ARTICLE IN PRESS

Quaternary International xxx (2014) 1–6

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

An exploratory analysis of ecological water requirements of macroinvertebrates in the Wuhan branch of the Yangtze River

Bao-Zhu Pan [a, b], Hong-Zhu Wang [a, *], Xuan Ban [c], Xin-An Yin [d]

[a] State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, Chinese Academy of Sciences, 430072 Wuhan, China
[b] Changjiang River Scientific Research Institute, Wuhan, Hubei 430010, China
[c] Key Laboratory for Environment and Disaster Monitoring and Evaluation, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan, Hubei 430077, China
[d] State Key Laboratory of Water Environment Simulation, School of Environment, Beijing Normal University, Beijing 100875, China

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Ecological water requirements
Flow
Instream Flow Incremental Methodology (IFIM)
Macroinvertebrates
The Yangtze River

ABSTRACT

The natural flow regime is confirmed to be the main driving factor in maintaining diverse species and abundant production of river floodplains. However, disturbance of human activities have affected natural hydro-geomorphical process, reduced habitat heterogeneity, and weakened ecological service functions. Thus, it is necessary to assess ecological water requirements and furthermore provide a quantitative operational basis for restoring natural flow regime. Macroinvertebrates are considered as good indicators of hydrological regime changes due to their confinement to the bottom, limited abilities of movement, and low tolerance. This paper deals with systematic ecological investigations in the Wuhan branch of the Yangtze River during 2007–2008. Altogether, 32 taxa of macroinvertebrates belonging to 13 families and 27 genera were identified. The density and biomass of total macroinvertebrates were 181 ind m^{-2} and 0.29 g dry mass m^{-2}, respectively. Canonical Correspondence Analysis (CCA) revealed that the important environmental factors influencing macroinvertebrate abundance were flow velocity (U), water depth (Z), and total nitrogen (TN). The relation between habitat weighted usable area and water discharge was analyzed on basis of creating suitability curves. Weighted usable area of habitat showed unimodal changes with increasing water discharge, i.e., first increased and then decreased, and weighted usable area of habitat reached the maximum when flow discharge was 21,000 m^3 s^{-1}.

1. Introduction

River floodplains are distinctive landscapes on Earth, and in natural states they are characterized by high biodiversity and production (Tockner and Stanford, 2002). Research revealed that natural flow regime is the main driving factor in maintaining diverse species and abundant production of river floodplains (Mahoney and Rood, 1998; Amoros and Bornette, 2002; Lytle and Poff, 2004; Junk, 2005; Rood et al., 2005). Due to disturbance of human activities, natural flow regimes of most river floodplains in the world have changed, hydrological connectivity has been seriously impeded, and biodiversity and service functions are under serious threat (Tockner and Stanford, 2002). With regard to the Yangtze River floodplain, dam construction and river-lake isolation altered the natural flow regimes, impeded natural hydro-geomorphical process, reduced habitat heterogeneity, and weakened ecological service functions (Pan et al., 2011). Thus, it is necessary to carry out research on eco-hydrological restoration in the Yangtze floodplain, as assessing ecological water requirements can provide a quantitative operational basis for restoring natural flow regime.

Ecological water requirements are the required hydrological regime for maintaining valuable features and functions of aquatic ecosystems (Tharme, 2003). From the theoretical and methodological research progress, research on ecological water requirements can be divided into three stages. The 1940s–1960s were the infancy of the theory of ecological water requirements in rivers. River management researchers conducted studies mainly to meet the needs of shipping capabilities, and mature theories and methods were lacking. The second stage was from the 1970s to the late 1980s, when can be considered as the prototype stage of studying ecological and environmental water allocation. During this period, river eco-environmental water requirement and its related concepts were widely recognized by people, and systematic

* Corresponding author.
E-mail address: wanghz@ihb.ac.cn (H.-Z. Wang).

http://dx.doi.org/10.1016/j.quaint.2014.10.011
1040-6182/

Please cite this article in press as: Pan, B.-Z., et al., An exploratory analysis of ecological water requirements of macroinvertebrates in the Wuhan branch of the Yangtze River, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.011

studies were started from different angles. Researchers analyzed flow requirement initially based on historical hydrological data, and put forward some hydrological methods such as 7Q10 Method, Tennant Method, and RVA Method (Tennant, 1976; Richter et al., 1996). Afterwards, hydrologists determined the required river flow according to hydraulic parameters of river section (i.e, river width, water depth, flow velocity and wetted perimeter, etc.), and put forward some hydraulic methods such as Wetted Perimeter Method and R2-Cross Method (Stalnaker and Arnette, 1976; Reiser et al., 1989). The aquatic biological factors were not considered in hydrological methods and hydraulic methods, thus, the credibility of results of ecological water requirements was influenced due to lack of ecological basis. After the 1990s, the study of ecological water requirements started its third stage. At this time, related studies on relation between water resources and ecological environment, especially water requirements of river ecosystems, were formally a global focus. The theories about river eco-environmental water requirements were gradually improved, and some new methods were developed.

The catalyst of links between flow discharge and ecology was “River Ecology and Humans”. At that time river management was an art rather than a science (Oglesby, 1972). The appearance of Instream Flow Incremental Methodology (IFIM) made instream discharge allocation tend to be objective (Gore and Judy, 1981). This method has become a widely-used method for evaluating stream ecological water requirements in North America. IFIM was initially used for evaluating salmon habitats with the changes of flow discharge. Macroinvertebrates are used as biological indicators of ecological water requirements due to their confinement to the bottom, limited abilities of movement, and low tolerance (Gore et al., 2001). However, research on ecological water requirements of macroinvertebrates has not been documented.

In China, research on ecological water requirements in rivers was restricted to two aspects: 1) definition, connotation, and composition of eco-environmental water requirements in rivers; 2) determination of calculation method. In recent years, from the perspective of hydrology and hydraulics, researchers have carried out studies of ecological water requirements in the Yellow River, the Haihe River, Han River, Liao River, and others (Yang et al., 2003, 2005, 2006; Wang et al., 2007). The studies on ecological water requirements of biological assemblages were scarce, and only related studies about spawning habitat simulation of Chinese sturgeon were reported (Ying, 2006; Ban and Li, 2007; Yi, 2008).

This paper deals with systematic ecological investigations in the Wuhan branch of the Yangtze River during 2007–2008. The purpose of this study is threefold: to describe the overall characteristics of macroinvertebrate assemblages in the studied river branch; to create habitat suitability curves for macroinvertebrates; and to analyze the ecological water requirements of macroinvertebrates in the studied river branch.

2. Study area and methods

The Yangtze River, the third longest river in the world, originates from the Qinghai-Tibetan Plateau. A river branch with the length of 2000 m was selected for this research (Fig. 1). Field investigations were conducted bimonthly during September 2007–August 2008. The data of flow discharge were collected from the hydrological website (http://www.cjh.com.cn). In this study, IFIM (Instream Flow Incremental Methodology) was used to calculate the ecological water requirements of macroinvertebrates, and the research programs are shown in Fig. 2.

Samples of bed sediment were taken and analyzed by Laser Diffraction Particle Size Analyzer (MS-2000), and sediment sizes were determined by Wentworth scale (Allan and Castillo, 2007). Flow velocity (U) was measured with a propeller type current meter (Model LS 1206B) manufactured by Nanjing Automation Institute of Water Conservancy and Hydrology, Chinese Ministry of Water Resources. Water depth (Z) and Secchi depth (Z_{SD}) were measured with a laser sounder (Model SM-5 & SM-5A) and a Secchi Disc, respectively. Water samples were taken near the surface and at the bottom, and combined for laboratory analyses. pH was measured with pH meter (Model STARTER 3100/B). Conductivity (Cond) was measured with conductivity meter (Model DDS-11A). Total nitrogen (TN) was analyzed by the alkaline potassium persulfate digestion-UV spectrophotometric method. Total phosphorus (TP) was analyzed by the ammonium molybdate method. All variables were analyzed according to Water and Waste Water Monitoring and Analysis Method (2002). Phytoplankton chlorophyll *a* (Chl *a*) concentration was measured after acetone extractions by reading absorbance at 665 nm and 750 nm using a spectrophotometer (Unico UV-2000, Shanghai, China).

Quantitative samples of macroinvertebrates were taken from the hyporheic zones with a weighted Petersen grab (0.0625 $m^2 \times 0.15$ m) and then passed through a 420-μm sieve. Specimens were sorted manually from sediment on a white

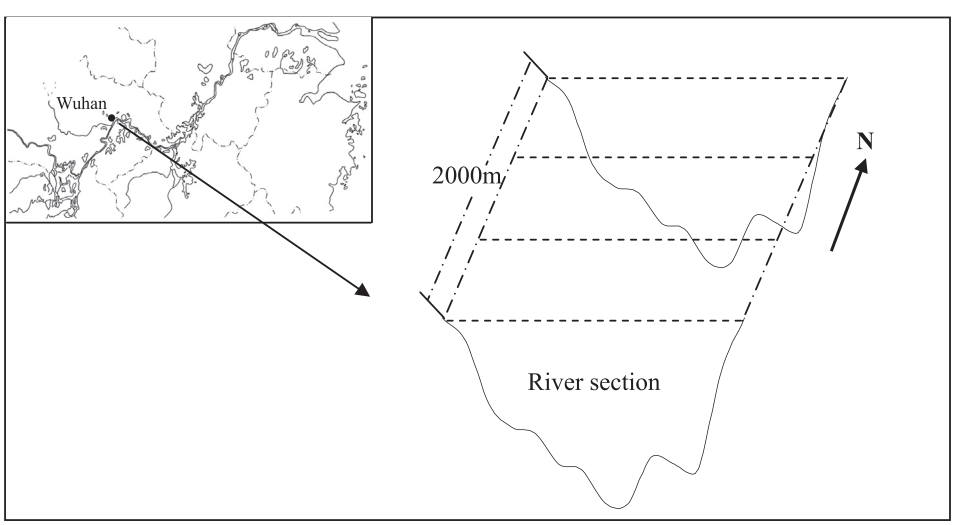

Fig. 1. Location of study river reach and sampling sections.

Please cite this article in press as: Pan, B.-Z., et al., An exploratory analysis of ecological water requirements of macroinvertebrates in the Wuhan branch of the Yangtze River, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.011

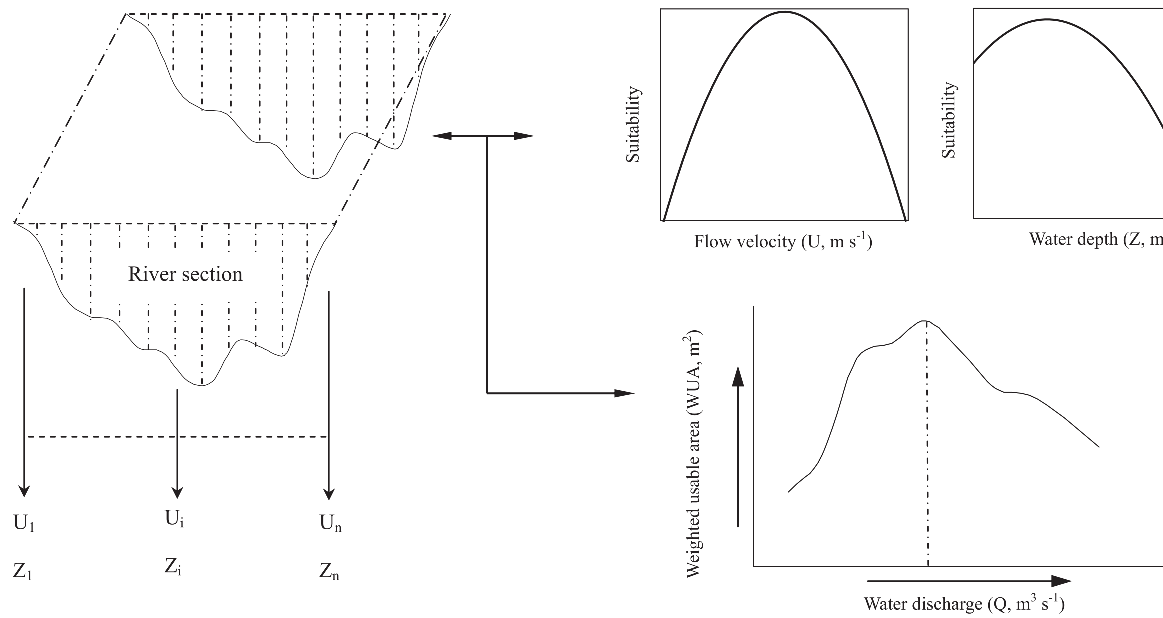

Fig. 2. Scheme design of ecological water requirements using IFIM. U, flow velocity (m s^{-1}); Z, water depth (m). WUA = $\sum_{i=1}^{n} A_i C_i$, WUA, weighted usable area; A_i, habitat area; C_i, product of suitability values of every environmental variable (Allan and Castillo, 2007).

porcelain plate and preserved in 10% formalin. Benthic animals were identified to the lowest feasible taxonomic level according to the relevant references (Morse et al., 1994; Wiggins, 1996; Dudgeon, 1999; Smith, 2001; Wang, 2002; Zhou et al., 2003) and counted. Wet mass of animals was determined with an electronic balance after being blotted, and then dry mass (mollusks without shells) was calculated according to the ratios of dry-wet mass and tissue-shell mass reported by Yan and Liang (1999).

STATISTICA 8.0 (StatSoft, Inc., Tulsa, Oklahoma) was used for creating habitat suitability curves. CANOCO 4.53 (Microcomputer Power, Ithaca, New York) was used for Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA). Detrended Correspondence Analysis (DCA) indicated that a normal model (gradient lengths > 2.0 standard units) would best fit the data, and CCA was used to analyze the relation between animal assemblages and environments. In CCA, analyses of forward selection and Monte Carlo permutation test were used to yield important environmental factors influencing abundance and distribution of macroinvertebrates. Altogether, 12 environmental variables (8 quantitative variables including U, Z, Z_{SD}, pH, Cond, TN, TP, Chl *a*; 4 qualitative variables including clay, silt, fine sand, coarse sand) and 32 macroinvertebrate taxa were used for CCA. During analysis, 1 or 0 was used to indicate appearance or absence of these types of substrates. Before statistical analyses, data were $\log_{10}(x + 1)$ transformed to reduce heterogeneity of variances. River_2D 0.93 (University of Alberta, Fisheries and Oceans, Canada) was used for analyzing the relation between water discharge and weighted usable area of habitat.

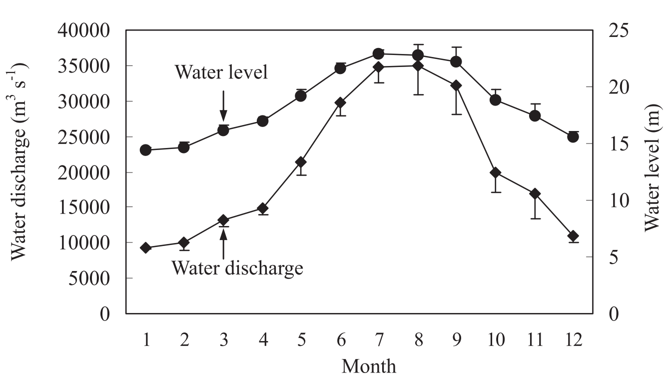

Fig. 3. Means of water level (m) and water discharge ($m^3 s^{-1}$) in Hankou Station during 2007–2008.

3. Results

3.1. Hydrological and environmental conditions of the studied river branch

The average monthly values of water level and flow discharge are shown in Fig. 3. Water level was higher and flow discharge was larger during June–September. The environmental variables in the studied branch are given in Table 1. The studied river was characterized by high flow velocity, low water transparency, and low phytoplankton chlorophyll *a* concentration.

Table 1
Environmental parameters (mean ± SE) of Wuhan branch.

Flow velocity (m s^{-1})	Water depth (m)	Secchi depth (m)	pH
0.59 ± 0.15	15.2 ± 4.8	0.35 ± 0.08	8.1 ± 0.5
Conductivity (μS cm^{-1})	Total nitrogen (mg m^{-3})	Total phosphorus (mg m^{-3})	Phytoplankton chlorophyll *a* concentration (mg m^{-3})
311 ± 60	620 ± 55	124 ± 26	2.2 ± 0.4

3.2. Taxa, densities and biomass of macroinvertebrates

Altogether, 32 taxa of macroinvertebrates belonging to 13 families and 27 genera were identified. Among them were 12 annelids, 4 mollusks, 12 arthropods and 4 other animal (Table 2). The density and biomass of total macroinvertebrates were 181 ind m^{-2}

and 0.29 g dry mass m^{-2}, respectively. Oligochaetes were the predominant group and made up 44.2% of the total density, and 82.8% of total biomass (Table 3).

Table 2
Species list of macroinvertebrates in the Yangtze mainstream.

Oligochaeta	**Insecta**
(1) *Paranais* sp.	(17) *Chironomus* sp.
(2) *Nais simplex* Piguet	(18) *Clinotanypus* sp.
(3) *Nais communis* Piguet	(19) *Cricotopus* sp.
(4) *Nais bretscheri* Michaelsen	(20) *Cryptochironomus* sp.
(5) *Limnodrilus grandisetosus* Nomura	(21) *Dicrotendipes* sp.
(6) *Limnodrilus* sp.	(22) *Microchironomus* sp.
(7) *Limnodrilu paramblysetus* Wang *et* Liang	(23) *Orthocladius* sp.
(8) *Teneridrilus mastix* (Brinkhurst)	(24) *Polypedilum* sp.
(9) *Ilyodrilus templetoni* (Southern)	(25) *Stictochironomus* sp.
(10) *Aulodrilus pluriseta* (Piguet)	(26) *Tanypus* sp.
(11) *Aulodrilus pigueti* Kowalewski	(27) Coenagrionidae
(12) *Branchiura sowerbyi* Beddard	(28) Psychomyiidae
Mollusca	**Others**
(13) Melaniidae	(29) Amphipoda
(14) *Semisulcospira* sp.	(30) Nematoda
(15) *Corbicula fluminea* (Müller)	(31) Polychaeta
(16) *Limnoperna lacustris* (Martens)	(32) Glossiphoniidae

Table 3
Density and biomass (mollusks without shells) (mean ± SE) of macroinvertebrates in the Yangtze mainstream.

	Density (ind m^{-2})	Biomass (g dry mass m^{-2})
Oligochaeta	80 ± 29	0.2400 ± 0.0800
Mollusca	54 ± 14	0.0320 ± 0.0290
Insecta	32 ± 14	0.0030 ± 0.0020
Others	15 ± 6	0.0130 ± 0.0050
Total	181 ± 35	0.2900 ± 0.0800

3.3. Important factors structuring macroinvertebrate assemblages

Analyses of forward selection and Monte Carlo permutation test revealed that the important environmental factors influencing macroinvertebrate abundance were flow velocity (U), water depth (Z), and total nitrogen (TN) (Fig. 4). Axes 1 and 2 accounted for 49.0% and 28.6% information of species–environment relations, respectively, and both axes were significant at $p < 0.05$ (Monte Carlo permutation test). The factors strongly correlated with the first axis were U and Z. The second axis was predominantly correlated with TN (Table 4).

Table 4
Summary statistics of the CCA for macroinvertebrates density in the Yangtze mainstream.

CCA axes	1	2	3
Eigenvalues	0.660	0.387	0.301
Species–environment correlations	0.910	0.801	0.815
Cumulative percentage variance:			
— of species data	7.3	11.6	15.0
— of species–environment relation	49.0	77.6	100.0
Inter-set correlations with axes:			
Flow velocity (U, m s^{-1})	0.7706	0.2371	0.5916
Water depth (Z, m)	0.6520	0.2580	−0.7130
Total nitrogen (TN, mg m^{-3})	−0.0961	0.9883	−0.1181

3.4. Habitat suitability curves

Total nitrogen is confirmed to be closely correlated with flow-induced external source input. Thus, influence of total nitrogen is not considered, and habitat suitability curves of flow velocity and water depth are created. Figs. 5 and 6 show plots of cumulative mean of macroinvertebrate densities and their derived preference curves of flow velocity and water depth, respectively. The cumulative curves of macroinvertebrate densities were fitted as cubic equations, and the environmental value which the fastest increasing plot on the cumulative curve corresponded to was the optimum value. The optimum flow velocity for survival of macroinvertebrates was 0.21 m s^{-1}, and the shallower water was more conducive to macroinvertebrate survival.

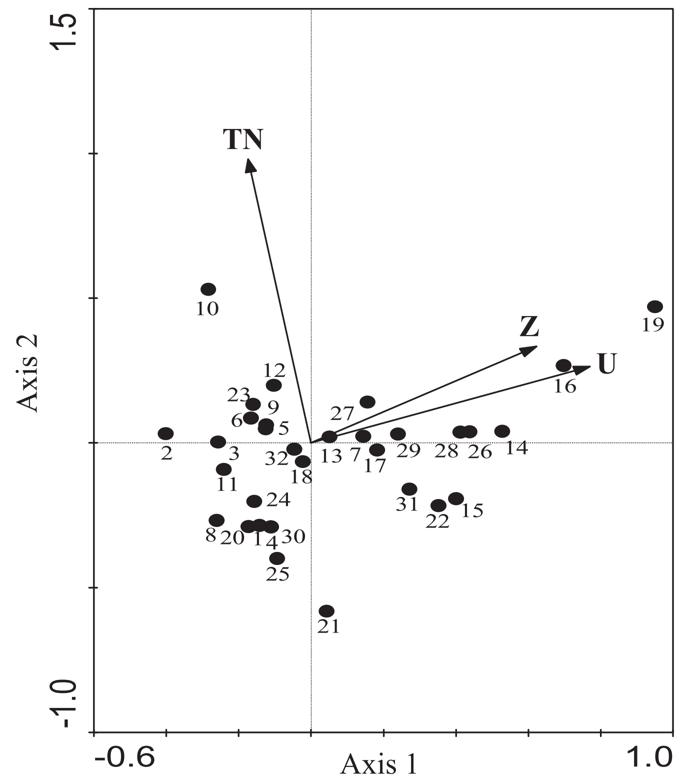

Fig. 4. CCA biplots for species association with the environmental parameters in the Yangtze mainstream. U, water velocity (m s^{-1}); Z, water depth (m); TN, total nitrogen concentration of water (mg m^{-3}). Species code information is given in Table 2.

3.5. Relation between discharge and weighted usable area of habitat

Fig. 7 shows the relation between water discharge and weighted usable area of habitat analyzed by distance weighted least squares. Weighted usable area of habitat showed unimodal changes with increasing water discharge, i.e., first increased and then decreased, and weighted usable area of habitat reached the maximum when flow discharge was 21,000 m^3 s^{-1}.

4. Discussion

In comparison with those of the Yangtze disconnected lakes, macroinvertebrates of the Yangtze mainstream were characterized by existence of potamophilic taxa, low density, and small biomass. The potamophilic taxa in the Yangtze mainstream were *Semisulcospira*, *Corbicula fluminea*, *Cryptochironomus*, *Stictochironomus*, Psychomyiidae and so on. As reported in previous research (Pan et al., 2012), the average densities of macroinvertebrates in the Yangtze disconnected lakes (2231 ind m^{-2} in macrophytic lakes and 2814 ind m^{-2} in algal lakes) were higher than that in the

Please cite this article in press as: Pan, B.-Z., et al., An exploratory analysis of ecological water requirements of macroinvertebrates in the Wuhan branch of the Yangtze River, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.011

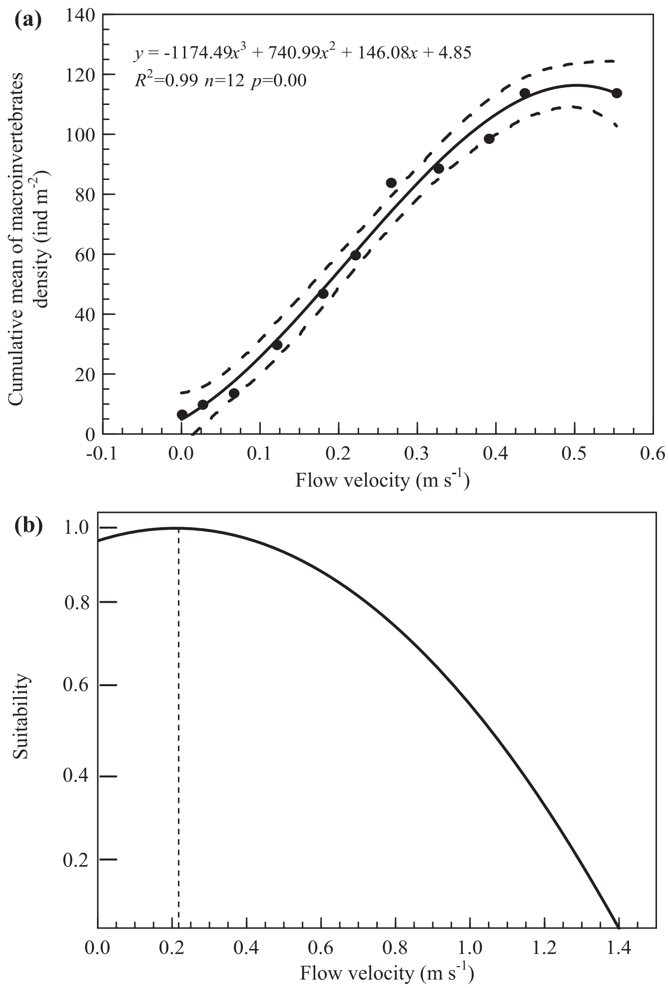

Fig. 5. Plots of cumulative mean of macroinvertebrates density (a) and its derived preference curve of flow velocity (b).

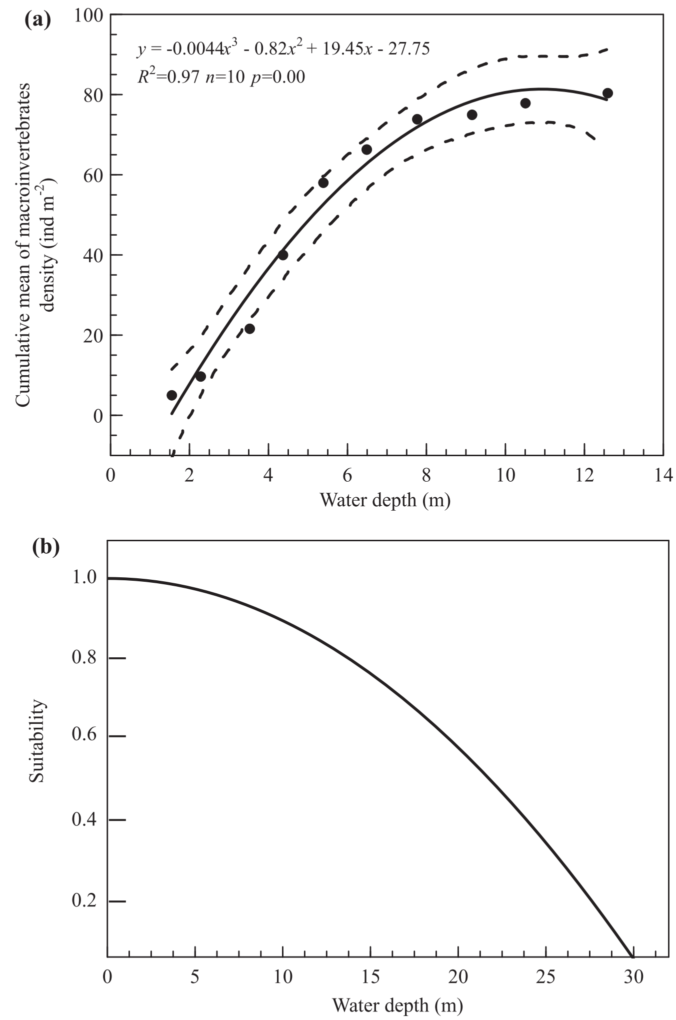

Fig. 6. Plots of cumulative mean of macroinvertebrates density (a) and its derived preference curve of water depth (b).

Yangtze mainstream. Moreover, the average biomass of macroinvertebrates in the Yangtze disconnected lakes (1.69 g dry mass m^{-2} in macrophytic lakes and 1.38 g dry mass m^{-2} in algal lakes) was greater than that in the Yangtze mainstream. The phenomenon can be ascribed to the unstable habitat condition in the Yangtze mainstream.

According to our analyses, factors structuring macroinvertebrate assemblages in the Yangtze River were mainly flow velocity, water depth, and total nitrogen (Fig. 4). Among these, river flow is regarded as the most important factor because it not only scours macroinvertebrates directly but also determines other habitat conditions. First, river flow of high velocity can inhibit the growth of plankton (Allan and Castillo, 2007; Pan et al., 2009), which leads to reduction of food sources for macroinvertebrates. Second, river flow determines substrate properties and subsequently affects benthic animals (Nowell and Jumars, 1984; Allan and Castillo, 2007). Third, river flow is closely related to external nutrients such as total nitrogen (Søballe and Kimmel, 1987), and it is the driving force for delivering nutrients to macroinvertebrates. Fourth, river flow of high velocity can result in unstable habitat condition which is not beneficial to assemblage development of macroinvertebrates. Water depth, reflecting water level fluctuation, can regulate phytoplankton biomass through light inhibition and thus affect food abundance of macroinvertebrates.

As shown in Fig. 5, the suitability curve of flow velocity was parabolic. When flow velocity was below 0.21 m s^{-1}, suitability value tended to increase with velocity. In this situation, benthic animals were thought to be determined mainly by flow-delivered nutrients. When flow velocity exceeded 0.21 m s^{-1}, suitability value tended to decrease, suggesting that inhibition effects of flow have prevailed over nutrients effects on survival of benthic

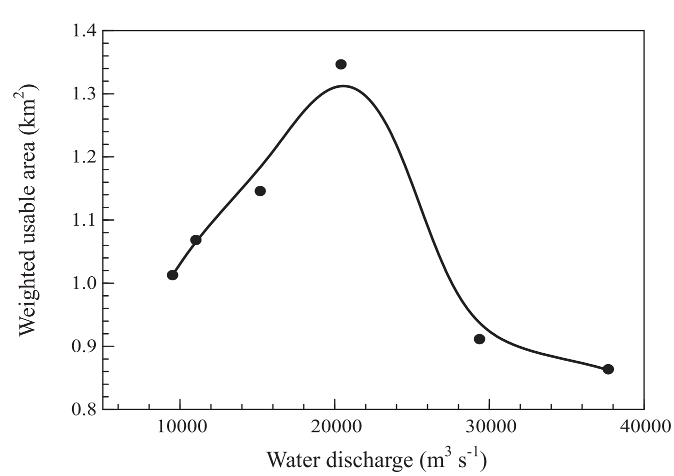

Fig. 7. Relationship between discharge and weighted usable area (WUA) analyzed by distance weighted least squares.

invertebrates. Previous research revealed that periphytons, the main food source of benthic animals, were more abundant in the shallower river regions (Leland, 2003; Jäger et al., 2008; Wu et al., 2011). As water depth increased, scarce food resource due to light inhibition was not favorable to animal survival.

In the Yangtze mainstream, habitat usable area for macroinvertebrates showed unimodal changes when water discharge increased (cf. Fig. 7). A similar response pattern has been found in the previous research (Conder and Annear, 1987; Jowett, 1992; Nehring and Anderson, 1993; Gallagher and Gard, 1999). However, differences of flow requirements exist between macroinvertebrates and fish. The flow requirement of macroinvertebrates was confirmed to be more than 5–25% of that of fish (Gore et al., 2001). To date, no studies on ecological flow requirement of fish have been conducted, and few studies on flow requirements of Chinese sturgeon spawning have been documented (Ying, 2006; Ying et al., 2013). The optimum discharge for Chinese sturgeon spawning was confirmed to be 15,000 $m^3\ s^{-1}$ (Ying et al., 2013), which may indicate that the flow requirement is lower because fish have better swimming ability.

Acknowledgements

The research was funded by State Key Laboratory of Freshwater Ecology and Biotechnology (2011FBZ14), National Natural Science Foundation of China (51479006 & 30900194), and 973 Programs (2008CB418006).

References

Allan, J.D., Castillo, M.M., 2007. Stream Ecology: Structure and Function of Running Waters. Springer, AA Dordrecht.
Amoros, C., Bornette, G., 2002. Connectivity and biocomplexity in waterbodies of riverine floodplains. Freshwater Biology 47, 761–776.
Ban, X., Li, D.M., 2007. Multi-parameter ecological hydrology model for spawning grounds of *Acipenser Sinensis* downstream of the Gezhouba Dam. China Rural Hydropower 6, 8–12 (In Chinese with English abstract).
Conder, A.L., Annear, T.C., 1987. Test of weighted usable area estimates derived from a PHABSIM model for instream flow studies on trout streams. North American Journal of Fisheries Management 7, 339–350.
Dudgeon, D., 1999. Tropical Asian Streams: Zoobenthos, Ecology and Conservation. Hong Kong University Press, Hong Kong.
Gallagher, S.P., Gard, M.F., 1999. Relationship between chinook salmon (*Oncorhynchus tshawytscha*) densities and PHABSIM-predicted habitat in the Merced and Lower American rivers, California. Canadian Journal of Fisheries and Aquatic Sciences 56, 570–577.
Gore, J.A., Judy Jr., R.D., 1981. Predictive models of benthic macroinvertebrate density for use in instream flow studies and regulated flow management. Canadian Journal of Fisheries and Aquatic Science 38, 1363–1370.
Gore, J.A., Layzer, J.B., Mead, J., 2001. Macroinvertebrate instream flow studies after 20 years: a role in stream management and restoration. Regulated Rivers: Research & Management 17, 527–542.
Jäger, C.G., Diehl, S., Schmidt, G.M., 2008. Influence of water-column depth and mixing on phytoplankton biomass, community composition, and nutrients. Limnology and Oceanography 53 (6), 2361–2373.
Jowett, I.G., 1992. Models of the abundance of large brown trout in New Zealand rivers. North American Journal Fisheries Management 12, 417–432.
Junk, W.J., 2005. Flood pulsing and the linkages between terrestrial, aquatic and wetland systems. Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie 29, 11–38.
Leland, H.V., 2003. The influence of water depth and flow regime on phytoplankton biomass and community structure in a shallow, lowland river. Hydrobiologia 506–509 (1–3), 247–255.
Lytle, D.H., Poff, N.L., 2004. Adaptation flow regimes. Trends in Ecology and Evolution 19, 94–100.
Mahoney, J.M., Rood, S.B., 1998. Streamflow requirement for cottonwood seedling recruitment – an integrative model. Wetlands 18, 634–645.
Morse, J.C., Yang, L.F., Tian, L.X., 1994. Aquatic Insects of China Useful for Monitoring Water Quality. Hohai University Press, Nanjing.
Nehring, R.B., Anderson, R.M., 1993. Determination of population-limiting critical salmonid habitats in Colorado streams using the Physical Habitat Simulation System. Rivers 4 (1), 1–19.
Nowell, A.R.M., Jumars, P.A., 1984. Flow environments of aquatic benthos. Annual Review of Ecology and Systematics 15, 303–328.
Oglesby, R.T., 1972. River Ecology and Man. Academic Press, New York.
Pan, B.Z., Wang, H.J., Liang, X.M., Wang, H.Z., 2009. Factors influencing chlorophyll *a* concentration in the Yangtze-connected lakes. Fresenius Environmental Bulletin 18 (10), 1894–1900.
Pan, B.Z., Wang, H.J., Liang, X.M., Wang, H.Z., 2011. Macrozoobenthos in Yangtze floodplain lakes: patterns of density, biomass and production in relation to river connectivity. Journal of the North American Benthological Society 30 (2), 589–602.
Pan, B.Z., Wang, H.J., Wang, H.Z., Wang, Z.Y., 2012. Macrozoobenthic assemblages in relation to environments of the Yangtze-isolated lakes. Frontiers of Environmental Science & Engineering 6 (2), 246–254.
Reiser, D.W., Wesche, T.A., Estes, C., 1989. Status of instream flow legislation and practise in North America. Fisheries 14 (2), 22–29.
Richter, B.D., Baumgartner, J.V., Powell, J., Braun, D.P., 1996. A method for assessing hydrologic alteration within ecosystem. Conservation Biology 10, 1163–1174.
Rood, S.B., Samuelson, G.M., Braatne, J.H., Gourley, C.R., Hughes, F.M.R., Mahoney, J.M., 2005. Managing river flows to restore floodplain forests. Frontiers in Ecology and the Environment 3 (4), 193–201.
Smith, D.G., 2001. Pennak's Freshwater Invertebrate of the United States, fourth ed. Wiley and Sons, Inc, New York.
Søballe, D.M., Kimmel, B.L., 1987. A large-scale comparison of factors influencing phytoplankton abundance in rivers, lakes, and impoundments. Ecology 68, 1943–1954.
Stalnaker, C.B., Arnette, S.C., 1976. Methodologies for the Determination of Stream Resource Flow Requirements: an Assessment. US Fish and Wildlife Services, Office of Biological Services Western Water Association.
Tennant, D.L., 1976. Instream flow regimes for fish, wildlife, recreation and related environmental resources. Fisheries 1 (4), 6–10.
Tharme, R.E., 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19, 397–441.
Tockner, K., Stanford, J.A., 2002. Riverine flood plains: present state and future trends. Environmental Conservation 29 (3), 208–330.
Wang, H.Z., 2002. Studies on Taxonomy, Distribution and Ecology of Microdrile Oligochaetes of China, with Description of Two New Species from the Vicinity of the Great Wall Station of China, Antarctica. Higher Education Press, Beijing (In Chinese).
Wang, X.Q., Zhang, Y., Liu, C.M., 2007. Estimation of eco-water requirement in the Liaohe River Basin. Geographical Research 26 (1), 22–28 (In Chinese with English abstract).
Water and Waste Water Monitoring and Analysis Method Committee, 2002. Water and Waste Water Monitoring and Analysis Method, fourth ed. China Environmental Science Press, Beijing (In Chinese).
Wiggins, G.B., 1996. Larvae of the North American Caddisfly Genera (Trichoptera), second ed. University of Toronto Press, Toronto.
Wu, N.C., Schmalz, B., Fohrer, N., 2011. Distribution of phytoplankton in a German lowland river in relation to environmental factors. Journal of Plankton Research 33 (5), 807–820.
Yan, Y.J., Liang, Y.L., 1999. A study of dry-to-wet mass ratio of aquatic macroinvertebrates. Journal of Huazhong University of Science and Technology 27 (9), 61–63 (In Chinese with English abstract).
Yang, S.M., Shao, D.G., Shen, X.P., 2005. Quantitative approach for calculating ecological water requirement of seasonal water-deficient rivers. Journal of Hydraulic Engineering 36 (11), 1341–1346 (In Chinese with English abstract).
Yang, Z.F., Cui, B.S., Liu, J.L., Wang, X.Q., Liu, C.M., 2003. Theory, Methods and Practice of Eco-environmental Water Demand. Science Press, Beijing (In Chinese).
Yang, Z.F., Liu, J.L., Sun, T., Cui, B.S., 2006. The Rule of Ecological Water Demand of River Basin. Science Press, Beijing (In Chinese).
Yi, Y.J., 2008. Impacts of Changjiang Flow and Sediment on Fish and Habitat Modeling of the Yangtze River. Tsinghua University doctoral thesis (in Chinese with English abstract).
Ying, X.M., 2006. Research on River Ecological & Environmental Modeling Based on Instream Flow Incremental Methodology. Hohai University Master's degree thesis (in Chinese with English abstract).
Ying, X.M., Yang, Y., Jia, H.L., Xie, J., 2013. Numerical simulation research on relation between spawning habitat of Chinese sturgeon and discharge in Yangtze River. Yangtze River 44 (13), 84–89 (In Chinese with English abstract).
Zhou, C.F., Gui, H., Zhou, K.Y., 2003. Larval key to families of Ephemeroptera from China (Insecta). Journal of Nanjing Normal University 26, 65–68 (In Chinese with English abstract).