patterns of headwater-stream fish communities in the Upper Paraguay–Paraná basins. Hydrobiologia 583:241–250

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE (1980) The river continuum concept. Can J Fish Aquat Sci 37:130–137

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Reidy Liermann C, Davis PM (2010) Global threats to human water security and river biodiversity. Nature 467:555–561

Walser CA, Bart HL (1999) Influence of agriculture on in-stream habitat and fish community structure in Piedmont watersheds of the Chattahoochee River System. Ecol Freshw Fish 8:237–246

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP (2005) The urban stream syndrome: current knowledge and the search for a cure. J North Am Benthol Soc 24:706–723

Walters DM, Roy AH, Leigh DS (2009) Environmental indicators of macroinvertebrate and fish assemblage integrity in urbanizing watersheds. Ecol Indic 9:1222–1233

Wang L, Lyons J, Kanehl P, Bannerman R (2001) Impacts of urbanization on stream habitat and fish across multiple spatial scales. J Environ Manage 28:255–266

Wang L, Lyons J, Kanehl P, Gatti R (1997) Influence of watershed land use on habitat quality and biotic integrity in Wisconsin streams. Fisheries 22:6–12

Wang L, Lyons J, Rasmussen P, Seelbach P, Simon T, Wiley M, Kanehl P, Baker E, Niemela S, Stewart PM (2003) Watershed, reach, and riparian influences on stream fish assemblages in the Northern Lakes and Forest Ecoregion, U.S.A. Can J Fish Aquat Sci 60:491–505

Wang L, Seelbach PW, Lyons J (2006) Effects of levels of human disturbance on the influence of catchment, riparian, and reach-scale factors on fish assemblages. Am Fish Soc Symp 48:199–219

Welcomme RL, Winemiller KO, Cowx IG (2006) Fish environmental guilds as a tool for assessment of ecological condition of rivers. River Res Appl 22:377–396

Xie YH (2007) Freshwater fishes in northeast region of China. Liaoning Science and Technology Press, Shenyang