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Zooplankton in highly regulated rivers: Changing with water environment

Changsen Zhao[a,b,d,*], Changming Liu[c,d], Jihua Zhao[e], Jun Xia[d], Qiang Yu[f], Derek Eamus[f]

[a] State Key Laboratory of Remote Sensing Science, Jointly Sponsored by Beijing Normal University and the Institute of Remote Sensing Applications of Chinese Academy of Sciences, Beijing 100875, PR China
[b] School of Geography, Beijing Normal University, Beijing 100875, PR China
[c] College of Water Sciences, Beijing Normal University, Beijing 100875, PR China
[d] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Datun Road 11A, Chaoyang District, Beijing 100101, PR China
[e] North China University of Water Resources and Electric Power, Zhengzhou 450045, PR China
[f] Plant Functional Biology and Climate Change Cluster, University of Technology, Sydney NSW 2007, Australia

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ABSTRACT

The Huai River Basin (HRB) of China is well-known globally for the extent of severe human activities (e.g., waste disposal and water project construction) which have resulted in severe water pollution and subsequently degraded water ecosystem quality in recent decades. However, influence of water pollution on water ecosystems has not yet been fully realized due to lack of water ecosystem data. In food webs of freshwater ecosystems, zooplankton occupy a critical position but they are highly susceptible to pollutants and temperature which in turn impact the community structure and biodiversity of zooplankton to a great extent. This paper aimed to assess impact of water chemistry variation on zooplankton through ecological-niche models and spatial heterogeneity of zooplankton along with water chemistry in the HRB. We investigated the impacts of nine dominant water chemistry indicators on zooplankton distribution and composition via ecological niche models based on water chemistry status and zooplankton communities at 71 typical sites of the HRB. A fuzzy clustering method (FCM) was employed to help study the impact characteristics and the spatial heterogeneity. Results indicate that across the nine water chemistry indicators, changes in water temperature has minimal impact on the zooplankton community of the Huai River while small variation in ammonia–nitrogen exerts significant stress on the community; with respect to water temperature and total phosphorous zooplankton species in the HRB are coexisting with little competition; as to spatial heterogeneity of zooplankton communities, communities in the southwest and southeast mountainous regions may adapt well to habitat variations, while those in the middle and northeast areas have a weak adaptability to habitat changes. We concluded that in highly polluted rivers with large spatial heterogeneity of water chemistry, like the Huai River, ammonia–nitrogen exerted great stress on the zooplankton community in nonlinear way with too high or low concentration of ammonia–nitrogen leading to reduction in abundance of zooplankton; zooplankton communities in the HRB is mainly impacted by pollutant instead of water-temperature. All these can provide scientific support for future restoration and wise water resources planning and management in the Huai River.

1. Introduction

Globally, freshwater ecosystems are vulnerable to long-term climate change and the impacts of human activities and such systems are increasingly threatened by human-induced habitat loss (Kagalou et al., 2010). Over the past several decades intense economic development and population increase have resulted in more pollutants being discharged into rivers in China. This has resulted in severe degradation of water quality and a loss of ecosystem service provision, which in turn severely hinders the sustainability of the economy and society. This is especially true for the Huai River, China.

The Huai River is the sixth largest river in China and divides the north from the south of China. The Huai River Basin (HRB) is one of the main grain-producing areas of China. In the last half-century, it has experienced massive construction of dams and weirs such that the number of hydraulic structures on this river accounts approximately for half of all of China and quarter of the world (Liu et al.,

* Corresponding author. Tel.: +86 10 64889083.
E-mail address: hzjohnson@gmail.com (C. Zhao).

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2011). Long-term poor management of these hydraulic structures and excessive pollution discharge have had major negative impacts on the freshwater ecosystems of the HRB. Water quality in more than 83% of tributaries of this river was poorer than the lowest national standard for river water quality (Zhang et al., 2010b). To restore ecosystem health to the HRB, it is necessary to understand the structure, composition and responses of aquatic ecosystems to their surroundings throughout the HRB. In aquatic ecosystems the composition and structure of zooplankton are one of the most important indictors of water quality. Zooplankton consumes phytoplankton which in turn are consumed by fish. Zooplanktons are the primary consumers in aquatic ecosystems and thus they play critical roles in biogeochemical cycling and energy flows (Liu et al., 2010). Zooplankton also influences the phytoplankton community through preferential grazing (Leonard and Paerl, 2005) and are a vital link in the food webs of large rivers. Their community structure can be affected by watershed ecological factors, including water chemistry, lake morphology and human activity in the watershed (Dodson et al., 2009; Dickerson et al., 2010; Van Egeren et al., 2011).

Ecological niche theory can well link the zooplankton to its surroundings, which is one of the most important concepts in ecology (Hutchinson, 1957; Pearce and Lindenmayer, 1998; Ferrier, 2002; Wiley et al., 2003). It takes niche as a function of measurable factors, which has become the basis of many theoretical and filed studies (Smith, 1982). Niche breadth and niche overlap are two principal models to study ecological niche (Thompson and Gaston, 1999; Jehle et al., 2000; Brandle et al., 2002) and have been widely applied in many aspects such as habitat selection, species conservation, spatial distribution and temporal dynamics, temporal and spatial niche-partitioning, species delimitation, exotic species invasion, community succession, etc. (McNyset, 2005a; Dominguez-Dominguez et al., 2006; Chen et al., 2007; Irfan-Ullah et al., 2007; Peterson et al., 2007; Raxworthy et al., 2007; Solano and Feria, 2007; Basille et al., 2008; Foulon et al., 2008; Friberg et al., 2008; Peterson and Nakazawa, 2008; Quero et al., 2008; Thorn et al., 2009; Waltari and Guralnick, 2009). They were also widely used globally to predict the geographic ranges of species, to study changes in distribution past through future and to investigate patterns of speciation and niche divergence (Wiens and Graham, 2005; Hijmans and Graham, 2006; Carstens and Richards, 2007; Kremen et al., 2007; Warren et al., 2008; Lozier et al., 2009). Though they were effective in reconstructing geographic distributions of terrestrial species, very few studies mentioned them in the aquatic realm (Wiley et al., 2003). It is especially true for those freshwater ecosystems lacking of large-scale, high-quality environmental data which are the basis of niche models generation (Iguchi et al., 2004; McNyset, 2005b; Dominguez-Dominguez et al., 2006). As an essential component of aquatic ecosystems, zooplankton have attracted extensive attention, but most attention has focused on community structure (Leonard and Paerl, 2005; Lam-Hoai et al., 2006; Drenner et al., 2009; Dickerson et al., 2010; Moderan et al., 2010; Zhang et al., 2010a; Van Egeren et al., 2011; Yang et al., 2011), e.g., zooplankton's community structure are greatly influenced by temperature, and the biodiversity of zooplankton community increases with temperature within the range of 20 through 30 °C but decreases with increase of temperature greater than 30 °C, and species number of *Protozoon* decreases with the increase of temperature greater than 20 °C (Jin et al., 1991). However, spatial distributions of zooplankton's ecological niche, and the spatial heterogeneity of zooplankton community along with water chemistry are seldom studied. Consequently the objectives of this paper are to study the impact of water chemistry variation on zooplankton communities via ecological niche theory (including breadth and overlap) as well as spatial heterogeneity of zooplankton along with water chemistry. In this study, spatial distribution and variations of zooplankton in the Huai River were initially analyzed based on the *in-situ* data (Section 3.1); then zooplankton community structure were dissected whereby dominant zooplankton species were determined (Section 3.2); in the following Section 3.3, ecological niche breadth and overlap of every individual dominant species were calculated and analyzed taking variation of zooplankton and water chemistry as basis; in Section 3.4, taking the six dominant species as representatives of the zooplankton communities of the HRB, spatial distributions of biodiversity, mean niche breadth and overlap were studied and finally, a fuzzy clustering method (FCM) was employed to recognize the ecological niche distribution pattern of zooplankton communities whereby to study impact characteristics and spatial heterogeneity of zooplankton along with water chemistry.

2. Methodology

2.1. Study area

The Huai River Basin (HRB) (30°55′–36°36′N, 111°55′–121°25′E) is located between the Yangtze River Basin and the Yellow River Basin of China (Wang and Xia, 2010) and covers 27,000 km^2. The Huai River is the 6th largest river in China and lies at China's transition between the colder northern semi-arid climate and the warmer semi-humid southern climate (Gao et al., 2010). It is the most densely inhabited river basin and the main grain-producing area of China. In 2005, the total population and grain yield respectively accounted for 13.1% and 16.1% of the national total (Xia et al., 2011).

In this basin, annual mean temperature is 11–16 °C, annual mean evaporation is 900–1500 mm and annual daily sunshine totals 1990–2650 h. Annual mean precipitation is approximately 888 mm of which 50–75% falls during the wet season (June–September) (Zhang et al., 2011). Flooding during the wet season is common. For example, the great flood of 1975 caused 26,000 deaths with one million people affected, and the collapse of two huge reservoirs and 60 smaller ones (Lin et al., 2010). Because of the extent and frequency of flooding, around 11,000 dams and sluices were built along the river by the year 2000. These have brought economic and social benefits throughout the basin. However, concern was shown in many researches about their detrimental impacts on the environment mainly including hydrologic "fragmentation" of the river, altered flow regimes (timing, duration, volume and frequency of high and low flow periods) (Wang and Xia, 2010; Zhao et al., 2010; Zhang et al., 2012, 2013). Furthermore, the rapid economic development in this region has resulted in increasingly large rates of pollution discharge into the river with concomitant declines in water quality and ecosystem function (Zhao et al., 2010; Xia et al., 2011).

In this study, the whole HRB is divided into eight regions: Main stream (R1), Hongru River (R2), Shaying River (R3), Guo River (R4), Baohui River (R5), Yishu River (R6), along East line of South–North Water Transfer Project (R7), Southern Mountain Area (R8), as shown in Fig. 1, following Zhao et al. (2012a).

2.2. Data

In order to investigate the status of the zooplankton community of the Huai River, we sampled across the whole basin during a period of July 10th through 20th, 2008. A field investigation group, composed of IGSNRR[1], WRBHRC[2] (IGSNRR and WRBHRC, 2006)

[1] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences.

[2] Water Resources Bureau of the Huai River Committee, the Ministry of Water Resources, China.

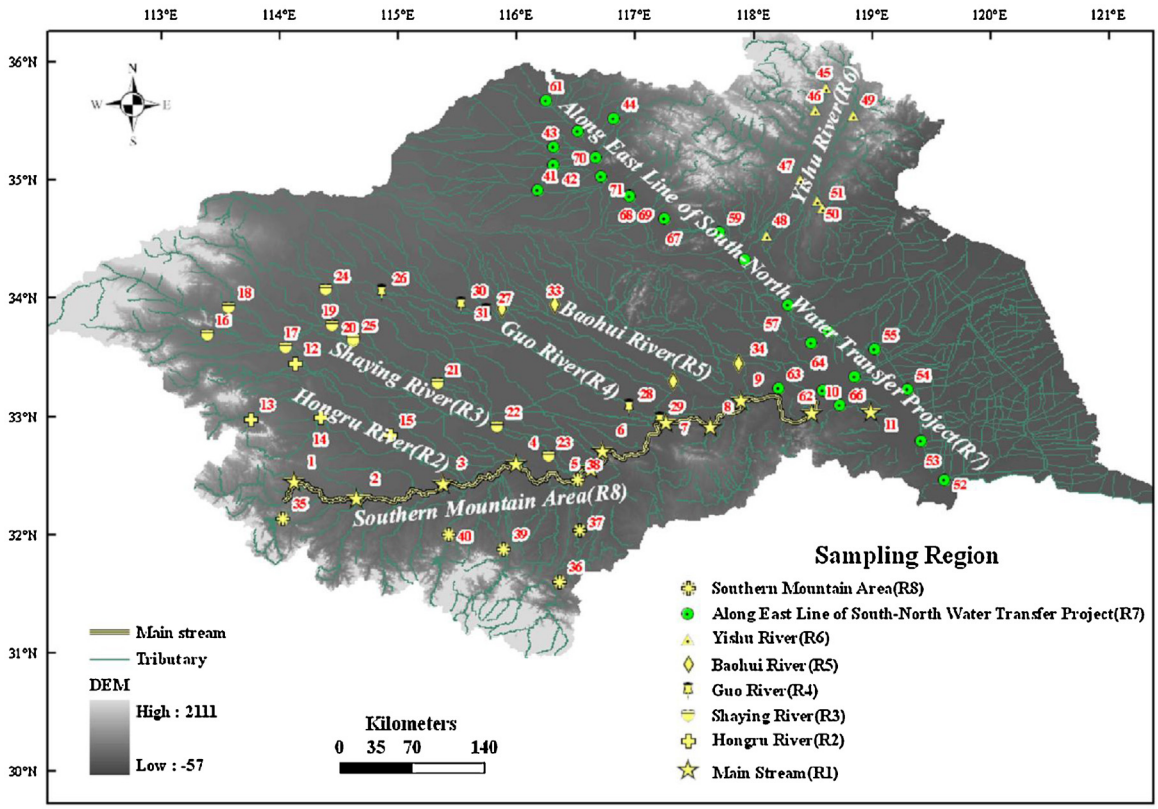

Fig. 1. Zooplankton sampling in HRB (modified from Zhao et al. (2012a)).

and the East China Normal University, conducted this investigation in typical sections of the Huai River, and collected relevant zooplankton and water chemistry data for this study.

2.2.1. Zooplankton in the Huai River

Sampling only in a local region makes it hard to determine the true niche of a community (Jiang et al., 2009). Therefore, zooplanktons were sampled at 71 typical sites in lakes, reservoirs, tributaries throughout the whole HRB, as shown in Fig. 1.

Five classes and 74 species of zooplankton were collected across all sites. Among these, 24 species were *Rotifera* (32% of total); 17 species were *Copepoda* (23% of total); 11 species were *Cladocera* (15% of total); 11 were *Protozoan* (15%); and 11 were in a number of other classes (15%), as shown in Table 1.

2.2.2. Water chemistry in the Huai River

We analyzed a total of 21 water environmental factors. We measured water temperature (WT), pH and dissolved oxygen (DO) by using a portable HACH PC101. Spectrophotometer (DR5000) was used to measure ammonia–nitrogen (NH_3–N), total phosphorus (TP), total nitrogen (TN) and hexavalent chromium; atomic absorption spectrophotometer (Thermo M6) was used for test of copper (Cu), zinc (Zn), cadmium (Cd) and lead (Pb); ion chromatograph (DIONEX-600) was employed to measure sulfate, fluoride, chloride and nitrate; automatic flow injection analyzer (KALAR SAN^{++}) to measure cyanide, volatile phenol, anionic detergent. The concentrations of many factors in most sampling sites were very small and hard to detect. Consequently we selected the nine main factors including WT, pH, DO, NH_3–N, permanganate index (COD_{Mn}), chemical oxygen demand (COD_{Cr}), TP, TN and fluoride as the water chemistry indicators of the Huai River, as shown in Table 2.

Table 1
Zooplankton community in the Huai River: Percentage stands for the proportion of a class to the total.

Class	Species number	Density (ind L^{-1})		Biomass (mg L^{-1})	
Rotifera	24	14837.17	43.50%	6.329	6.38%
Copepoda	17	987.03	2.89%	39.48	39.82%
Cladocera	11	15232.49	44.66%	49.615	50.04%
Protozoan	11	200.16	0.59%	0.0102	0.01%
Other	11	2854.51	8.37%	3.7215	3.75%

2.3. Method

2.3.1. In-situ zooplankton sampling and taxa determination in laboratory

In the field, the number of sampling-point per site depends on water area and depth. For example, in a lake, only one point of 0.5 m beneath water surface is sampled when water depth is less than 3 m, and two points near the surface and bottom are sampled and then mixed when water depth is in the range of 3–6 m; in a

Table 2
Water environmental factors in the Huai River (Zhao et al., 2012a,b).

No.	Environmental factor	Mean ± SD	Mode
1	Water temperature (WT)	29.9 ± 1.34	30.6(8.82%)
2	pH	7.33 ± 0.39	7.55(5.63%)
3	Dissolved oxygen (DO)	5.76 ± 2.37	7.80(11.1%)
4	Ammonia–nitrogen (NH_3–N)	1.13 ± 2.39	0.27(7.04%)
5	Permanganate index (COD_{Mn})	5.58 ± 2.78	4.40(7.04%)
6	Chemical oxygen demand (COD_{Cr})	22.6 ± 10.1	13.5(6.45%)
7	Total phosphorus (TP)	0.16 ± 0.26	0.03(8.45%)
8	Total nitrogen (TN)	2.66 ± 2.97	3.07(4.23%)
9	Fluoride	0.65 ± 0.17	0.50(52.1%)

WT is in °C, pH has no unit and the rest are all in mg L^{-1}; Mode value in Table 2 is expressed as "Mode (proportion of mode number to total number)".

river, only one point of 0.5 m beneath water surface is sampled when water depth is less than 2 m (SL167-96[3]; Wei, 2002).

When sampling *Protozoon* and *Rotifera*, an 1 L capacity organic glass bottle was used to get water below the water surface. 15 mL of Lugol's solution was quickly added to the bottle. When sampling *Cladocera* and *copepods*, a 10 L capacity organic glass bottle was used and the 10 L water was then filtered and concentrated into 5 mL with a 200-mesh plankton net. Finally, 4% formaldehyde was added (SL167-96[3]; Wei, 2002; Zhao et al., 2010).

In the laboratory, each *Protozoa/Rotifera* sample was allowed to settle for more than 24 h and then concentrated to 30 mL. A subsample of 0.1 mL was transferred into a 0.1 mL plankton counting chamber and a microscope was used to classify and count *Protozoon* and *Rotifera*. For the *Cladocera* and *Copepods* samples, the 10 L water sample was fully concentrated and all *cladocera* and *copepods* were classified and counted. For *Protozoon* and *Rotifera*, the biomass was converted from biovolume assuming a specific gravity of 1.0. To determine individual biovolume, individual size (length, height and breadth, or diameter) of a species was measured with the plankton microscope. Average size of at least 50 individuals was used to calculate average biovolume of a species. As to *Copepoda* and *Cladocera*, a regression equation between individual body-weight and body-length was employed to calculate individual weight and then biomass. In term of *Nauplius*, the biomass was calculated by using individual weight of 0.003 mg (SL167-96[3]).

2.3.2. Biodiversity

We employ the widely used Shannon–Weaver biodiversity index (Weaver and Shannon, 1949):

$$H = -\sum_{i=1}^{s}[(\frac{n_i}{N})\ln(\frac{n_i}{N})] \tag{1}$$

where H stands for the biodiversity; n_i refers to the number the ith species, in [ind L^{-1}]; N is the total number of all species in a sample, in [ind L^{-1}]; s refers to the species type number in a sample. When species distribute evenly in different types, H reaches its peak value.

2.3.3. Niche breadth and niche overlap

There are many models to calculate niche breadth and overlap (Levins, 1968; Pianka, 1974; Hurlbert, 1978; Smith, 1982). Here we employ the widely used Levins breadth model (Eq. (2)) and Pianka overlap model (Eq. (3)) to estimate niche breadth and niche overlap, respectively (Levins, 1968).

$$B_i = \frac{1}{\sum_{j=1}^{R}(P_{ij})^2} \tag{2}$$

where B_i is the niche breadth of species i; P_{ij} stands for the ratio of individual number of species i in resource state j to the total individual number of species i. R refers to the total number of resource states. Resources available includes biochemical oxygen demand (BOD5), dissolved oxygen (DO), permanganate index (COD_{Mn}), ammoniacal nitrogen (NH_3–N), and so on (Pianka, 1974).

$$O_{ik} = \frac{\sum_{j=1}^{R} P_{ij}P_{kj}}{\sqrt{\sum_{j=1}^{R} P_{ij}^2 \sum_{j=1}^{R} P_{kj}^2}} \tag{3}$$

where O_{ik} is the niche overlap of species i on species k; P_{ij} and P_{kj} are respectively the ratios of individual numbers of species i and species k in resource state j to the total individual number of species i and k; $O_{ik} \neq O_{ki}$.

Calculation of niche breadth and niche overlap can be conducted in the software "Data Processing System (DPS)" (Tang and Zhang, 2012).

2.3.4. Fuzzy clustering method (FCM)

Clustering is important for pattern recognition, classification, model reduction and optimization. Clustering analysis methods can be divided into traditional hard clustering method and typical fuzzy clustering method (FCM). The hard clustering method is more suitable for clustering conditions with clear boundaries whereas for problems with unclear boundaries, a fuzzy clustering method is usually adopted (Pan, 2010). In this paper, the study basin is to be clustered according to the species averaged ecological niche in different sampling sites. The latter are computed based on individual dominant species' distribution. In a basin, a species may distribute everywhere or confine to a local region and it is hard to find clear boundaries. Therefore, clustering with FCM is the best choice.

There are many algorithms and software for FCM and detailed algorithms could be found in Li et al. (2007), Pan (2010) and Shafi et al. (2010). Here, we use the statistical software—data processing system (DPS) to conduct the fuzzy clustering analysis. To facilitate calculation, data in a $(n \times m)$ matrix were pre-processed by using model

$$x'_{ij} = \frac{(x_{ij} - \overline{x_j})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_{ij} - \overline{x_j})}} \quad (i = 1, \ldots, n; \quad j = 1, \ldots, m)$$

with the average value $\overline{x_j} = \sum_{i=1}^{n} x_{ij}/n$. During the establishment of similar matrix, the widely used Euclidean distance ($r_{ij} = 1 - \frac{\sqrt{\sum_{k=1}^{m}(x_{ik}-x_{jk})^2}}{\max(\sqrt{\sum_{k=1}^{m}(x_{ik}-x_{jk})^2})}$) was adopted.

3. Results

3.1. Spatial distribution and variation of zooplankton in the Huai River

The zooplankton density and biomass at the 71 sampling sites in the eight regions are listed in Table 3.

To test whether there exist significant differences among sampling regions, we applied two widely used nonparametric tests (median test and Kruskal–Wallis test) because they make no

[3] "Standard for the investigation of reservoir fishery resources" issued by the Ministry of Water Resources of China.

Table 3
Distribution of zooplankton density, biomass and biodiversity in the Huai River: Cv stands for coefficient of variance.

Region	Sampling size	Density (ind L^{-1})		Biomass (mg L^{-1})		Biodiversity	
		Mean	Cv	Mean	Cv	Mean	Cv
R1	11	22.68	0.91	0.17	0.55	1.39	0.11
R2	4	67.08	1.92	0.08	1.70	0.80	0.82
R3	10	420.73	1.99	0.84	2.20	0.73	0.58
R4	5	2978.80	2.17	8.57	2.14	0.78	0.84
R5	4	809.75	0.74	4.21	0.61	0.93	0.24
R6	7	20.74	1.99	0.17	2.39	0.67	0.74
R7	24	457.95	2.39	1.10	2.10	0.77	0.65
R8	6	22.47	1.99	0.20	2.24	0.71	0.76
Asymp. Sig. (median test)		0.0017		0.0813		0.0216	
Asymp. Sig. (Kruskal–Wallis test)		0.0003		0.0030		0.0285	

assumptions about distribution of the data and they allow unequal sampling size. These tests revealed there were significant differences in density, biomass and biodiversity among our sampling regions (most 'Asymp. Sig.' values in Table 3 are less than 0.05).

Over the whole HRB, the maximum values of density and biomass were observed in R4, while the minimum was observed in R6 and R8. With respect to biodiversity, the *H* value was the highest in R1, indicative of the greatest biodiversity, while R6 had the lowest *H* value. Spatial variation of biodiversity (coefficient of variation: Cv in Table 3) was the highest in R4 and lowest in R1.

R4 had the highest density and biomass on average but these varied greatly with sampling sites, with approximately higher values in the middle reach and lower values in the upper and lower reaches. The middle reaches of R4 have the maximum density and biomass but a relatively lower biodiversity.

R6 and R8 exhibited similar trends, with relative high values in density and biomass in the upstream; and biodiversity values gradually increase in the downstream.

R1 (main stream) exhibited irregular variation in density, biomass and biodiversity and these reflect differences in water chemistry across different tributaries. In general, higher density and biomass usually correspond with a lower biodiversity. Interestingly, tributaries in the middle, for example, R2, R3 and R4, were found to have a significant negative influence on R1 because of pollutant discharge.

3.2. Dominant species selection

Table 1 gives the density and biomass of the Huai River zooplankton. *Cladocera* was the most dominant class and *Moina rectirostris* and *Diaphanosoma brachyurum* were the dominant species accounting for 56.9% and 36.5% of the *Cladocera*. *Rotifera* were the second most dominant class with high biodiversity. *Brachionus calyciflorus*, *Asplanchna* sp., *Brachionus angularis* and *Keratella valga* accounted for 29.15%, 21.19%, 12.52% and 10.73% of the *Rotifera*, respectively. In term of the whole zooplankton community, the proportions of the six dominant species in the whole community are respectively *M. rectirostris* (25.14%, named as SP1), *D. brachyurum* (16.12%, SP2), *B. calyciflorus* (12.83%, SP3), *Asplanchna sp.* (9.33%, SP4), *B. angularis* (5.51%, SP5) and *K. valga* (4.72%, SP6). Overall, SP1–SP6 account for more than 70% of the whole community density and hence we take the six species as the dominant species of the zooplankton community in the Huai River.

3.3. Ecological niche of the dominant species taking as basis variation of zooplankton and water chemistry

In Table 4, among the six dominant species the fourth dominant species, SP4 i.e., *Asplanchna* sp., had the highest mean breadth value (3.429). It had the broadest niche along the gradient in water temperature (5.020) and the narrowest niche along the gradient of NH_3–N (1.983). The most dominant species, SP1 (*M. rectirostris*), however, did not have the broadest breadth along the nine environmental factors' gradient and was only ranked 4th on average (3.183). However it did have the broadest breadth along the gradient of WT and TP, but had the narrowest breadth along the pH gradient. SP6—*K. valga* had the narrowest mean niche breadth (2.862).

Across all nine environmental factors examined, the dominant zooplankton species in the River had the broadest niche breadth along the gradient in water temperature (mean: 4.321, Table 4). In contrast, they had the narrowest breadth along the NH_3–N gradient (2.105). Analysis indicated that too low and too high a concentration of NH_3–N resulted in a decline in the abundance of the dominant zooplankton. The optimal range for NH_3–N was within 0.15–0.5 mg L^{-1} in the study area.

In Table 5, of the nine factors' gradient zooplankton species of the Huai River had the largest niche overlap with others along the

Table 4
Niche breadth of the six dominant species along the nine environmental factors' gradient.

Species	WT	pH	DO	NH_3–N	COD_{Mn}	COD_{Cr}	TP	TN	Fluoride	Mean	Rank
SP1 (*Moina rectirostris*)	4.235	2.400	3.130	3.130	2.880	2.880	4.235	2.483	3.273	3.183	4
SP2 (*Diaphanosoma brachyurum*)	4.348	2.941	4.000	1.923	3.125	4.167	4.651	2.469	3.077	3.411	2
SP3 (*Brachionus calyciflorus*)	4.960	2.962	2.747	1.781	3.117	4.167	3.906	3.197	2.887	3.303	3
SP4 (*Asplanchna* sp.)	5.020	2.781	3.314	1.983	3.123	4.285	4.383	3.060	2.908	3.429	1
SP5 (*Brachionus angularis*)	3.903	2.782	3.063	2.283	2.547	3.612	4.482	2.521	3.103	3.144	5
SP6 (*Keratella valga*)	3.462	2.228	3.082	1.531	2.711	2.647	3.358	2.922	3.814	2.862	6
Mean	4.321	2.682	3.223	2.105	2.917	3.626	4.169	2.775	3.177	3.222	
Rank	1	8	4	9	6	3	2	7	5		

Unit of WT is centigrade, pH has no unit and the rest are all in (mg L^{-1}).
WT: water temperature; DO: dissolved oxygen; NH_3–N: ammoniacal nitrogen; $COD_{Mn:}$ permanganate index; $COD_{Cr:}$ chemical oxygen demand; TP: total phosphorus; TN: total nitrogen.

Table 5
Niche overlap of the six dominant species along the nine environmental factors' gradient.

Species	WT	pH	DO	NH_3–N	COD_{Mn}	COD_{Cr}	TP	TN	Fluoride	Mean	Rank
SP1	5.4821	5.1770	5.5427	5.7250	5.5040	5.7041	5.4643	5.6317	5.4814	5.5240	6
SP2	5.7282	5.5090	5.5841	5.9012	5.7640	5.7488	5.7165	5.7900	5.7275	5.7190	3
SP3	5.7437	5.7926	5.7415	5.9112	5.7690	5.7909	5.7710	5.7875	5.6929	5.7780	1
SP4	5.6755	5.7701	5.7746	5.9132	5.8281	5.7453	5.7330	5.8368	5.6756	5.7720	2
SP5	5.5098	5.7605	5.5536	5.8910	5.6044	5.6832	5.7731	5.6450	5.5284	5.6610	4
SP6	5.0833	5.6448	5.7369	5.8550	5.7911	5.7373	5.3527	5.4976	5.6862	5.5980	5
Mean	5.5370	5.6090	5.6560	5.8660	5.7100	5.7350	5.6350	5.6980	5.6320		
Rank	9	8	5	1	3	2	6	4	7		

NH_3–N (mean: 5.866) but the breadth along the NH_3–N was ranked last. This means that the six dominant species had the narrowest niche breadth along it but all were concentrated in a narrow NH_3–N gradient. Spatial distribution analysis of species and water environmental factors supported this conclusion as most individuals (50–80%) of every dominant species were all living in the second gradient level of NH_3–N (0.15–0.50 mg L^{-1}). In contrast, all six species were distributed evenly along the gradient in water temperature. All species had a broader breadth but less overlap along the gradient in water temperature. Overall, reverse trends of niche breadth and degree of overlap in the Huai River (Tables 4 and 5) implies that species were coexisting with little competition with respect to water temperature and total phosphorous.

Table 6 shows the average overlap values along the nine environmental factors' gradient. SP3 had the largest total overlap value. The first dominant species SP1 had the smallest total overlap value. The middle dominant species SP4, with the greatest mean breadth (Table 4), had the second largest total overlap value. The last dominant species SP6, with the least mean breadth, had a total overlap ranking of the second smallest. Overall, the total overlap and mean breadth of the zooplankton species in the Huai River displayed approximately the same trend—a broader mean niche breadth of a species was usually associated with a larger overlap with other species.

3.4. Clustering of ecological niche of the dominant species

Based on the six dominant species, we analyzed biodiversity, niche breadth and overlap of the zooplankton community in the HRB. According to their distribution, mean breadth and mean overlap distribution in the whole basin were obtained. Spatial interpolation of the biodiversity (Fig. 2), mean niche breadth (Fig. 3) and mean niche overlap (Fig. 4) were conducted by the inverse distance weighted (IDW) method using ArcGIS 9.3. Since the ecological niche well established relationships between zooplankton and water chemistry, the whole basin was clustered into different classes with FCM to analyze the impact characteristics and spatial heterogeneity of zooplankton communities along with water chemistry taking the mean niche breadth and overlap as basis.

Fig. 2 shows the spatial distribution pattern of zooplankton biodiversity. Peak values appear in the main stream (R1), the Hongru River (R2) and south part of R7. This indicates these water regions have a relatively robust zooplankton community. Three sites in R1 (No. 3, 7, 9 in Fig. 1) and one site in R2 (No. 15 in Fig. 1) were sampled in 1980s. Their biodiversity values in 1980s are 0.71, 1.31, 1.24, 0.71, respectively (WRBHRC, 1989), whereas they are 1.52, 1.50, 1.54, 0.94 in the year 2008. Apparently, biodiversity in these regions has been improved significantly during the period of 1980s through 2008.

However, most northern regions have a lower biodiversity, especially in regions of the middle and upper reaches of tributaries to the northern of the main stream (R1)—the middle north part of HRB. According to Zhao et al. (2008), those regions are relatively highly developed in agriculture and industry and have a higher population density. Consequently rivers in this region were severely polluted by chemical fertilizers and pesticides and this resulted in very low biodiversity.

The broadest mean breadth values appear in the regions along R1 and R2 (Fig. 3). Over the whole HRB, they lie in the southwest and southeast mountainous areas. Broader-breadth regions can also be found in the northeast of the basin. However, lower values are distributed in the middle and northeast areas of the basin.

Greater mean overlap regions were distributed relatively evenly across the region (Fig. 4). They occupy most regions except for those in the east and northwest of the basin. Peak values, similar to the mean breadth, were mainly distributed in the southwest and southeast areas. Across the whole HRB, broader mean niche breadth areas usually have greater mean niche overlap.

To study the niche distribution more extensively whereby to explore the impact pattern of water chemistry variation on zooplankton, we used FCM to cluster the whole basin based on the results of ecological niche breadth and overlap values (Fig. 5).

In Fig. 5, ecological niches in the HRB were categorized into four clusters when similarity coefficient was set to 0.975.

Cluster 1: this was composed of species with high values of mean breadth (3.43–3.30; average: 3.36) and overlap (5.78–5.75; average: 5.77). This cluster is dominated by SP3 and SP4, which have greater breadth values (ranked the third and the first, respectively as shown in Table 4) and overlap values (No. 1 and No. 2, as shown in Table 5). This cluster was notable by having a relatively higher WT, DO and TP but lower pH, NH_3–N, TN and fluoride.

Cluster 2: this was composed of species with a large range in mean breadth (3.37–3.22; average: 3.29) and overlap (5.78–5.67; average: 5.72). This cluster is dominated by SP3, SP4 and SP5, with SP5 having a smaller (ranked last but one in Table 4) mean niche breadth and overlap (No. 4 in Table 5). It is distinguishable by its relatively higher NH_3–N, COD_{Mn}, COD_{Cr}, TN and fluoride but lower DO.

Cluster 3: this was composed of species having low values of mean breadth (3.25–3.18; average: 3.21) and overlap (5.72–5.65; average: 5.70). This cluster is dominated by SP6, SP3 and SP4, with SP6 having the smallest mean niche breadth (Table 4) and smaller overlap value (No. 5 in Table 5). It is notable for its lower WT, COD_{Mn}, COD_{Cr} and TP.

Table 6
Mean niche overlaps between the dominant species: A bigger value means greater similarity in resource utilization or potential competition.

	SP1	SP2	SP3	SP4	SP5	SP6	Total	Rank
SP1	1	0.900	0.929	0.930	0.904	0.861	5.524	6
SP2		1	0.965	0.970	0.952	0.932	5.719	3
SP3			1	0.992	0.944	0.949	5.778	1
SP4				1	0.943	0.938	5.772	2
SP5					1	0.919	5.661	4
SP6						1	5.598	5

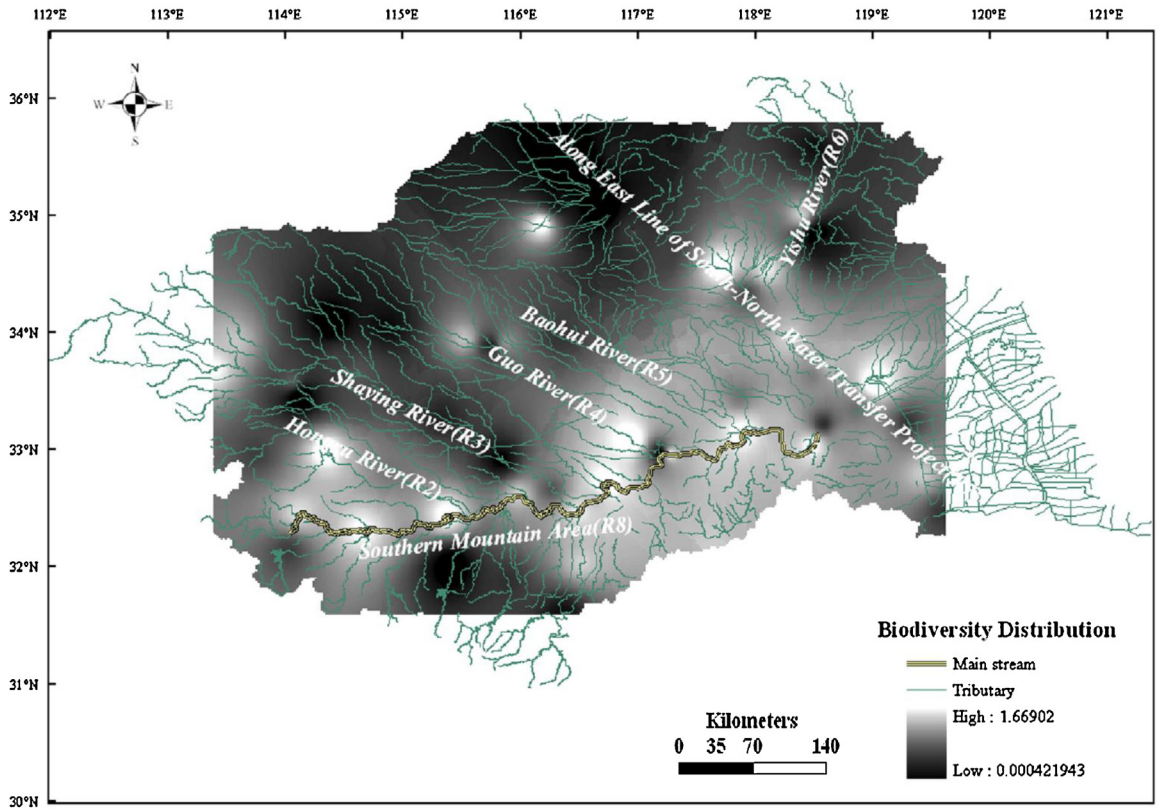

Fig. 2. Zooplankton's biodiversity distribution in the Huai River: The interpolated Shannon–Weaver biodiversity value varies from the lowest 0.0004 to the highest 1.6690.

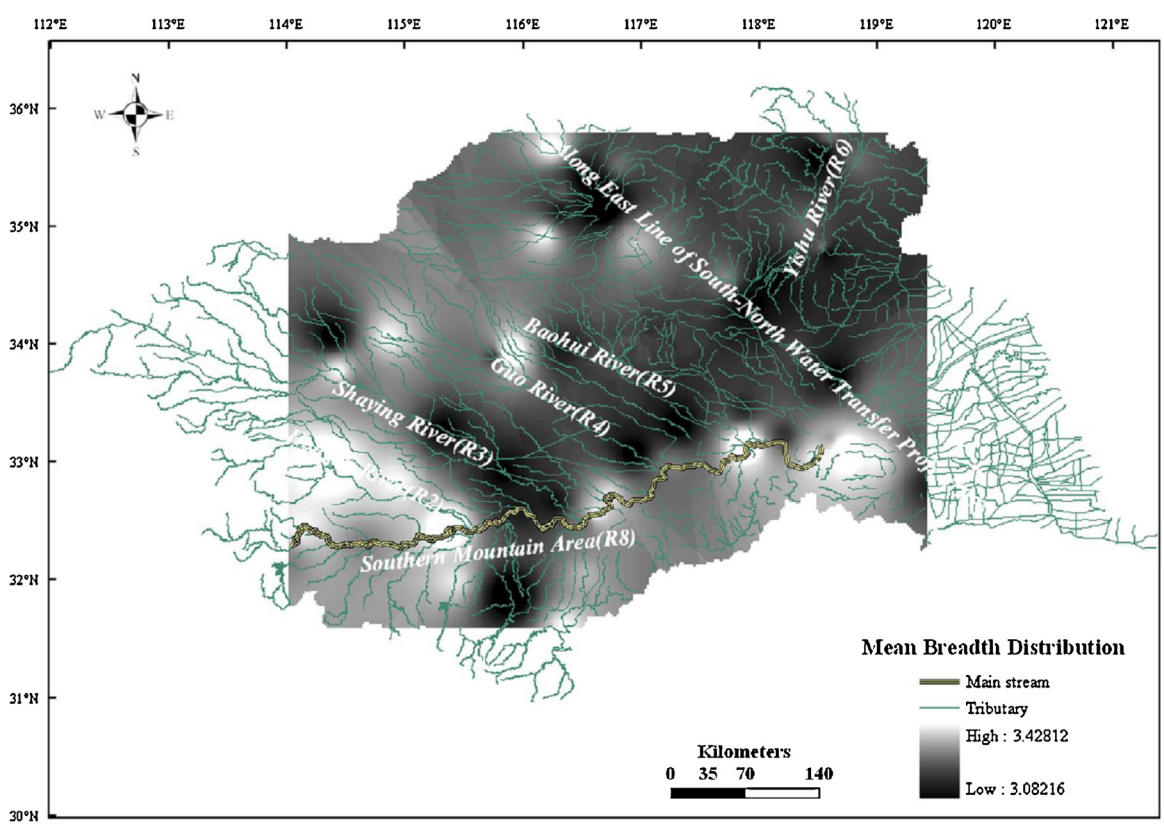

Fig. 3. Spatial distribution of zooplankton's mean niche breadth: A bigger value means zooplankton communities have greater adaptability to environment change.

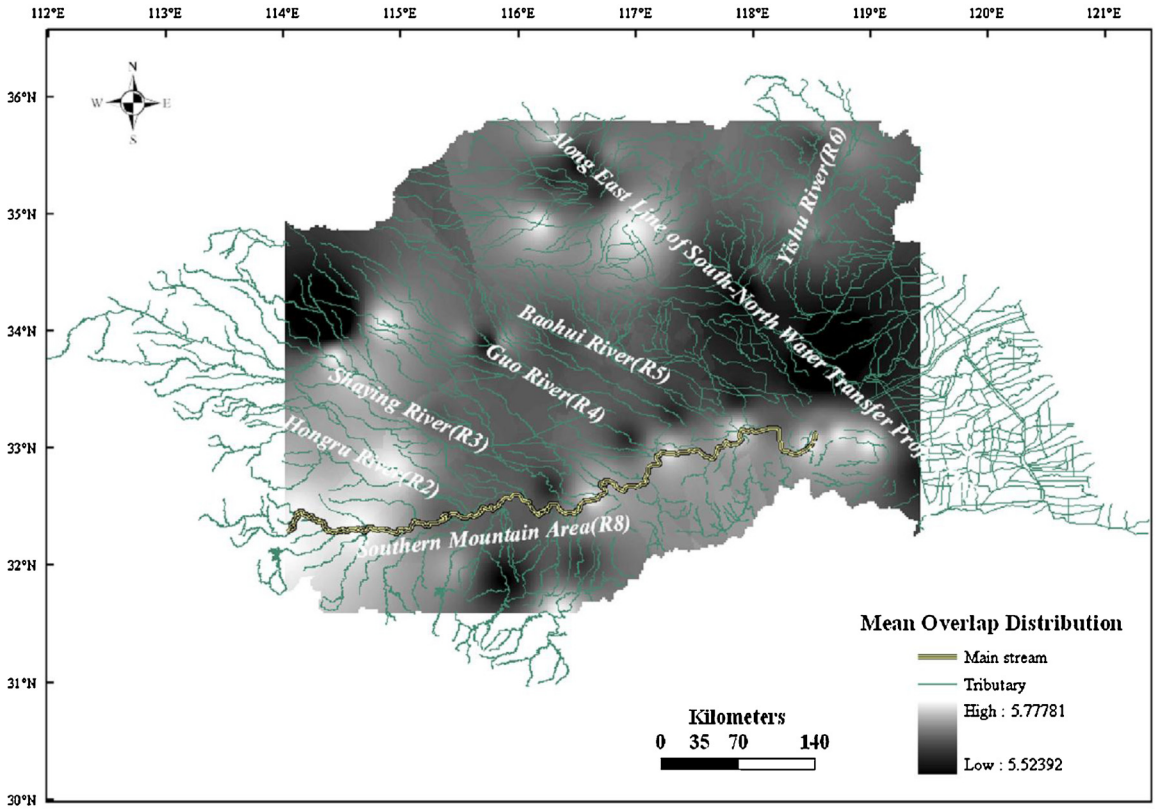

Fig. 4. Spatial distribution of zooplankton's mean niche overlap: A bigger value means species inside zooplankton communities have greater similarity in resource utilization or potential competition.

Cluster 4: it is composed of species from other areas.

The four clusters cover most of the Huai River and can well represent the *in situ* ecological niche status of the zooplankton in the HRB.

Those four clusters are marked in Fig. 6. Cluster 1 mainly distributes along R1 and downstream R2; Cluster 2 mainly concentrates in the northeast of the basin, especially the north part of R7; Cluster 3 mainly occupied the center of the basin: middle and lower reaches of R3–R5, and R7; Cluster 4 is mainly located in the western and southern mountainous areas of the basin.

From the above discussion, we conclude that ecological niche breadth and overlap display approximately the same trend, and water chemistry indices of water temperature and total phosphorous correlate positively to the mean ecological niche (breadth and overlap) in the Huai River in our study period.

4. Discussion

4.1. Adaptability to environment and similarity in resource utilization

Species with a broader niche breadth, or "generalized species", have greater adaptability, while those with a narrower niche breadth, or "specialized species", are sensitive to environmental change (Chen et al., 2009). Under limited resources, the former often have a greater probability of survival due to their strong adaptability; they have an advantage over the latter. However, the latter are usually more competitive in their local habitat when resources are abundant for their higher resources use efficiency is very high (Chen et al., 2009).

Therefore, among the six dominant species, SP4 (*Asplanchna* sp.) in Table 4 had the highest mean breadth value (3.429), suggesting a better adaptability and hence increased capacity to survive in a changing environment and possibly a wider distribution in the Huai River. In contrast, SP6 (*K. valga*) had the narrowest mean niche breadth (2.862), indicating that a small change in environment conditions may have the greatest influence on this species compared with the other five dominant species.

The broad mean breadth values in the southwest and southeast mountainous areas, the northeast of the HRB (Fig. 3) imply the zooplankton communities in these areas have relative greater adaptability to the climate change and human activities. However, lower values in the middle and northeast areas signify zooplankton communities there live in uncertainties—when resources are sufficient, they can live well. Otherwise, they may hardly survive. The latter regions should be paid much more attention in the future water-related socio-economy development.

In general, the similarity of different species in resource utilization can be reflected by using niche overlap (Jiang et al., 2009). Thus SP3 (*B. calyciflorus*) in Table 6 had the largest similarity in resource use to the others while SP1 (*M. rectirostris*) had the smallest. In relation to their niche breadth, SP4 (*Asplanchna* sp.), which was distributed in the Huai River the most widely, had the largest similarity to other species with respect to resource utilization. Under limited resources, it may experience high rate of competition. SP6 (*K. valga*) is able to survive in its local habitat under abundant resources but is sensitive to environmental change because of its narrow niche breadth. It is especially sensitive to change in NH_3–N. The optimal concentration is less than 0.5 mg L^{-1}, over which SP6 can be inhibited greatly.

From the research of Jiang et al. (2009), one can conclude that high mean overlap at a site means the zooplankton community there either faces intensive competition in resource utilization or

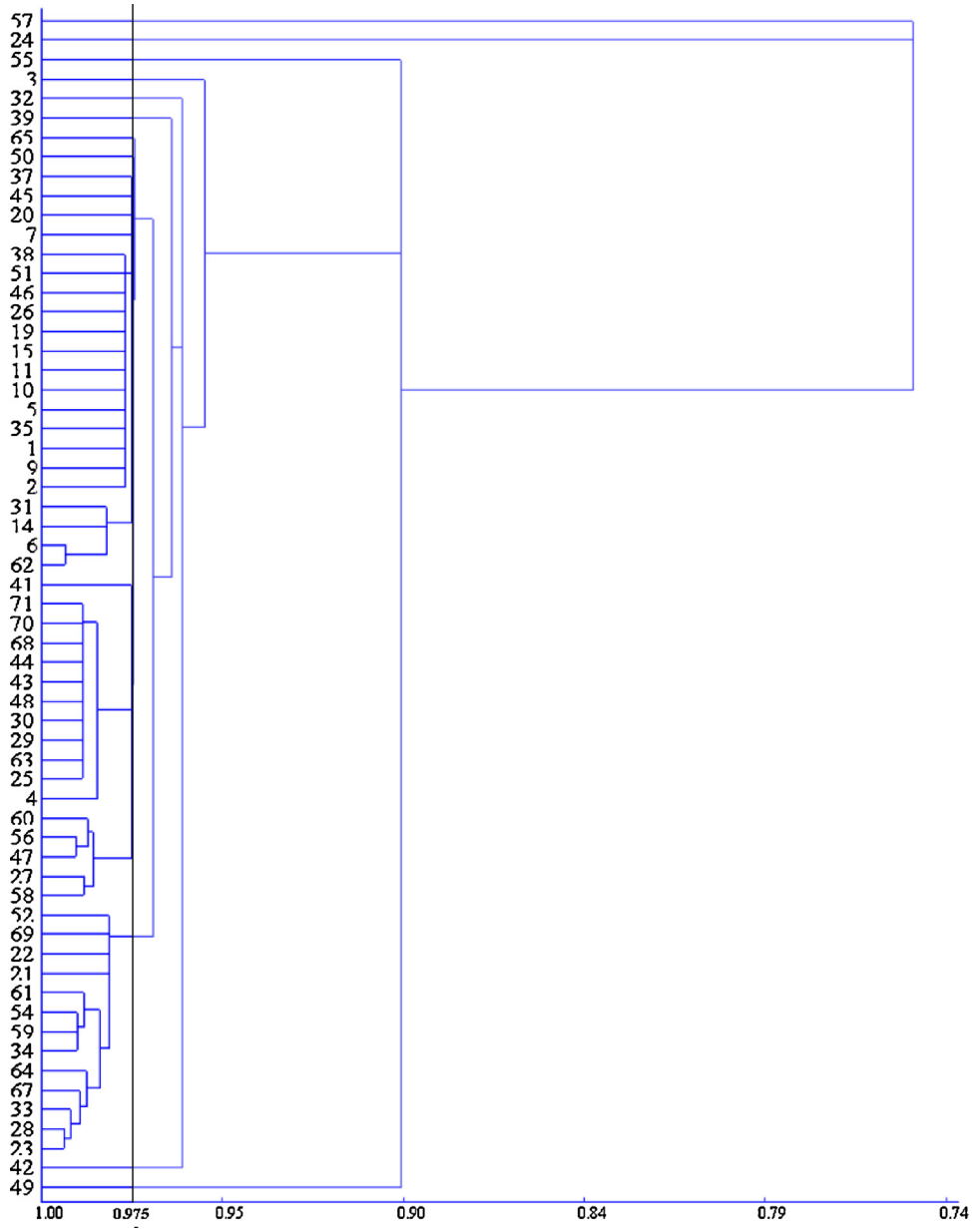

Fig. 5. Clustering with FCM: Fuzzy clustering method, usually used for clustering problems with unclear boundaries. A threshold value of 0.975 was used for identifying the clusters.

has some zooplankton species, dominant or non-dominant ones, with different habitat/behavior or functional feeding types coexisting. Peak values of the mean niche overlap (Fig. 4) were mainly distributed in the southwest and southeast areas of the HRB. As such, southwest and southeast regions may exist potential fierce competition in nutrition utilization.

4.2. Impact of water chemistry on zooplankton

The broadest niche breadth of the dominant species is along the water temperature while the narrowest one is along the NH_3–N (as shown in Table 4). This suggests that whilst changes in WT may have minimal impact on the zooplankton community of the Huai River, any small variation in NH_3–N is likely to exert a much larger stress on the community. Influence of total phosphorous on plankton communities is the second minimum while that of total nitrogen is the third maximum.

Researches of Castro et al. (2005), Hessen et al. (2007) and Buyurgan et al. (2010) suggest that species number variation of zooplankton is positively influenced by water temperature. However, changes in water temperature of the Huai River has little impact on the spatial distribution of zooplankton community during the study period in our study. This is similar to research of Liu et al. (2010) but contrast to the former three researches. The reason is that in the former researches water temperature variation covered a large range (it varied from 8 to 27 °C, from 4.5 to 16.5 °C and from 10.45 to 23.5 °C, respectively) while in our study it covered a small range (from 27.3 to 33.4 °C). Additionally, the former researches did not take into account water chemistry indices, such as total phosphorus and ammonia–nitrogen, which is significantly important for the growth of zooplankton especially in severe polluted areas. At the 71 sampling sites in our study, correlation coefficient between species number (SN) and water temperature (R^2 = 0.0006) is far less than those between SN and main pollutant

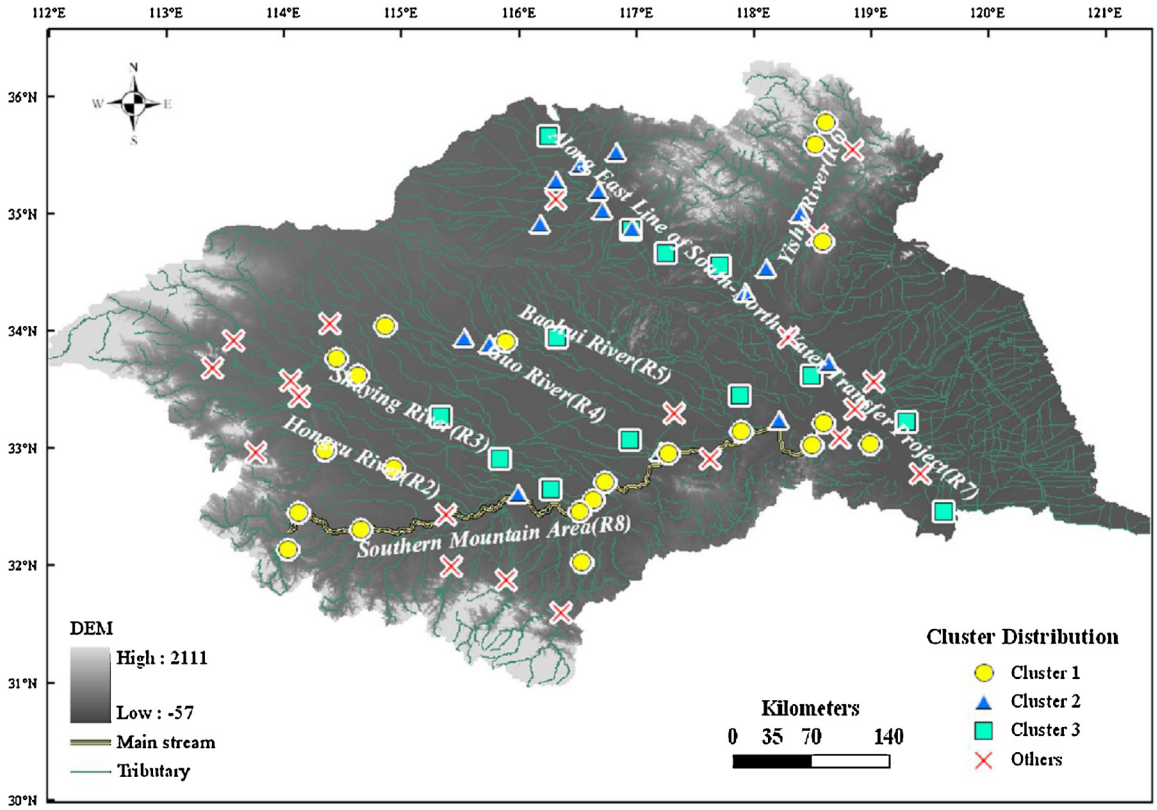

Fig. 6. Clusters distribution in the whole basin.

indices (total phosphorus: 0.01; ammonia–nitrogen: 0.10; total nitrogen: 0.10). We therefore argue that study areas in the former researches had water temperature-dominant zooplankton communities while study areas of the latter research and our study had pollutant-dominant zooplankton communities.

Though water temperature is one of critical factors influencing freshwater zooplankton communities according to previous studies (Castro et al., 2005; Hessen et al., 2007; Buyurgan et al., 2010), this critical role of water temperature may be replaced by dominant pollutant-index, e.g., ammonia–nitrogen. Taking the middle reaches of the Guo River (R4) as an example, synchronous water chemistry monitoring data show too much nitrogen was discharged into this river-section which made *Cladocera* and *Rotifera* soar in density and biomass. This signifies that too much pollutant makes plankton with higher pollutant-tolerance boom especially when freshwater rivers are severely polluted.

Across the Huai River, variation of detrimental pollutant such as ammonia–nitrogen plays critical role in the spatial pattern of zooplankton communities. Too low and too high concentration of ammonia–nitrogen both resulted in decline in the abundance of the dominant species of zooplankton. Variation in ammonia–nitrogen had great impact on the zooplankton community but in nonlinear way, which means higher concentration than 0.5 mg L^{-1} or lower concentration than 0.15 mg L^{-1} will both result in reduction in abundance of zooplankton. Contrarily, research of Liu et al. (2010), conducted in severely polluted city rivers, suggested ammonia–nitrogen had no clear impact on zooplankton. It is because that in their study area, mean concentration of ammonia–nitrogen (3.52 mg L^{-1}) was much higher than that in this study (1.13 mg L^{-1}). This resulted in fewer species richness (64 species) than in the HRB (74), and also cultivated more high-pollutant-tolerant species (*Rotifera*: 44) than in the HRB (24). This indicates that much too high concentration of ammonia–nitrogen (as in Liu et al., 2010) make high-pollutant-tolerant species overwhelming and biodiversity decrease, which resulted in that species heterogeneity was very small and therefore the influence of ammonia–nitrogen variation on species heterogeneity was hard to find in Liu et al. (2010).

Our study suggests that influence of total phosphorous on zooplankton is not prominent. This is contrary to the research of Van Egeren et al. (2011) which indicates summer total phosphorus has negative influence on zooplankton community composition of the studied lakes. The reason is because of difference in dominant species. In the research of Van Egeren et al. (2011), low concentration of total phosphorus (~10% that in our study) cultivated dominant *cladoceran* and *copepod* which have low pollutant-tolerance while in the HRB, density of high pollutant-tolerant *rotifera* and protozoan occupied 88% of total zooplankton community. This suggests that in a clean river, total phosphorus may have negative influence on zooplankton community composition but the influence of total phosphorus is not evident in highly polluted rivers.

Broader-niche-breadth species usually have greater adaptability to the surrounding environment, and *vice versa* (Chen et al., 2009). Zooplankton communities of Cluster 1 have high adaptability, higher dissolved oxygen and total phosphorus but lower ammonia–nitrogen. These communities lie in the main stream and nearby the Hongru River, having higher biodiversity, should be maintained and further improve zooplankton's habitat conditions. Cluster 2 is a transient class, mainly located in the north part of the East line of South–North Water Transfer Project and lower reach of the Yishu River. Biodiversity in these areas is relatively low and measures of pollution cut and sewage treatment are necessary in these areas. Zooplankton communities of Cluster 3 have weak adaptability. Communities of this cluster mainly located mainly in the downstream of tributaries north of the main stream.

Community structure in these areas is susceptible to changes of environmental factors. Overall, the north part of the East line of South–North Water Transfer Project and lower reaches of the tributaries in the north of the main stream need special attention in the future water resources management.

5. Conclusions

In the Huai River Basin (HRB), change in water temperature has minimal impact on the zooplankton community during the study period. In contrast, small variation in ammonia–nitrogen exerts significant stress on the community in a nonlinear way and too high or low concentration will lead to reduction in abundance of zooplankton. Species in the HRB are coexisting with little competition with respect to water temperature and total phosphorous. When freshwater rivers are highly polluted, the critical role of water temperature is replaced by dominant pollutant-index. The HRB has pollutant-dominant zooplankton communities instead of water-temperature-dominant ones. In a higher polluted river, like the Huai River, the influence of total phosphorus is not evident.

The main stream, the Hongru River and the southern part of the East line of the South–North Water Transfer Project have a robust zooplankton community. Zooplankton communities in the southwest and southeast mountainous regions, especially areas in the main stream and the Hongru River, may be able to adapt well to environmental variation. However, communities in the middle and northeast areas of the basin, especially in the north part of the East line of South–North Water Transfer Project and in the lower reaches of the tributaries north of the main stream, have a weaker adaptability to habitat change and therefore considerable care should be made in any future water-related socio-economy development.

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