Diversity and Spatiotemporal Dynamics of Macrobenthic Feeding Functional Groups in Jinan Rivers: Postprint

Authors: Wang Bo-Han, Wu Dan, Zhang Ji, Yin Xu-Wang, Zhao Chang-Sen, Dou Tong-Wen

Date: 2017-11-10T00:00:00+00:00

Abstract

Field investigations of macrobenthic animals and water environmental physicochemical factors were conducted at 24 sampling sites in the Jinan area during spring (May), summer (August), and autumn (November) 2014. Community composition and spatial structure characteristics of macrobenthic animals were analyzed using diversity indices and canonical correspondence analysis. The results showed that a total of 57 macrobenthic animal species belonging to 3 phyla were collected, namely Arthropoda, Mollusca, and Annelida. In spring, summer, and autumn, 45, 35, and 33 macrobenthic animal species were collected, respectively. The dominant species in spring were Limnodrilus hoffmeisteri and Bithynia fuchsiana; in summer were Chironomus riparius and Bithynia fuchsiana; and in autumn were Chironomus salinarius and Bithynia fuchsiana. The average densities in spring, summer, and autumn were 2.49×10^3, 0.56×10^3, and 1.03×10^3 individuals/m^2, respectively; the average biomasses were 495.59, 137.26, and 109.45 g/m^2; the average Shannon-Wiener indices were 1.37, 1.33, and 1.17; and the average evenness indices were 0.55, 0.67, and 0.59. Five functional feeding groups of macrobenthic animals were identified across the entire region. Collectors had the highest number of species in spring (20), scrapers had the highest number in summer (12), and both collectors and scrapers had the highest number in autumn (11). In all three seasons, collectors dominated in density, followed by scrapers. Canonical correspondence analysis revealed that the primary environmental factors influencing the functional feeding groups of macrobenthic animals in the Yellow River Basin and Huai River Basin were total phosphorus and total nitrogen in spring, pH and dissolved oxygen in summer, and dissolved oxygen and pH in autumn.

Full Text

Diversity and Temporal-Spatial Dynamics of Macroinvertebrate Functional Feeding Groups in the Rivers of the Jinan Region

Wang Bohan[1], Wu Ji[1], Zhang Jing[1], Yin Xuwang[1]*, Zhao Changsen[2], Dou Tongwen[3]

[1]College of Fisheries and Life Science, Dalian Ocean University, Dalian 116023, China

[2]College of Geography and Remote Sensing Science, Beijing Normal University, Beijing 100875, China

[3]Jinan Hydrological Bureau, Jinan 250014, China

Abstract

The objective of this study was to investigate the relationship between macroinvertebrate community structure and associated environmental factors in the Jinan Region from spring 2014 (May) to autumn 2014 (November), using independent sample t-tests, scatter plot analysis, macroinvertebrate functional feeding group classification, and Canonical Correspondence Analysis (CCA). We identified 57 macroinvertebrate species, consisting of Arthropoda, Mollusca, and Annelida. A total of 45, 35, and 33 macroinvertebrate species were identified in spring, summer, and autumn, respectively. *Bithynia fuchsiana* was the dominant class, followed by *Limnodrilus hoffmeisteri* and then *Chironomus riparius*. The average values of macroinvertebrate densities, biomass, Shannon-Wiener index, and Pielou index ranged from 0.56×10^3 ind/m^2 to 2.49×10^3 ind/m^2, from 109.45 g/m^2 to 495.59 g/m^2, from 0.55 to 0.67, and from 1.17 to 3.75 from spring to autumn, respectively. Overall, we categorized these taxa into five functional feeding groups. Gatherer-collector density was dominant. Canonical correspondence analysis results showed that macroinvertebrate community structure was largely determined by the interactions between total phosphorus and total nitrogen in spring in the Huang River Basin and Huai River Basin. Dissolved oxygen and pH were the main environmental factors limiting macroinvertebrate community structure in summer in both basins. In autumn, the primary environmental factors limiting macroinvertebrate community structure were dissolved oxygen and pH in both the Huang River Basin and Huai River Basin.

Keywords: Jinan Region; macroinvertebrate; functional feeding group; environmental factors

Introduction

Macroinvertebrates play important ecological roles in river ecosystems. They typically feed on organic particles, detritus, and algae, and serve as food sources for fish. They are crucial for material cycling, energy flow, and information transfer in river ecosystems. Macroinvertebrates occupy a key position in benthic detritus food chains and accelerate water self-purification processes by ingesting organic matter from sediments as a nutrient source. As indicator taxa for river ecosystem health, macroinvertebrates offer many advantages for bioassessment, such as stable habitats, long life cycles, and wide distribution. Their community structure and diversity largely reflect the overall health of river ecosystems and provide guidance for river conservation, management, and utilization.

In river ecosystem research, macroinvertebrates can be classified into shredders, scrapers, gatherer-collectors, filter-collectors, and predators based on feeding habits—these are known as functional feeding groups (FFGs). This classification method differs from traditional morphological taxonomy and can more precisely reflect relationships between macroinvertebrate communities and different aquatic environments. Macroinvertebrate FFGs can reflect community structural characteristics and habitat adaptation features, as well as the intensity of human disturbance and the condition of river ecosystem impairment.

International research on macroinvertebrate FFGs mainly focuses on two aspects: (1) macroinvertebrate FFG responses to human activities, and (2) establishment of FFG assessment systems and their applications. However, there are few reports on freshwater macroinvertebrate FFGs in China. This study investigated macroinvertebrates and water environmental factors at sampling sites in the Jinan region, which is traversed by both the Huang River Basin and Huai River Basin, from spring to autumn 2014. We analyzed the temporal-spatial distribution of macroinvertebrate FFGs and the correlation between macroinvertebrate communities and water environmental factors to identify the main environmental factors affecting community structure and provide baseline data for ecological protection and management in the Jinan region.

1. Study Area and Sampling Site Setup

Jinan is located in central-western Shandong Province, with a complex aquatic ecosystem type. Human activities have led to reduced vegetation coverage, continuous depletion of groundwater resources, increased pollution, and reduced biodiversity, which seriously hinders sustainable development. To better distinguish spatial differences in macroinvertebrate community structure in the Jinan region, we established 22 monitoring sites in representative areas of Jinan city and its counties based on geographic characteristics, water quality conditions, and pollution distribution patterns. The Huang River Basin and Huai River Basin traverse the region, with 10 sampling sites in the Huang River Basin and 12 in the Huai River Basin. Some sites in the Huang River Basin have sediment accumulation, long and numerous tributaries, slow water flow, and sand-gravel substrates. The Huai River Basin is mostly mountainous with elevations generally around 100 m, with fewer riparian vegetation and sediment substrates.

2. Macroinvertebrate Sample Collection

At each selected site, we collected macroinvertebrates using a Surber net (30 cm × 30 cm opening, 500 m mesh size) from three parallel samples. Samples were fixed with 100 mL of 75% alcohol in the field and brought back to the laboratory. In the lab, macroinvertebrates visible to the naked eye were separated from stones and other debris, then identified and counted under a stereomicroscope (Olympus-SZX7) and biological microscope (Olympus-CX21). Identification followed relevant literature to the lowest possible taxonomic unit.

3. Measurement of Water Physico-Chemical Properties

Water physico-chemical indices were measured through a combination of field and laboratory methods. In the field, a handheld multi-parameter water quality analyzer (YSI ProPlus) was used to measure water temperature (Temp), pH, and dissolved oxygen (DO). Water samples were collected at each site and brought back to the laboratory for measurement of conductivity (Cond), alkalinity (ALK), total dissolved solids (TD), permanganate index (CODMn), total nitrogen (TN), and total phosphorus (TP) according to standard methods within 48 hours.

4. Classification of Macroinvertebrate Functional Feeding Groups and Ecosystem Attributes

Based on the feeding types of macroinvertebrates and the classification method of Cummins et al., macroinvertebrates in the Jinan region were divided into five functional feeding groups. This study analyzed ecosystem attributes from perspectives of material cycling, longitudinal transport capacity, riparian input, and coarse/fine particulate organic matter input based on the research of Yoshimura et al.

[**Figure 1: see original paper**] Sampling sites distribution in Jinan Region

**** Macroinvertebrate functional feeding group composition in Jinan Region

Functional Feeding Group	Feeding Habit	Representative Taxa
Scrapers	Feed primarily on sessile organisms such as periphyton	*Chironomus* spp.
Shredders	Feed primarily on detritus and coarse particulate organic matter	*Limnodrilus hoffmeisteri*

Functional Feeding Group	Feeding Habit	Representative Taxa
Gatherer-collectors	Feed on various organic particles from river bottom	*Bithynia fuchsiana*
Filter-collectors	Feed on fine particulate organic matter in water flow (0.45 mm < FPOM < 1 mm)	*Hydropsyche* sp.
Predators	Feed on other aquatic animals	*Gomphus* sp.

**** Functional feeding groups of macroinvertebrates related to ecosystem attributes

Metrics Based on Functional Feeding Groups	Ecosystem Attributes
Density of scrapers, G2	Primary producers
Ratio of scrapers to filterers and gatherer-collectors, G2/(G3+G4)	Secondary producers
Density of shredders and gatherer-collectors, G1+G4	Longitudinal transport capacity
Density of filterers, G3	Relative longitudinal transport capacity
Ratio of filterers to shredders and gatherer-collectors, G3/(G1+G4)	Lateral input
Density of shredders, G1	Relative lateral input
Ratio of shredders to total abundance, G1/total density	Coarse particulate organic matter input
Ratio of shredders to filterers and gatherer-collectors, G1/(G3+G4)	Fine particulate organic matter input

Note: G1: shredders; G2: scrapers; G3: filterers; G4: gatherer-collectors; G5: predators; CPOM: coarse particulate organic matter; FPOM: fine particulate organic matter

5. Data Processing and Analysis

Diversity indices including Shannon-Wiener index (H) and Pielou' s evenness index (J) were calculated using Biodiversity Pro software. Dominant species were determined based on dominance values ($Y > 0.02$), where $Y = (ni/N) \times fi$, with ni being the density of species i, N the total macroinvertebrate density, and fi the frequency of occurrence of species i.

Box plots and line charts were used to analyze the distribution characteristics of macroinvertebrate communities and functional feeding groups across seasons. Bar charts were used to compare ecosystem attributes among seasons. Independent sample t-tests were used to analyze correlations among environmental factors across seasons and their relationships with macroinvertebrates.

Canonical Correspondence Analysis (CCA) was performed on selected water environmental parameters and macroinvertebrate community data using Canoco 4.5 software. Macroinvertebrate density data were log-transformed [log(x+1)] before analysis. Detrended Correspondence Analysis (DCA) was first performed to determine species response values. Since the standard deviation (SD) of species turnover was > 2, CCA was selected. Monte Carlo permutation tests (499 permutations) were used to determine environmental factors significantly affecting macroinvertebrate community spatial distribution patterns. All analyses were conducted using SPSS 16.0, OriginPro 7.5, and Canoco 4.5.

1. Macroinvertebrate Species Composition and Community Structure

A total of 57 macroinvertebrate species were identified across spring, summer, and autumn in the Jinan region. Arthropoda had the most species in all seasons, followed by Mollusca and Annelida. The dominant species were *Limnodrilus hoffmeisteri* in spring, *Bithynia fuchsiana* in summer, and *Chironomus salinarius* in autumn. Common species included *Radix auricularia*, *Chironomus salinarius*, and *Bithynia fuchsiana*.

**** Dominant species of macroinvertebrate in each season

Season	Dominant Species	Dominance (Y)
Spring	*Limnodrilus hoffmeisteri*	0.07
Summer	*Bithynia fuchsiana*	0.05
Autumn	*Chironomus salinarius*	0.07

The average macroinvertebrate density was 2.49×10^3 ind/m^2 in spring, 0.56 $\times 10^3$ ind/m^2 in summer, and 1.03×10^3 ind/m^2 in autumn. Average biomass was 495.59 g/m^2, 137.26 g/m^2, and 109.45 g/m^2, respectively. Shannon-Wiener index averaged 1.37, 1.33, and 1.17, while evenness index averaged 0.55, 0.67, and 0.59 across the three seasons.

Overall, macroinvertebrates showed significant spatial heterogeneity across seasons. Density and biomass differed significantly between spring and summer ($P = 0.03$, $P = 0.02$), but Shannon-Wiener and evenness indices showed no significant differences among seasons ($P > 0.05$). Between basins, density and biomass showed no significant differences in any season, but Shannon-Wiener and evenness indices differed significantly between basins in summer ($P = 0.04$, $P = 0.04$).

[**Figure 2: see original paper**] Comparison of community structure of macroinvertebrates in spring, summer, and autumn (D-Density; B-Biomass; H -Shannon-Wiener index; J-Pielou index)

2. Classification of Macroinvertebrate Functional Feeding Groups and Ecosystem Assessment

Five functional feeding groups were identified in the Jinan region. All seasons had five FFG types. [**Figure 3: see original paper**] shows the composition and density of FFGs in both basins across seasons. In terms of species richness, scrapers were most abundant in summer in both basins, while gatherer-collectors were most abundant in spring. In autumn, both scrapers and gatherer-collectors were abundant in the Huang River Basin, while scrapers dominated in the Huai River Basin.

In terms of density, gatherer-collectors were absolutely dominant across all seasons. Filterer density was highest in the Huai River Basin in spring. Gatherer-collector density was highest in both basins across seasons. No significant correlations were found between FFG types/densities and seasons or basins ($P > 0.05$).

Analysis of FFG-based parameters showed spatial differences between basins: F4 and F7 values were significantly higher in the Huai River Basin, while F1, F2, and F5 were higher in the Huang River Basin. Temporal analysis revealed: F1 and F5 were significantly higher in spring than in summer and autumn; F7 and F8 were higher in autumn than in spring and summer; F2 and F6 were higher in summer and autumn than in spring.

Regarding material cycling, primary productivity (F2) was significantly higher in the Huai River Basin than in the Huang River Basin, with no significant seasonal differences. Longitudinal transport capacity (F3) was higher in the Huai River Basin, significantly greater in autumn than other seasons. Lateral input (F7) was higher in the Huai River Basin, significantly greater in spring than other seasons. Fine particulate organic matter input showed no significant differences between basins but was higher in summer and autumn than in spring.

[**Figure 4: see original paper**] Seasonal variation of ecosystem attribute values in the Huang River Basin and Huai River Basin

3. Relationships Between Macroinvertebrate Functional Feeding Groups and Environmental Factors

Water temperature was lowest in spring and highest in summer, with water remaining weakly alkaline year-round (pH 7.74–8.21). **** compares environmental factors across seasons and basins. The Huai River Basin had higher conductivity, alkalinity, total dissolved solids, CODMn, total nitrogen, and total phosphorus than the Huang River Basin, while the Huang River Basin had higher dissolved oxygen content. No significant correlations were found for any of the eight environmental indicators between basins across seasons ($P > 0.05$).

**** Comparison of spring, summer, and autumn environmental factors in Jinan Region (Mean ± SD)

Environmental Factor	Huang River Basin	Huai River Basin
Spring		
Temp (°C)	19.38 ± 2.06	22.30 ± 3.71
pH	8.21 ± 0.30	7.81 ± 0.32
Cond (ms/m)	654.25 ± 497.27	1222.67 ± 925.47
DO (mg/L)	8.45 ± 1.96	7.90 ± 2.69
TN (mg/L)	3.85 ± 2.57	6.61 ± 6.25
TP (mg/L)	0.37 ± 1.03	0.39 ± 0.42
Summer		
Temp (°C)	27.90 ± 1.70	26.45 ± 3.31
pH	8.20 ± 0.30	7.74 ± 0.35
Cond (ms/m)	550.07 ± 395.45	1151.08 ± 744.14
DO (mg/L)	8.21 ± 1.11	6.79 ± 2.50
TN (mg/L)	3.63 ± 2.44	6.34 ± 4.64
TP (mg/L)	0.14 ± 0.19	0.31 ± 0.40
Autumn		
Temp (°C)	14.37 ± 1.37	14.31 ± 1.60
pH	8.17 ± 0.30	7.96 ± 0.39
Cond (ms/m)	563.52 ± 436.54	1194.39 ± 746.45
DO (mg/L)	8.17 ± 1.28	7.54 ± 1.85
TN (mg/L)	3.68 ± 2.57	6.54 ± 4.90
TP (mg/L)	0.17 ± 0.20	0.49 ± 1.01

CCA was performed on macroinvertebrate FFG densities and environmental factors for each season. [**Figure 5: see original paper**] shows the species-environment relationships. In spring, total phosphorus and total nitrogen were the main factors affecting FFGs in both basins. In summer, dissolved oxygen and pH were the primary limiting factors in both basins. In autumn, dissolved oxygen and pH remained the main limiting factors in both the Huang and Huai River Basins.

1. Characteristics of Macroinvertebrate Functional Feeding Groups and Community Structure

This survey identified 57 macroinvertebrate species in the Jinan region, predominantly Diptera (Chironomidae) larvae. Arthropods dominated across all seasons, with the highest species richness in spring (45 species). Most species inhabit polluted water, muddy sediments, or organically enriched water bodies, indicating that some water bodies in Jinan are polluted to some degree.

The dominant species showed seasonal variation: *Limnodrilus hoffmeisteri* and *Bithynia fuchsiana* in spring, *Chironomus riparius* in summer, and *Chironomus salinarius* and *Bithynia fuchsiana* in autumn. The community structure was dominated by Chironomidae larvae and adherent snails across seasons. The highest densities in summer and autumn occurred at sites J16 (17.33×10^3 ind/m^2) and J22 (6.54×10^3 ind/m^2), primarily due to Diptera larvae. Site J16 is located in the Huai River Basin with slow flow, while J22 has substrate dominated by bedrock and sand, providing habitat for attached macroinvertebrates.

The Shannon-Wiener index is an effective tool for monitoring community structure changes and assessing organic pollution. Values of 2.0–3.0 indicate light pollution, 1.0–2.0 moderate pollution, and <1.0 heavy pollution. The average Shannon-Wiener index in Jinan (1.17–1.37) indicates moderate pollution, likely due to dense population, domestic sewage discharge, and industrial pollution.

Five FFGs were identified, with gatherer-collectors showing significantly higher density than other groups. Gatherer-collectors feed on organic detritus, which deposits more easily in low-flow areas, explaining their preference for slow-flow habitats. Their density was higher in the Huang River Basin due to muddy substrate, wider water surface, and abundant organic nutrients. Shredders feed on riparian vegetation and leaf litter, with higher densities in spring and autumn, particularly in the Huang River Basin where riparian farmland vegetation provides abundant food. Scrapers feed on periphyton and were more abundant in the Huai River Basin due to more cobble substrate, which provides larger surface area for algal attachment. Filterers feed on fine particulate organic matter and were more abundant in the Huai River Basin, especially in summer when food availability and hydraulic conditions were optimal. Predators showed no significant difference between basins but were more abundant in spring when other groups provided ample food resources.

2. Relationships Between Macroinvertebrate Functional Feeding Groups and Environmental Factors

Assessing the suitable range of environmental factors for aquatic organisms is important for river ecological restoration. Studies show that environmental factors affecting macroinvertebrate distribution differ significantly among seasons. In the Jinan region, total phosphorus and nitrogen are important indicators of nutrient pollution. The Huang River Basin has high sediment content and turbidity, with elevated total phosphorus affecting filterers (positively) and scrapers (negatively). In the Huai River Basin, total nitrogen negatively affected scrapers and predators, altering their living environment.

Dissolved oxygen directly affects macroinvertebrate survival and reproduction; reduced levels can cause mortality. In the Huai River Basin, low dissolved oxygen limited shredders while tolerant scrapers proliferated. In the Huang River Basin, dissolved oxygen negatively affected filterers. pH also influenced shredder abundance, with positive correlations observed.

These results demonstrate that environmental factors affecting FFG communities vary across temporal and spatial scales, and can be categorized into: (1) eutrophication factors (nitrogen, phosphorus, ions), (2) organic matter and nutrients, and (3) hydrological factors (flow velocity, conductivity).

References

[1] Rosi-Marshall E J, Wallace J B. Invertebrate food webs along a stream resource gradient. *Freshwater Biology*, 2002, 47(1): 129-141.

[2] Heino J, Muotka H, Mykrä R, Paavola R, Hämäläinen H, Koskenniemi E. Defining macroinvertebrate assemblage types of headwater streams: implications for bioassessment and conservation. *Ecological Applications*, 2003, 13(3): 842-852.

[3] Cummins K W. Structure and function of stream ecosystems. *BioScience*, 1974, 24(11): 631-641.

[4] Benthic Animals and River Ecological Assessment. Tsinghua University Press, 2010: 47-91.

[5] Koskenniemi E. The role of chironomids (Diptera) in the profundal macrozoobenthos in Finnish reservoirs. *Netherlands Journal of Aquatic Ecology*, 1992, 26(2/4): 503-508.

[6] Barbour M T, Gerritsen J, Snyder B D, Stribling J B. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish*. 2nd ed. Washington, DC: US EPA, Office of Water, 1999.

[7] Wright J F. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology*, 1995, 20(1): 181-197.

[8] Hughes D L, Gore J A, Brossett M P, Olson J R. *Rapid Bioassessment of Stream Health*. New York: CRC Press, 2010.

[9] Zhang Y, Zhao R, Kong W J, Geng S W, Bentsen C N, Qu X D. Relationships between macroinvertebrate communities and land use types within different riparian widths in three headwater streams of Taizi River, China. *Journal of Freshwater Ecology*, 2013, 28(3): 307-328.

[10] Barbour M T, Gerritsen J, Snyder B D, Stribling J B. *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*. 2nd ed. Washington, DC: U.S. Environmental Protection Agency, Office of Water, 1999.

[11] Bode R W, Novak M A, Abele L E, Heitzman D L, Smith A J. *Quality Assurance Work Plan for Biological Stream Monitoring in New York State*. Albany, NY: NYS Department of Environmental Conservation, 2002.

[12] Ecology of Macroinvertebrate Functional Feeding Groups in the Xiangxi River System. *Acta Ecologica Sinica*, 2009, 29(10): 5207-5218.

[13] Thorp J H, Covich A P. *Ecology and Classification of North American Freshwater Invertebrates*. 2nd ed. New York: Academic Press, 2001.

[14] Fauna Sinica: Mollusca. Science Press, 2002.

[15] Macroinvertebrate Community Characteristics and Habitat Relationships in the Liao River Basin. 2012.

[16] Merritt R W, Cummins K W, Berg M B. *An Introduction to the Aquatic Insects of North America*. 4th ed. Dubuque: Kendall Hunt Publishing, 2008.

[17] Wang B H, Li Y L, Li X Y, Liu Y. Community structure of macroinvertebrates and its relationship with environmental factors in the Wei River Basin. *Chinese Journal of Applied Ecology*, 2013, 24(1): 218-226.

[18] Wang B H, Li Y L, Li X Y, Liu Y. Community structure and biological integrity of periphytic algae in the Wei River Basin. *Acta Scientiae Circumstantiae*, 2013, 33(2): 518-527.

[19] State Environmental Protection Administration. *Water and Wastewater Monitoring and Analysis Methods*. China Environmental Science Press, 2002.

[20] Yoshimura C, Tockner K, Omura T, Moog O. Species diversity and functional assessment of macroinvertebrate communities in Austrian rivers. *Limnology*, 2006, 7(2): 63-74.

[21] Wang B H, Li Y L, Li X Y, Liu Y. Water ecosystem health assessment of the Taizi River Basin based on periphytic algae. *Acta Scientiae Circumstantiae*, 2012, 32(6): 1677-1691.

[22] Zhang Y, Zhao R, Kong W J, et al. Community characteristics and comprehensive health assessment of macroinvertebrates during low-water periods. *Acta Ecologica Sinica*, 2015, 35(14): 4784-4796.

[23] Hong Lake Benthic Animal Community Structure and Preliminary Water Quality Assessment. *Acta Hydrobiologica Sinica*, 1995, 19(2): 124-134.

[24] Van Dolah R F, Hyland J L, Holland A F, Rosen J S, Snoots T R. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern USA. *Marine Environmental Research*, 1999, 48(4/5): 269-283.

[25] Taihu Basin Main River Macroinvertebrate Community Structure and Biological Water Quality Assessment. *Journal of Lake Sciences*, 2011, 23(5): 686-694.

[26] Mérigoux S, Oledéc S. Hydraulic requirements of stream communities: a case study on invertebrates. *Freshwater Biology*, 2004, 49(5): 600-613.

[27] Moles M C Jr. Trichopteran communities of streams associated with aspen and conifer forests: long-term structural change. *Ecology*, 1982, 63(1): 1-6.

[28] Cummins K W, Wilzbach M A, Gates D M, Perry J B, Taliaferro W B. Shredders and riparian vegetation. *BioScience*, 1989, 39(1): 24-30.

[29] Dobson M. Microhabitat as a determinant of diversity: stream invertebrates colonizing leaf packs. *Freshwater Biology*, 1994, 32(3): 565-572.

[30] Haapala A, Muotka T, Laasonen P. Distribution of benthic macroinvertebrates and leaf litter in relation to streambed retentivity: implications for headwater stream restoration. *Boreal Environment Research*, 2003, 8(1): 19-30.

[31] Southwest Mountain Headwater Stream Epilithic Aquatic Insect Community Characteristics and Diversity: A Case Study of Chongqing Yudu River. *Acta Hydrobiologica Sinica*, 2011, 35(5): 887-892.

[32] River Biological Habitat Assessment Research Progress. *Chinese Journal of Ecology*, 2008, 26(17): 82-88.

[33] Seasonal Dynamics of Macroinvertebrate Community Structure in the Xiangxi River. *Chinese Journal of Applied Ecology*, 2009, 20(4): 923-928.

[34] Distribution of Macroinvertebrates and Their Relationship with Environment in the Oujiang Estuary. *Chinese Journal of Applied Ecology*, 2009, 20(8): 1958-1964.

[35] Determining Nutrient Concentration Thresholds in Rivers Based on Macroinvertebrates: A Case Study of the Upper Xitiaoxi River Basin. *Chinese Journal of Applied Ecology*, 2010, 21(2): 483-488.

[36] Effects of Environmental Factors on Benthic Animal Life Activities. *Journal of Zhejiang Ocean University (Natural Science)*, 2005, 24(3): 253-257, 280.

[APPENDIX A] List of macroinvertebrate species in Jinan Region

Note: Figure translations are in progress. See original paper for figures.